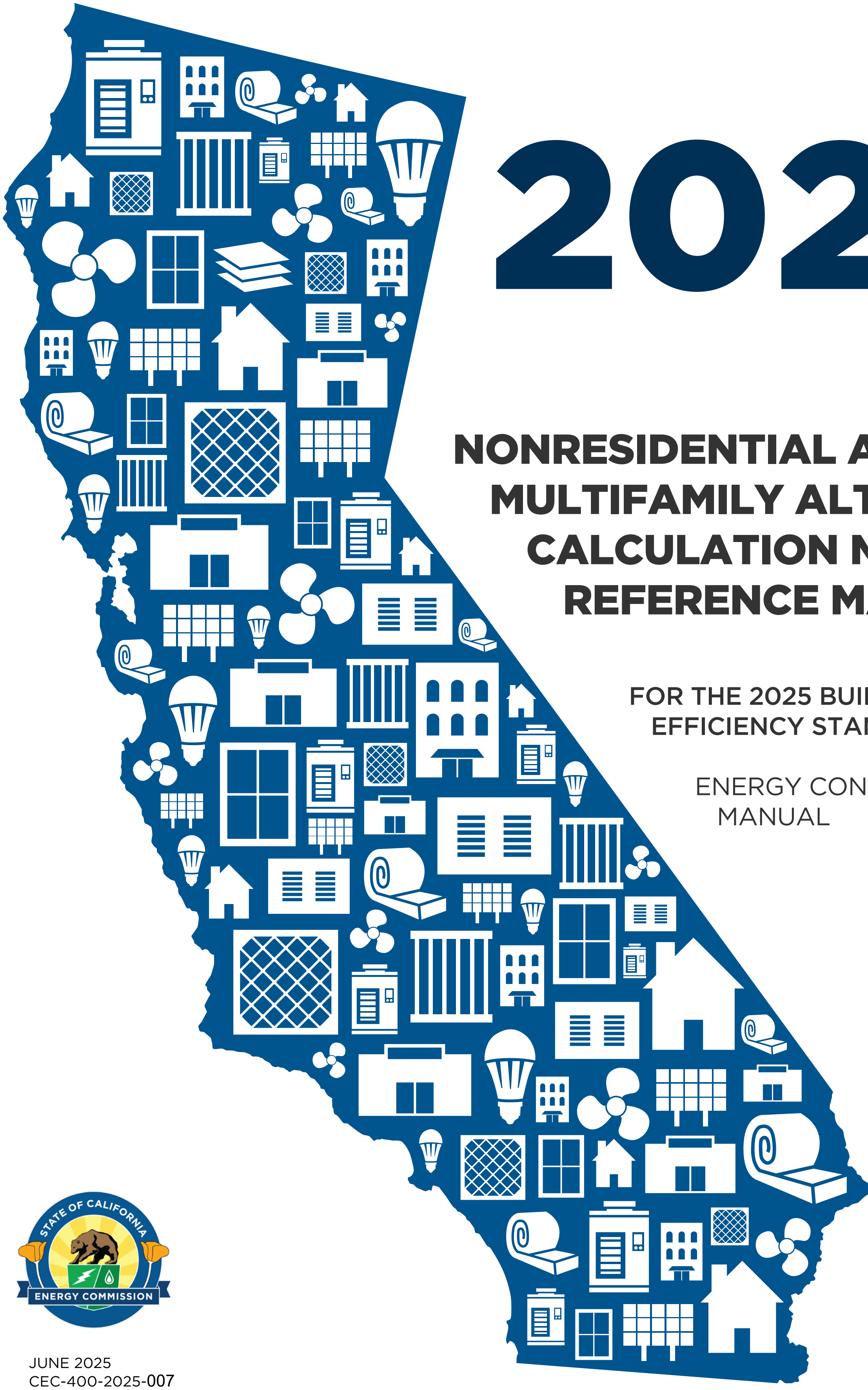


2025

NONRESIDENTIAL AND MULTIFAMILY ALTERNATIVE CALCULATION METHOD REFERENCE MANUAL

FOR THE 2025 BUILDING ENERGY EFFICIENCY STANDARDS

ENERGY CONSERVATION MANUAL

JUNE 2025
CEC-400-2025-007

CALIFORNIA ENERGY COMMISSION
Gavin Newsom, Governor

California Energy Commission

STAFF REPORT

2025 Nonresidential and Multifamily Alternative Calculation Method Reference Manual

FOR THE 2025 BUILDING ENERGY EFFICIENCY STANDARDS

Energy Conservation Manual

June 2025 | CEC-400-2025-007

California Energy Commission

Haile Bucaneg
RJ Wichert, P.E.
Primary Authors

Haile Bucaneg
Nikhil Kapur
RJ Wichert, P.E.
Project Managers

Gypsy Achong
Branch Manager
BUILDING STANDARDS BRANCH

Will Vicent
Deputy Director
EFFICIENCY DIVISION

Michael J. Sokol
Director
EFFICIENCY DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGMENTS

The California Energy Commission (CEC) adopted and put into effect the first *Building Energy Efficiency Standards* in 1978 and have updated these standards periodically in the intervening years. The *Building Energy Efficiency Standards* are a unique California asset that has placed the state on the forefront of energy efficiency, sustainability, energy independence, and climate change issues and have provided a template for national standards within the United States as well as for other countries around the globe. They have benefitted from the conscientious involvement and enduring commitment to the public good of many persons and organizations along the way. The *2025 Building Energy Efficiency Standards* for residential and nonresidential buildings development and adoption process continues a long-standing practice of maintaining the standards with technical rigor, challenging but achievable design and construction practices, public engagement, and full consideration of the views of stakeholders.

The revisions in the *2025 Building Energy Efficiency Standards* for residential and nonresidential buildings were conceptualized, evaluated, and justified through the excellent work of CEC staff and consultants working under contract to the CEC, supported by the utility-organized Codes and Standards Enhancement Initiative and shaped by the participation of more than 150 stakeholders and the contribution of formal public comments.

CEC Efficiency Division staff would like to acknowledge Commissioner Andrew McAllister and his adviser, Bill Pennington, for their unwavering leadership throughout the standards development; Javier Perez, who served as project manager for the 2025 standards code cycle; Payam Bozorgchami, P.E., who served as the senior engineer and senior technical lead; Gypsy Achong, who served as manager for the Buildings Standards Branch; Mikey Shewmaker, who served as the supervisor for the Standards Development Unit; Devin Black, Josephine Crosby, Ana Gonzalez, Michael Murza, Albert Kim, and Isaac Serratos, who provided legal counsel and support; and technical staff contributors of the Building Standards Branch, including Haider Alhabibi; Jessica Arroyo: Ronald Balneg; Stephen Becker; Amie Brousseau; Thao Chau, P.E.; Sahar Daemi; Kyle Grewing; Simon Lee, P.E; Elmer Mortel; Gagandeep Randhawa; Anushka Raut; Muhammad Saeed; Danny Tam; Trevor Thomas; Bach Tsan; RJ Wichert, P.E.; and Allen Wong, and of the Standards Compliance Branch, including Joe Loyer; and Cheng Moua, P.E. Additional staff input and assistance came from the Energy Hotline staff and the CEC's Web Team. Administrative support and editing were provided by Corrine Fishman; Tajanee Ford-Whelan; and Michi Mason.

Critical support for the staff in conceptualizing, evaluating, and reviewing this document came from consultants and stakeholders, including NORESCO, Bruce Wilcox, and the Codes and Standards Enhancement Initiative, which is supported by a consortium of California utility providers which includes the Pacific Gas and Electric Company, Southern California Edison, San Diego Gas & Electric, Sacramento Municipal Utility District, and Los Angeles Department of Water and Power.

ABSTRACT

The California Energy Commission's (CEC) *2025 Building Energy Efficiency Standards* for residential and nonresidential buildings allow compliance by either a prescriptive or performance method. The performance compliance approach uses computer modeling compliance software to trade-off efficiency measures. Performance compliance is the most popular compliance method because of the flexibility it provides in building design.

Compliance software must be certified by the CEC, following rules established for modeling compliance software. This document establishes the rules for creating a building model, describing how the proposed design is defined, explaining how the standard design is established, and reporting on the performance compliance certificate. This document also describes the procedure for performance calculation, necessary rule sets, reference method for testing compliance software accuracy, and the minimum reporting requirements. The CEC reserves the right to approve vendor software for limited implementations of what is documented in this manual.

This *Nonresidential and Multifamily Alternative Calculation Method Reference Manual* explains how the proposed and standard designs are determined. The explanations for single-family building proposed and standard designs are described in the *Single-Family Residential Alternative Calculation Method Reference Manual*.

The compliance manager, public domain compliance software provided by the CEC, is called California Building Energy Code Compliance (CBECC). CBECC and all third-party compliance software must meet rules described in the *Nonresidential and Multifamily Buildings ACM Reference Manual*.

Keywords: ACM, alternative calculation method, Building Energy Efficiency Standards, California Energy Commission, California Building Energy Code Compliance, CBECC compliance manager, compliance software, computer compliance, energy budget, time dependent valuation, energy code, energy use, prescriptive compliance, performance compliance, design, proposed design, standard design, VRF

Please use the following citation for this report:

Bucaneg, Haile, Nikhil Kapur, and RJ Wichert, P.E. 2025. *2025 Nonresidential And Multifamily Alternative Calculation Method Reference Manual*. California Energy Commission, Building Standards Branch.CEC-400-2025-007.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Overview

1.1 Purpose

The Warren-Alquist Act created the California Energy Commission's authority to establish and regularly update building efficiency standards codified in Public Resources Code Sections 25402 subdivisions (a)-(b). Public Resources Code, section 25402.1(e) directs the CEC to certify an energy conservation manual for use by designers, builders, and contractors of residential and nonresidential buildings, specifically including instructions for use of a public domain computer program for calculating energy consumption in residential and nonresidential buildings (Public Resources Code, section 25402.1(e)5).

The *Nonresidential and Multifamily Alternative Calculation Method (ACM) Reference Manual* explains the requirements for approval of nonresidential and multifamily Energy Code compliance software in California. Approved compliance software is used to demonstrate minimum compliance with the 2025 *Building Energy Efficiency Standards* (Energy Code), CALGreen (Title 24, Part 11), or any metric approved by the California Energy Commission (CEC). Definitions and terms in this manual may be found in the 2025 Energy Code. The procedures and processes described in this manual are designed to provide consistency and accuracy while preserving integrity of compliance. This manual addresses compliance software for nonresidential buildings, hotels, motels, and multifamily buildings as specified in Title 24, Part 6, Subchapter 5, Section 140.1, and Subchapter 11, Section 170.1. A separate ACM reference manual applies to single-family residential buildings. The approval process for nonresidential and multifamily compliance software programs is specified in Title 24, Part 1, Section 10-109, 10-110, and 10-116 of the California Code of Regulations. The ACM Reference Manual can be updated outside of the standard Energy Code update process to incorporate new modeling features or address modeling and rule errors. The ACM Reference Manual will be updated no more than twice annually, in January and July.

1.2 Scope

This manual is intended to be used as a reference for the modeling methods of compliance software and a guide to software programs seeking certification as Energy Code compliance software for nonresidential and multifamily buildings.

The *ACM Reference Manual* can be modified during a code cycle without a formal rulemaking. Therefore, the goal of the compliance software development team is to provide periodic updates to improve the accuracy and usability of compliance software.

1.3 Organization

This document is organized in five chapters and several appendices, as follows:

Chapters and descriptions:

1. Overview
   The purpose, organization, and content of the manual.
2. General Modeling Procedures
   An overview of the modeling process, outlining the modeling rules and assumptions that are implemented in the same way for the standard design and the proposed design, and procedures for determining system types and equipment sizes.
3. Compliance Software Requirements
   Requirements for the simulation engines and implementation of compliance rules used to make calculations, and special reporting requirements for nonstandard building features.
4. Content and Format of Standard Reports
   The content and organization of the standard reports produced by qualifying compliance software.
5. Nonresidential Building Descriptors Reference
   The acceptable range of inputs for the proposed design and a specification for the standard design for nonresidential buildings.
6. Multifamily Building Descriptors Reference
   The acceptable range of inputs for the proposed design and a specification for the standard design for multifamily buildings.

In addition, there are several appendices that contain reference material supporting definition of the proposed design and standard design. The numbering for these appendices generally aligns with the chapter numbers in the main manual that reference the appendices.

1.4 Compliance Software

Compliance software is software that has been approved by the Energy Commission to demonstrate compliance with the Energy Code through the performance compliance pathway. Compliance software must meet the appropriate application procedures and requirements in the Energy Code Section 10-109, 10-110 and 10-116. Compliance software approval process and compliance software vendor requirements are further supported in this ACM Reference Manual, Alternative Calculation Method Compliance Software Approval Process and Vendor Requirements. Compliance software requirements are further supported in this ACM Reference Manual, Compliance Software Test Requirements. Compliance software includes the compliance manager, other public domain computer programs, and ACM compliance software.

Companion documents that are helpful in preparing software for certification as compliance software include the latest editions of the following CEC publications:

- *Energy Efficiency Standards*
- *Appliance Efficiency Regulations*
- *Nonresidential Compliance Manual*
- *Reference Nonresidential Appendices*
- *Reference Appendices*

1.5 Modeling Assumptions

When calculating annual energy use, it is necessary to make assumptions about how the proposed building is operated. Operating assumptions include thermostat settings, number of occupants, receptacle loads, process loads, hot water loads, and operation schedules for heating, ventilation, and air-conditioning (HVAC) systems, lighting systems, and other systems. Sometimes these data points are known with some certainty, and other times (for instance, for buildings with as yet to be determined occupancy), it is necessary to make estimates. Some of these inputs are prescribed (fixed for the proposed and standard design buildings and cannot be changed), while others are defaults.

Modeling assumptions used by compliance software are provided in this ACM Reference Manual, General Modeling Procedures, Nonresidential Building Descriptors Reference, and Multifamily Building Descriptors Reference.

1.6 Reference Method

To ensure a minimum level of deviation in modeled building energy usage and compliance results between compliance software offered by different vendors, a reference method is developed. The reference method includes procedures that compliance software must meet and test cases that compliance software must run. The test cases are compared against a reference to ensure that modeled energy usage and efficiency between compliance software are approximately the same. All compliance software is compared against modeling results of the compliance manager. The reference method includes:

- A series of reference method test cases used for comparison.
- Input that may vary for credit, and input that is fixed or restricted.
- Standard report output requirements.
- Certification of the software vendor requirements in this manual.

General requirements for compliance software can be found in this ACM Reference Manual, General Compliance Software Modeling Procedures and Requirements. Description of compliance software testing requirements used in the reference method can be found in this ACM Reference Manual, Compliance Software Test Requirements. These descriptions are based on requirements laid out in Section 10-109 and 10-116 of the 2025 California Building Standards Code, Title 24, Part 1.

1.7 Alternative Calculation Method Compliance Software Approval Process

The alternative calculation method compliance software approval process is documented in Sections 10-109, 10-110, and 10-116 of the Energy Code. This section of the ACM Reference Manual supports this process. Alternative calculation method compliance software that is being submitted for approval through this process is considered alternative calculation method (ACM) candidate compliance software until approved by the Energy Commission. The proponent of ACM candidate compliance software is considered the compliance software vendor or the vendor of the compliance software.

1.7.1 Application Checklist

The following items shall be included in an application package submitted to the CEC for compliance software approval:

- Compliance Software Vendor Certification Statement. A copy of the statement provided by the Energy Commission to the applicant, signed by the compliance software vendor, certifying that the ACM candidate compliance software meets all Energy Commission requirements, including requirements for accuracy and reliability when used to demonstrate compliance with the energy code.
- ACM Candidate Compliance Software Computer Runs and Summary Sheets. Copies of the computer runs specified in Chapter 3: Compliance Software Test Requirements of this manual on machine-readable forms as specified in Chapter 3: Compliance Software Test Requirements to enable verification of the runs.
- User Manual, or Changelog or Both. The compliance software vendor shall submit a complete copy of the ACM candidate compliance software user manual, including material on the use of the ACM candidate compliance software for compliance, a changelog, including a complete list of changes to the ACM compliance software, or both.
- Executable ACM candidate compliance software and weather data. A machine-readable copy of the ACM candidate compliance software for random verification of compliance analyses. The compliance software vendor shall use approved CEC weather files.
- Long-term System Cost (LSC) Documentation. The ACM candidate compliance software shall be able to convert modeled building energy consumption to LSC as described in Reference Appendices, Joint Appendix JA3.
- Source Energy. The software shall be able to calculate source energy as described in Chapter 2.1.5: Source Energy.
- Application Fee. The compliance software vendor shall provide an application fee of $1,000.00 as authorized by Section 25402.1(b) of the Public Resources Code, payable to the State of California to cover costs of evaluating the application and to defray reproduction costs.

A cover letter acknowledging the shipment of the completed application package should be emailed to ExecutiveOffice@energy.ca.gov.

Two copies of the full application package should be sent to:

Compliance Software Nonresidential Certification
California Energy Commission
715 P Street, MS-26
Sacramento, CA 95814-5512

Following submittal of the application package, the CEC may request additional information under Title 24, Part 1, Sections 10-109, 10-110, and 10-116. This additional information is often necessary due to the complexity of software. Failure to provide such information in a timely manner may be considered cause for rejection or disapproval of the application. A resubmittal of a rejected or disapproved application will be considered a new application and must include a new application fee.

1.7.2 Types of Approval

An ACM candidate compliance software application can be approved unconditionally, approved with restrictions to specified occupancies, designs, materials, or devices, or rejected.

If approved, the ACM candidate compliance software is considered compliance software and may be used to demonstrate compliance with the Energy Code through the performance compliance pathway. Demonstration of compliance may be restricted to specific occupancies, designs, materials, or devices if the compliance software was approved with restrictions.

1.7.3 Alternative Calculation Method Compliance Software Updates

Approved alternative calculation method compliance software may need to be updated throughout the current code cycle. The Energy Commission classifies updates as major updates or minor updates.

Major updates are changes that would affect compliance values, or changes to match rules established for modeling compliance software documented in the current version of the Alternative Calculation Method Reference Manual. The steps for major alternative calculation method compliance software updates are provided in Section 10-116(d)1 of the Energy Code. Examples of scenarios that may result in major updates to alternative calculation method compliance software include:

- Energy Code revisions that alter the basic compliance process.
- The Energy Commission determines that new analytic capabilities are widespread and should be a required software capability.
- The vendor of the ACM compliance software implements new algorithms into the compliance software which results in changes to building model compliance margins.

Minor updates are changes to the user interface or changes that do not result in changes to compliance values. The steps for minor updates are provided in Section 10-116(d)2.

1.7.4 Decertification of Compliance Software

Decertification is the formal process of withdrawing approval of alternative calculation method compliance software. The process for decertification of compliance software is described in the Energy Code Section 10-116(f). Compliance software can be decertified as a result of the following:

- The Energy Code undergoes substantial changes such that the software would fail to confirm compliance with the Building Efficiency Standards.
- A letter from the vendor of the alternative calculation method compliance software requests a particular version of the alternative calculation method compliance software to be decertified. The decertification request shall briefly describe the nature of the program errors or “bugs“ that justify the need for decertification.
- Any ”initiating party“ may begin decertifying any compliance software according to the steps outlined in the Energy Code Section 10-116(f)3. The intent is to include a means whereby unfavorable compliance software tests, serious program errors, flawed numeric results, improper forms, or incorrect program documentation not discovered in the certification process or a combination thereof can be verified, and use of the particular compliance software version discontinued. In this process, there is ample opportunity for the Energy Commission, the vendor of the compliance software, and all interested parties to evaluate any alleged problems with the compliance software program.

NOTE 1: The primary rationale for a challenge is unfavorable compliance software tests, which means that for some particular building design with a set of energy efficiency measures, the compliance software fails to meet the criteria used for testing compliance software programs described in Chapter 3: Compliance Software Test Requirements.

NOTE 2: Another challenge rationale is flawed numeric results, where the compliance software meets the test criteria in Chapter 3: Compliance Software Test Requirements, in particular, when compliance software fails to properly create the standard design building.

The following is the process for challenging compliance software or initiating a decertification procedure:

- Any party may initiate a review of compliance software approval by sending a written communication to the Executive Director. (The Energy Commission may be the initiating party for this type of review by noticing the availability of the same information listed here.)
- The initiating party shall:
    - State the name of the compliance software and the program version number(s) that contain the alleged errors.
    - Identify concisely the nature of the alleged errors in the compliance software that require review.
    - Explain why the alleged errors are serious enough in the effect on analyzing buildings for compliance to justify a decertification procedure.
    - Include appropriate data on any media compatible with Windows 7 or newer and/or information sufficient to evaluate the alleged errors.

The Executive Director shall make a copy or copies of the initial written communication available to the compliance software vendor and interested parties within 30 days.

- Within 75 days of receipt of the written communication, the Executive Director may request any additional information needed to evaluate the alleged compliance software errors from the party who initiated the decertification review. If the additional information is incomplete, this procedure will be delayed until the initiating party submits complete information.
- Within 75 days of receipt of the initial written communication, the Executive Director may convene a workshop to gather additional information from the initiating party, the compliance software vendor, and interested parties. All parties will have 15 days after the workshop to submit additional information regarding the alleged program errors.
- Within 90 days after the Executive Director receives the application or within 30 days after receipt of complete additional information requested of the initiating party, whichever is later, the Executive Director shall either:
  - Determine that the compliance software need not be decertified.
  - Submit to the Energy Commission a written recommendation that the compliance software be decertified.
- The initial written communication, all relevant written materials, and the Executive Director's recommendation shall be placed on the consent calendar and considered at the next business meeting after submission of the recommendation. The matter may be removed from the consent calendar at the request of one of the Commissioners.
- If the Energy Commission approves the compliance software decertification, it shall take effect 60 days later. During the first 30 days of the 60-day period, the Executive Director shall send out a notice to building officials and interested parties announcing the decertification.

All initiating parties have the burden of proof to establish that the review of alleged compliance software errors should be granted. The decertification process may be terminated at any time by mutual written consent of the initiating party and the Executive Director.

As a practical matter, the compliance software vendor may use the 180- to 210-day period outlined here to update the compliance software program, get it reapproved by the Energy Commission, and release a revised version that does not have the problems initially brought to the attention of the Energy Commission. The vendor of the compliance software may wish to be the initiating party to ensure that a faulty program version is taken off the market.

1.8 Guidance for the Vendor of the Compliance Software

Each vendor shall meet all of the following requirements as part of the compliance software approval and as part of an ongoing commitment to users of the particular program.

1.8.1 Availability to California Energy Commission

All compliance software vendors are required to submit at least one fully working program version of the compliance software to the CEC. An updated copy or access to the approved version of the compliance software shall be kept by the CEC to maintain approval for compliance use of the compliance software.

The CEC agrees not to duplicate the compliance software except for analyzing it, for verifying building compliance with the compliance software, or for verifying that only approved versions of the compliance software are used for compliance.

1.8.2 Enforcement Agency Support

Compliance software vendors shall provide ongoing enforcement agency support. Compliance software vendors shall provide a copy of the compliance software users' manual or help system or both to all enforcement agencies who request one in writing.

1.8.3 User Support

Compliance software vendors shall offer support to their users with regard to the use of the compliance software for compliance. Compliance software vendors shall include a users' manual or help system or both that provides appropriate guidance for specifying inputs and running a simulation for compliance. Requirements for the user manual are described in the 2025 California Building Standards Code, Title 24 Part 1. Vendors may charge a fee for user support.

1.8.4 Compliance Software Vendor Demonstration

The Energy Commission may request that compliance software vendors offer a live demonstration of the capabilities of their compliance software. One or more demonstrations may be requested before approval is granted.

2. General Compliance Software Modeling Procedures and Requirements

This section describes the modeling procedures and requirements that must be met by all compliance software. This includes requirements for inputs, zoning, and other functionality of compliance software. Note that the application process for alternative calculation method compliance software and requirements for vendors of compliance software can be found in this ACM Reference Manual, Alternative Calculation Method Compliance Software Approval Process and Vendor Requirements for Vendors of Compliance Software. Testing requirements for compliance software can also be found in this ACM Reference Manual, Compliance Software Test Requirements.

2.1 General Requirements for User-Entered Data

This document lists the building descriptors that are used in the compliance simulation. Users must provide valid data for all descriptors that do not have defaults specified and that apply to parts of the building that must be modeled.

2.1.1 Type of Project Submittal

The type of compliance for the project should be identified to ensure that the appropriate compliance requirements are used. This includes the following options:

- New building or Addition Alone. Compliance software may model the addition alone, but an addition modeled in this way shall be reported on all output forms as an addition (modeled alone).
- Addition Plus Alteration of Existing Building (if compliance software is approved for this optional capability).
- Alteration of Existing Building (if compliance software is approved for this optional capability).

2.1.2 Scope of Compliance Calculations

For each building or separately permitted space, compliance software shall require the user to identify the scope of the compliance submittal from a combination of the following list:

- Envelope
- Lighting or Partial Lighting
- Mechanical or Partial Mechanical (may include or exclude Domestic Hot Water)

Each combination requires specific assumptions, input procedures, and reporting requirements. Modeling assumptions are documented in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptors Reference. Reporting requirements are documented in Chapter 4: Content and Format of Standard Reports. Compliance software shall produce only compliance reports specific to the scope of the submittal determined for the run. For example, if the scope is envelope only, only the PRF-01 forms with envelope-only components are produced.

Lighting compliance for a partial compliance scenario may be for the entire building or may be specified for only portions of the building. When the building applies for partial lighting compliance, the space(s) where lighting for the space is unknown or undefined shall be marked as "undefined," and the compliance software shall use the standard design lighting power for the user-defined space type for both the proposed design and standard design. Under this compliance scope, the entire building shall be modeled, and the compliance forms shall indicate the spaces for which lighting compliance is not performed.

The combination of the above scopes will determine the standard design to which the proposed design is compared. When a scope is excluded from the performance calculation, the standard design will match the proposed for all features covered by that scope. Specific rules for each building model descriptor can be found in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptors Reference of this manual.

2.1.3 Climate Zones

The program shall account for variations in energy use due to the effects of the California climate zones and local weather data. Climate information for compliance simulations shall use the applicable data set in Reference Appendices, Joint Appendix JA2.

2.1.4 Long-term System Cost (LSC)

The compliance software shall calculate the LSC for both the standard design and the proposed design by multiplying the LSC factor for each hour of the year by the predicted site energy use for that hour. LSC factors have been established by the CEC for residential and nonresidential occupancies, for each of the climate zones, and for each fuel type (electricity, natural gas, and propane). The LSC approach is documented in more detail in Reference Appendices, Joint Appendix JA3. The Total LSC for nonresidential and multifamily buildings consists of the LSC for all efficiency measures (Efficiency LSC) and the LSC for all photovoltaic system, building energy storage systems, and demand flexibility measures as described in the following equations:

For nonresidential buildings:

$$Efficiency\ LSC = \sum(SC_{kwh,i} \times LSC_{kWh,i}) + \sum(SC_{gas,i} \times LSC_{gas,i}) + \sum(WH_{kwh,i} \times LSC_{kWh,i}) + \sum(WH_{gas,i} \times LSC_{gas,i}) + \sum(MV_{kwh,i} \times LSC_{kWh,i}) + \sum(MV_{gas,i} \times LSC_{gas,i}) + \sum(L_{regulated,i} \times LSC_{kWh,i})$$

For multifamily buildings:

$$Efficiency\ LSC = \sum(SC_{kwh,i} \times LSC_{kWh,i}) + \sum(SC_{gas,i} \times LSC_{gas,i}) + \sum(WH_{kwh,i} \times LSC_{kWh,i}) + \sum(WH_{gas,i} \times LSC_{gas,i}) + \sum(MV_{kwh,i} \times LSC_{kWh,i}) + \sum(MV_{gas,i} \times LSC_{gas,i}) + \sum(L_{regulated,i} \times LSC_{kWh,i}) + \sum(SUC_i \times LSC_{kWh,i})$$

Where:

PV_i = The energy generation of the photovoltaic system in the i^{th} hour. Additional information for export considerations are described below.

$LSC_{kWh,\ i}$ = The LSC factor for electricity in the i^{th} hour.

$BESS_i$ = Battery energy storage system energy in the i^{th} hour.

DF_i = The demand flexibility energy in the i^{th} hour.

$SC_{kwh,i}$ = The space-conditioning electric energy used in the i^{th} hour.

$SC_{gas,i}$ = The space-conditioning gas energy used in the i^{th} hour.

$LSC_{gas,\ i}$ = The LSC factor for gas in the i^{th} hour.

$WH_{kwh,i}$ = The water heating electric energy used in the i^{th} hour.

$WH_{gas,i}$ = The water heating gas energy used in the i^{th} hour.

$MV_{kwh,i}$ = The mechanical ventilation electric energy used in the i^{th} hour.

$MV_{gas,i}$ = The mechanical ventilation gas energy used in the i^{th} hour.

SUC_i = The energy associated with the self-utilization credit in the i^{th} hour.

$L_{regulated,i}$ = Regulated lighting energy used in the i^{th} hour.

The LSCs that apply to photovoltaic and BESS systems depend on whether generated energy is used on site or exported to the grid. If energy is used on site the LSC factors are based on the LSC factors as described in Reference Appendices, Joint Appendix JA3. If energy is exported to the grid, the hourly export LSC factors provided by the CEC are used. These export LSC factors account for the LSC costs that are avoided by the exports in each hour.

To comply through the performance compliance approach, the Total LSC and Efficiency LSC of the proposed design must be equal to or less than the total LSC and Efficiency LSC of the standard design. This applies to newly constructed buildings, additions to existing buildings, additions plus alterations of existing buildings, and alterations of existing buildings. The hourly LSC factors can be found at the Energy Commission website (https://www.energy.ca.gov/files/2025-energy-code-date-and-hourly-factors).

2.1.5 Source Energy

The compliance software shall calculate the long-run marginal, hourly source energy use for both the standard design and the proposed design as specified in the equation below.

$$Source\ Energy = \sum(Electricity\ Use_i \times SE_{kWh,i}) + \sum(Gas\ Use_i \times SE_{gas,i})$$

Where:

Electricity Use_i = The electric energy used in the i^{th} hour.

$SE_{kWh,\,i}$ = The source energy factor for electricity in the i^{th} hour.

Gas Use_i = The gas energy used in the i^{th} hour.

$SE_{gas,\,i}$ = The source energy factor for gas in the i^{th} hour.

The hourly source energy factors provided by the CEC are used to determine compliance. To comply through the performance compliance approach, the Source Energy of the proposed design must be equal to or less than the Source Energy of the standard design. This applies to newly constructed buildings only. The hourly source energy factors can be found at the Energy Commission website (https://www.energy.ca.gov/files/2025-energy-code-date-and-hourly-factors).

2.1.6 Reporting Requirements for Unsupported Features

The compliance software shall have the input capabilities described in Chapter 2: General Compliance Software Modeling Procedures and Requirements and meet required capabilities and pass applicable certification tests as defined in Chapter 3: Compliance Software Test Requirements. While the vendor's ACM candidate compliance software does not need to implement every modeling rule in the Nonresidential and Multifamily ACM Reference Manual, all ACM candidate compliance software features, systems, components, and controls that are modeled must follow the modeling rules in the Nonresidential and Multifamily ACM Reference Manual. Vendors seeking certification for ACM candidate compliance software programs to be used for Energy Code compliance should clearly state the extent of the capabilities of their ACM candidate compliance software with respect to compliance. Support of a modeling feature includes correctly processing user input, specifying the standard design correctly, applying that information to simulation models, and processing the results.

Any building features or systems that cannot be modeled in a compliance software program shall show compliance using prescriptive forms.

2.1.7 Building Envelope Descriptions

The user shall provide accurate descriptions for all building envelope assemblies including exterior walls, demising surfaces, fenestration, doors, roofs, exterior floors, slab-on-grade floors, below-grade walls, and below-grade floors. The user shall provide data for all the required descriptors listed in Chapter 5.5 Building Envelope Data for nonresidential occupancies and Chapter 6.10.7 Exterior Surfaces for multifamily occupancies that correspond with these assemblies. However, the following exception applies:

- Exterior surfaces with an azimuth orientation and tilt differing by no more than 45° that is otherwise the same, may be described as a single surface or described as using multipliers. This specification would permit a circular form to be described as an octagon.

2.1.8 Space-Use Classification

The user must designate space-use classifications that best match the uses for which the building or spaces are designed. Space-use classifications determine the default occupant density, occupant activity level, receptacle power, service water heating, lighting load, daylighting set points, and operating schedules used in the analysis. Process loads and refrigeration loads are also provided for applicable space types. Each space-use classification must be associated with a ventilation space function that sets the outdoor ventilation and/or exhaust requirement for the space. The user must choose a ventilation space function from one or more options, depending on the space function.

The user must specify the space-use classifications using the area category method. The area category method uses the area categories in the standard design, which were developed for lighting requirements. The area category method requires area category entry of floor area and space-use designations. More than one area category may be used if the building is a mixed-use facility.

The user may override the default assumptions for some building descriptors dependent on the space-use classification with supporting documentation. Details are provided in Chapter 5.4: Space-Uses for nonresidential occupancies and Chapter 6.10: Zones for multifamily occupancies of this manual.

2.1.9 Treatment of Descriptors Not Fully Addressed by This Document

This document provides input and rating rules covering a full range of energy-related features encountered in commercial buildings. However, this goal is unlikely to ever be achieved due to the large number of features that must be covered and the continuous evolution of building materials and technologies. Building features or systems not covered in this manual must apply for approval through the exceptional calculation method to the CEC. This manual may be amended with provisions to model additional features or HVAC systems during the code cycle. When this occurs, it is the responsibility of the compliance software vendor to pass the necessary acceptance tests and apply for approval for the additional feature(s).

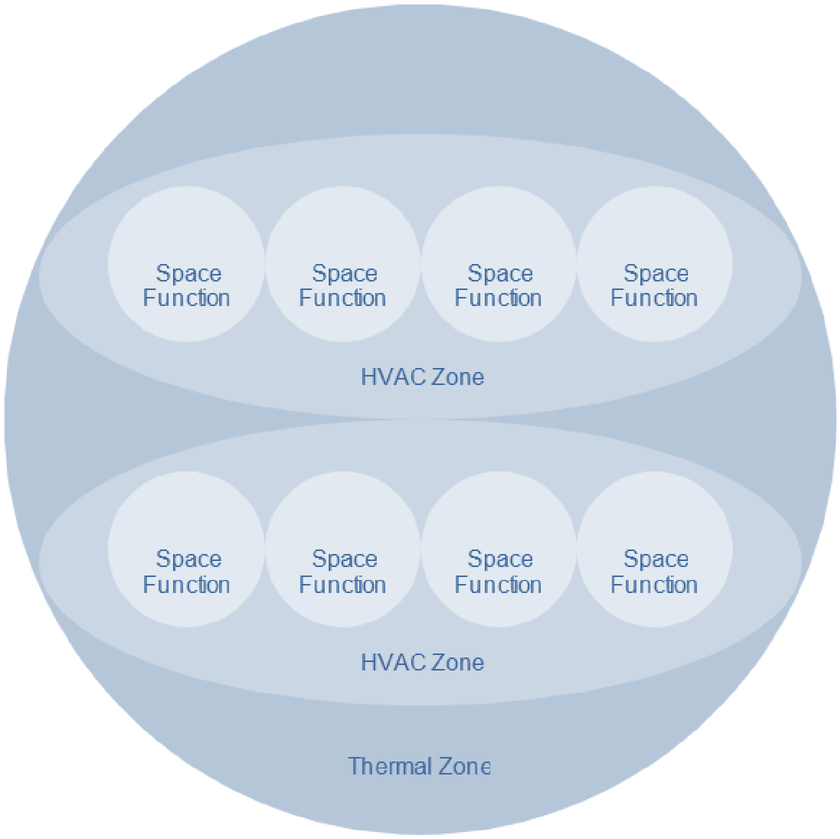
2.2 Thermal Zones, HVAC Zones, and Space Functions

2.2.1 Definitions

A *thermal zone* is a space or collection of spaces having similar space-conditioning requirements, has the same heating and cooling set point, and is the basic thermal unit (or zone) used in modeling the building. A thermal zone will include one or more spaces. Thermal zones may be grouped together, but systems serving combined zones shall be subject to efficiency and control requirements of the combined zones.

An *HVAC zone* is a physical space within the building that has a thermostat and zonal system for maintaining temperature. HVAC zones are identified on the HVAC plans. HVAC zones should not be split between thermal zones; however, a thermal zone may include more than one HVAC zone. A *space function* is a space-use classification that has specific standard design lighting requirements and for which there are associated defaults for occupancy, receptacle loads, and hot water consumption. Space functions are associated with ventilation space functions that set outdoor air-ventilation requirements documented in the ACM appendices. An HVAC zone may contain more than one space function. Particular space functions in a building may require multiple HVAC zones to serve the needs of the space function. Appendix 5.4A lists the space functions that may be used with the compliance software. Daylit areas should be assigned to specific spaces, even if they have the same classification from Appendix 5.4A, so that lighting reductions due to daylighting can be determined at the appropriate resolution.

Figure 1: Hierarchy of Space Functions, HVAC Zones, and Thermal Zones



Source: California Energy Commission

2.3 Compliance Software Modeling Requirements for Zones

2.3.1 Required Zone Modeling Capabilities

For California compliance, compliance software shall accept input for and be capable of modeling a minimum of 50 thermal zones, each with a control. Compliance software may use zone multipliers for identical zones.

2.3.2 Modeling Requirements for Unconditioned and Indirectly Conditioned Spaces

Unconditioned space is enclosed space that is neither directly nor indirectly conditioned as specified by the definition in Section 100.1. Examples include stairways, warehouses, unoccupied adjacent tenant spaces, parking garages, attics, and crawl spaces.

Unconditioned spaces shall be modeled if they are part of the permitted space. All applicable envelope information shall be specified in a similar manner to conditioned space as designed, but is not subject to compliance with the standards.

If unconditioned space is not a part of the permitted space, the space may be either explicitly modeled or the impact thereof on the permitted space may be approximated by modeling the space as outdoor space. For unconditioned spaces that are explicitly modeled, all internal gains and operational loads (occupants, water heating, receptacle, lighting, and process loads) shall be modeled as specified in Appendix 5.4A.

Indirectly conditioned spaces are enclosed spaces that are not directly conditioned and meet the indirectly conditioned space definition in Section 100.1. These spaces can be either occupied or unoccupied. For spaces that are unoccupied, such as plenums, attics, or crawlspaces, lighting, receptacle, and occupant loads shall be zero. For spaces that can be occupied, such as stairwells or storage rooms, modeling assumptions shall be taken from Appendix 5.4A.

Return air plenums are considered indirectly conditioned spaces and shall be modeled as part of the adjacent conditioned space with equipment, lighting, and occupant loads at zero. Unconditioned spaces may not be located in the same thermal zone as conditioned spaces. Conditioned spaces and indirectly conditioned spaces may be located in the same thermal zone or in separate zones. When located in the same thermal zone, the indirectly and directly conditioned spaces are assumed to have the space temperature schedule. When indirectly conditioned space is assigned to a thermal zone, the zone cannot have heating/cooling system but can have a ventilation or exhaust system.

2.3.3 Space-Use Classification Considerations

Thermal zones shall be combined only if the spaces have similar space-conditioning requirements and operating schedules. Space function inputs, as how they translate to thermal zone and HVAC system analysis assumptions, are defined by the following rules:

Spaces: Building spaces are sections of a building sharing the same space function (for example, office, retail, lab) and serve as the structure for modeling the envelope, ventilation, exhaust, lighting, daylighting, and occupancy and process loads of the building. Spaces can have only one space function, can be assigned to only one thermal zone, and can't span multiple building floors.

Space Functions: Each building space is assigned one space function. Design internal loads and other space function input assumptions are defined in Appendix 5.4A. Appendix 5.4A also defines the schedule group associated with each space function. The schedule group and the schedule values for each space function are prescribed for compliance analysis.

Some space functions are common to many schedule groups. These space functions are defined in Appendix 5.4A as having schedule groups that are editable. This addresses the issue of conflicting schedule profiles if these common functions are combined into a single thermal zone or served by the same HVAC system as surrounding zones. In the event the user does not assign a schedule group to these common space types, a default assumption is defined in the Appendix 5.4A.

Thermal Zones: Spaces can be combined into thermal zones. In this situation, peak internal loads and other design inputs for the thermal zone are modeled separately or weight-averaged based on floor area. The thermal zone schedules (occupancy, HVAC schedule, lighting schedule, space setpoint schedule) are based on the predominant schedule group described below. Thermal zones cannot combine spaces that are associated with different building floors. Dwelling units shall be modeled using at least one thermal zone per dwelling unit, except that those units facing the same orientations may be combined into one thermal zone. Corner dwelling units and dwelling units with roof or floor loads shall only be combined with dwelling units sharing these features. If multiple floors are the same, then the modeler can use the floor multiplier to model multiple floors.

Schedule Group: There are many different schedule groups defined in Appendix 5.4B for California compliance. Each schedule group defines hourly profiles for thermostat set points, HVAC system availability, occupancy, lighting, receptacles, service hot water, gas equipment, infiltration, refrigeration elevators, and escalators. The schedule group is based on the space function.

HVAC Systems: In many cases, more than one conditioned thermal zone is served by an HVAC system, which has scheduled availability (ON or OFF) to address the occupancy and internal load patterns of the thermal zones it serves.

Predominant Schedule Group: For a building thermal zone or building floor that includes multiple schedule groups, the hourly profiles are determined by the compliance software according to the predominant schedule group for each thermal zone or building floor. The predominant schedule group for the thermal zone or building floor is determined by the schedule group, as defined above, associated with the largest floor area of the thermal zone or building floor. Residential multifamily dwelling units, hotel/motel guestrooms, and common areas associated with these residential spaces, as well as enclosed parking garages and covered process spaces (laboratory, data, and commercial kitchen), shall always have their own prescribed schedule group, regardless of the predominant schedule group for the thermal zone.

2.4 Unmet Load Hours

This manual uses the term “unmet load hours” (UMLHs) as a criterion for determining if the proposed design heating/cooling capacities are sufficient to meet the simulated loads. The concept of unmet load hours applies to thermal zones. For a thermal zone, it represents the number of hours during a year when the HVAC system serving the thermal zone is unable to maintain the set point temperatures for heating or cooling or both. During periods of unmet loads, the zone temperature drifts above the cooling set point or below the heating set point. A thermal zone is considered to have one UMLH if the zone temperature is outside a specified tolerance below the heating or above the cooling set point for the entire hour. The set-point tolerance for nonresidential occupancies is defined in Chapter 5.3.5 Space Temperature Control. 5.3.5.

UMLHs occur only during periods when the zone is occupied. UMLH are accounted for in each zone of the building. No zone in the building should exceed the maximum allowed UMLH.

UMLHs can occur because fans, terminal units, coils, furnaces, air conditioners, or other equipment are undersized. UMLH can also occur because of user errors such as inappropriate supply air control set-points. It is the responsibility of the user to address other causes of UMLH in the proposed design.

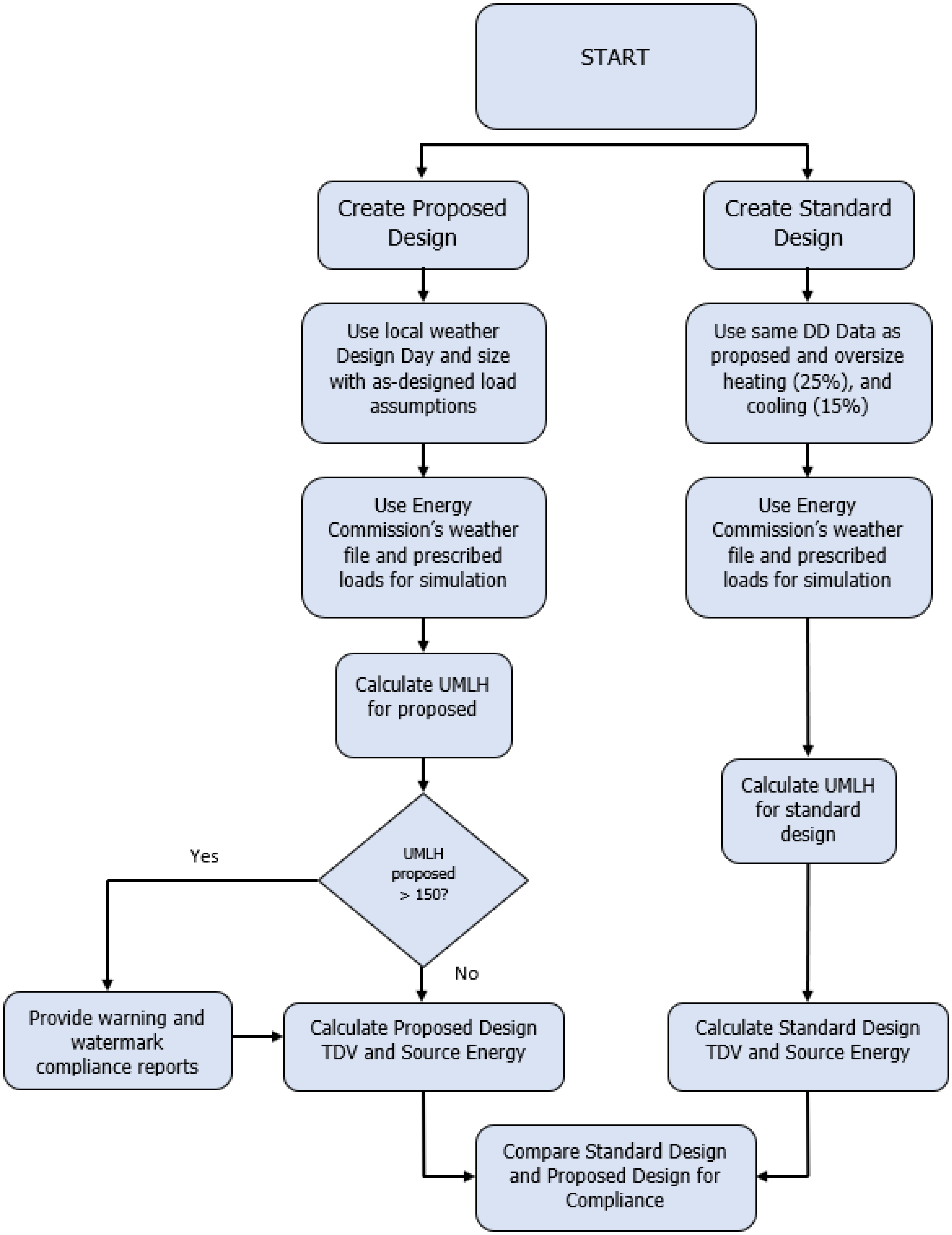
UMLH apply to thermal zones that contain any space type that is normally occupied. Thermal zones that contain only the space types listed below will not have UMLH criteria applied to them:

- Commercial and industrial storage areas
- Corridors, restrooms, stairs, and support areas
- Electrical, mechanical, telephone rooms
- Laundry rooms
- Locker/dressing rooms
- Parking garage areas
- Unoccupied gross floor areas
- Zones that are not subject to any UMLH checks or restrictions are listed in Appendix 5.4A.

2.5 Calculation Procedures

The general calculation procedure is illustrated below in Figure 2: Calculation Process for Title 24Energy Code. The proposed design Total LSC, Efficiency LSC, and source energy use are compared to the standard design by the compliance manager and must be equal to or less than the standard design for the project to comply through the performance method.

Figure 2: Calculation Process for Energy Code Compliance



Source: California Energy Commission

1. The process begins with a detailed description of the proposed design. Information is provided in enough detail to enable an estimate of annual energy use for a typical weather year. The required information depends on the scope of the project to be simulated by the compliance software but generally includes the building envelope, lighting systems, HVAC systems, water heating systems, and other important energy-using systems. This collection of information is referred to in this manual as *building descriptors*. Details on the building descriptors are provided in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptors Reference. Where applicable, user inputs are checked to be consistent with the guidance provided in this manual and the limitations of the simulation software.
2. Before the calculations are performed, some of the building descriptors are modified for the proposed design to incorporate prescribed modeling assumptions. Prescribed modeling assumptions include operating schedules, occupant density, equipment power density, and water-heating loads.
3. An annual simulation of the proposed design is performed to calculate hourly energy use and determine whether the heating and cooling loads are satisfied. The indicator, UMLHs, may for example, include the number of occupied hours during the year when the space temperature in one or more thermal zones is outside the throttling range. A large number of hours indicates system control issues, an undersized system, or a combination of factors.
4. If the proposed UMLHs are greater than 150 for the year, a warning will be presented after the simulation is complete, and the compliance report will be watermarked as not usable for compliance. No zone, other than zones that are completely comprised of the irregularly occupied space types listed above, may exceed 150 UMLH. It is up to the designer to adjust system control, flow rates, or equipment sizes as necessary.
5. For comparison with the proposed design compliance simulation, the standard design is generated following the rules in this manual.
6. Sizing calculations are performed for the standard design and heating equipment is oversized by 25 percent and cooling equipment by 15 percent.
7. An annual simulation of the standard design is performed with the equipment capacities determined from sizing to calculate the hourly energy use. The number of unmet UMLH for the standard design is calculated and the information is available as an optional output. It is unlikely for the standard design to have more than 150 UMLH since the standard design system capacities are determined using a sizing run with additional oversizing multipliers, and controls are prescribed to be consistent with the system type.
8. If the UMLHs in the standard design are greater than 150 the compliance software developer should be notified for review. This situation does not impact the validity of proposed design compliance.
9. Finally, the proposed design Total LSC, Efficiency LSC, and source energy use and standard design Total LSC, Efficiency LSC and source energy use are compared for compliance depending on if the project is a newly constructed building, addition alone, addition plus alteration of existing building, or alteration of existing building.

2.6 HVAC Capacity Requirements and Sizing

To ensure that the simulated space-conditioning loads are adequately met, adequate capacity must be available in each of the components of the HVAC system, for example, supply-airflow rates, cooling coils, chillers, and cooling towers. If any component of the system is incapable of adequate performance, the simulation may understate the required energy use of space-conditioning equipment and report unmet load hours. Therefore, adequate capacities are required in the simulations of both the proposed design and standard design. The subchapters below describe the procedures that shall be followed to ensure that both versions of the design are simulated with adequate space-conditioning capacities.

The UMLHs criterion is used to prevent simulation of HVAC systems that may not adequately serve space-conditioning needs. This requirement does not mandate that a specific cooling or heating capacity be specified. With this requirement, if the proposed design appears as undersized, the user will be prompted to adjust plant, system, zonal capacities, or a combination as needed to meet the UMLH criteria.

The special case of a building designed with no cooling system (typically, in a temperate coastal climate) is accommodated by the compliance software automatically adding a minimally compliant packaged constant-volume, single-zone system.

2.6.1 Specifying HVAC Capacities for the Proposed Design

As described in Chapter 2.5: Calculation Procedures, the proposed design shall have no more than 150 UMLH for any thermal zone. If this limit is exceeded, the compliance software allows the user to make changes to the proposed design building description to bring the UMLH equal to or below 150. This process is not automated by the compliance software.

If the proposed design does not meet the UMLH criteria, the user should indicate the condition on the forms to add necessary equipment capacity to the proposed design. If the space-conditioning criteria are not met because the HVAC equipment in the proposed design lacks the capability to provide either heating or cooling, equipment capable of providing the needed space conditioning must be specified by the user.

Equipment sizes for the proposed design shall be entered into the model by the energy analyst and shall agree with the equipment sizes specified in the construction documents. When the simulations of these actual systems indicate that specified space conditions are not being adequately maintained in one or more thermal zone(s), the user shall be prompted to make changes to equipment sizes or zones as necessary. Space conditions are not being adequately met when the UMLH exceed 150 for the year. The use of equipment sizes that do not match the actual equipment sizes as indicated on construction documents triggers an exceptional condition that is noted on the compliance forms.

2.6.2 Sizing Equipment in the Standard Design

For sizing heating and cooling equipment capacities, the compliance software shall use design day schedules as specified in Chapter 5.2: Project Data. For cooling capacity sizing, compliance software shall use the OnDay schedule from Appendix 5.4B for occupant, lighting, and equipment schedules, respectively. For heating capacity sizing, compliance software shall use the OffDay schedule from Appendix 5.4B for occupant, lighting, and equipment schedules, respectively.

Equipment in the standard design is automatically sized by the program as described below. Net coil capacities are calculated using the adjustments described in Section 5.7.5 Cooling Systems and Section 5.7.6 Heating Systems. The compliance software will tabulate the zone UMLH for the standard design in the same manner as the proposed design. However, standard design UMLH will not influence compliance analysis.

Single-Zone Air-Source Heat Pump Systems:

For standard design single-zone air-source heat pump systems, the sizing run shall be performed using an electric resistance heating coil. The autosized electric resistance coil capacity is then used as an input to determine the gross heating capacity of the heat pump at 47°F and the heat pump supplemental heating coil using the equation below, which is used for determining the annual heat pump heating coil capacities for the annual compliance simulation as described in the next paragraph.

$$GrossHPHtgCap_{sizing} = GrossERCap_{sizing} \times (1 + 0.0167 \times (47 - DesignHeatingDBT))$$

$$GrossSuppHtgCap_{sizing} = GrossERCap_{sizing}$$

Where:

$GrossHPHtgCap_{sizing}$ = the estimated gross heating capacity of the heat pump at 47°F outdoor air temperature
$GrossERCap_{sizing}$ = the autosized gross electric resistance heating capacity from the sizing run
DesignHeatingDBT = the design heating outdoor air temperature used for sizing run
$GrossSuppHtgCap_{sizing}$ = the autosized gross electric resistance supplemental heating capacity

The heat pump gross coil capacity for cooling at standard rating conditions is 1.15 times the maximum of either the autosized gross cooling capacity plus the calculated design fan heat, or the autosized gross heating capacity as determined using the equation for gross heating capacity calculated above multiplied by 0.75 less the calculated design fan heat. The heat pump gross coil capacity for heating at standard rating conditions is the same as the cooling capacity.

Fan capacity is 1.15 times the maximum of the autosized heating or cooling airflow, or the minimum ventilation airflow, whichever is greater. The final calculated cfm/ton_{gross} shall not be less than 280 and not more than 450.

All Other Secondary Systems: The gross coil capacity for heating at standard rating conditions is 1.25 times the autosized gross heating capacity. The gross coil capacity for cooling at standard rating conditions is 1.15 times the autosized gross cooling capacity plus the calculated design fan heat. For DX coils, the final calculated cfm/ton_{gross} shall not be less than 280 and not more than 450.

Fan capacity is 1.15 times the maximum of the autosized heating or cooling airflow, or the minimum ventilation airflow, whichever is greater. For multi-zone systems, autosized airflow is determined based on the coincident peak airflow needed by all thermal zones at the design supply air temperature.

Plant Equipment: The gross coil capacity for boilers at standard rating conditions is 1.25 times the design day peak loop load. The gross coil capacity for chillers/heat rejection at standard rating conditions is 1.15

times the design day peak loop load. Pump capacity is calculated using the final capacity and design deltaT of the primary equipment served by the pump.

2.6.3 Handling Proposed Design With No HVAC Equipment

If mechanical system compliance is included, as described in Chapter 5.2.3: Partial Compliance Model Input Classification, and a compliance model does not contain an HVAC system, the compliance software will generate an error and not run the simulation. For zones designed to not have a cooling system, the compliance software will automatically generate a minimally compliant, single-zone HVAC system to meet the cooling loads for the zone. In cases where the design has cooling but is insufficient to meet the UMLH criteria, the user can select “Add cooling system to meet load,” and the compliance software will automatically generate a minimally compliant, single-zone HVAC system to meet the cooling loads for the zone. The compliance software shall make an appropriate note on compliance documentation indicating that the modeled HVAC system does not match design requirements. If the compliance software provides a means for the user to identify that the building has no cooling system, this information is reported on the compliance reports.

2.7 Ventilation Requirements

Design decisions regarding outside air ventilation shall be based on Section 120.1 of the Energy Code. If local codes do not apply, minimum values from Appendix 5.4A shall be used. Chapter 5.6: HVAC Zone Level Systems of the ACM has additional information on the ventilation requirements used in the building descriptors for the proposed and standard design. While no compliance credit can be claimed for reducing ventilation rates in the proposed design below the required levels, the user can specify higher ventilation rates in the proposed design.

3. Compliance Software Test Requirements

This chapter contains the procedures used to test and certify vendor's compliance software as acceptable for compliance with Title 24, Part 6. The compliance software shall have the input capabilities described in Chapter 2: General Compliance Software Modeling Procedures and Requirements and meet required capabilities and pass applicable certification tests as defined in Chapter 3: Compliance Software Test Requirements. Compliance software must also follow all modeling rules specified in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptors Reference. The reference method test verifies compliance software functionality and accuracy of simulation results by identifying reference method test cases and comparing the results of ACM candidate compliance software to the results of the compliance manager. The reference method test cases fall into the following categories:

- Reference method test cases to verify that the compliance software is evaluating thermal loads and the response of the HVAC systems to these loads in an acceptable manner. These tests reference *ASHRAE Standard 140-2023, Method of Test for Evaluating Building Performance Simulation Software*.
- Reference method test cases that verify that compliance software is capable of modeling envelope, lighting, HVAC, and water heating efficiency features and provides precise estimates of energy tradeoffs and reasonably accurate predictions of building energy consumption.
- Reference method test cases to verify that the standard design building is created correctly. For example, the standard design HVAC system is properly specified, other components of the standard design are correctly defined, and rules that fix and restrict inputs (such as schedules and plug loads) are properly applied. These tests do not verify simulation outputs but may require simulations to be run to specify inputs that depend on system sizing.

The reference method test cases are designed to cover representative compliance software functionality for building envelope, space uses, lighting, daylighting, HVAC, and water heating, both for simulation performance and for proper implementation of ACM rules specified in Chapter 5 Building Descriptors Reference. The CEC reserves the right to add ruleset implementation tests or software sensitivity tests to verify existing or future compliance software requirements. Moreover, the CEC reserves the right to adjust the passing criteria for the compliance software sensitivity tests to reflect the capabilities of commonly available energy simulation programs.

CEC approval of ACM candidate compliance software programs is intended to provide flexibility in complying with the Energy Code. In achieving this flexibility, however, the ACM candidate compliance software shall not fail to meet the Energy Code or evade the intent of the Energy Code to achieve a particular level of energy efficiency. The vendor has the burden of proof to demonstrate the accuracy and reliability of the ACM candidate compliance software relative to the reference method test cases and demonstrate the conformance of the ACM candidate compliance software to the requirements of this manual. The accuracy of simulation are evaluated based on the following:

- The ACM candidate compliance software shall demonstrate acceptable levels of accuracy by performing and passing the required certification tests discussed in Chapter 3.5: Software Sensitivity Tests. The ACM candidate compliance software vendor conducts the specified certification tests in Appendix H, evaluates the results, and certifies in writing that the ACM candidate compliance software passes the tests. The CEC will perform spot checks and may require additional tests to verify that the proposed ACM candidate compliance software is appropriate for compliance.

When energy analysis techniques are compared, two potential sources of discrepancies are 1) the differences in user interpretation when entering the building specifications, and 2) the differences in the ACM candidate compliance software algorithms (mathematical models) for estimating energy use. The approval tests minimize differences in interpretation by providing explicit detailed descriptions of the test buildings that must be analyzed. For differences in the ACM candidate compliance software algorithms, the CEC allows algorithms that yield equivalent results. The vendor shall follow the procedure described in this document to certify publicly to the CEC that the ACM candidate compliance software meets the criteria in this document for:

- Accuracy and reliability when compared to the reference method test cases.
- Suitability in terms of the accurate calculation of the correct energy budget, the generation of output for transmission to standardized forms, and documentation on how the program demonstrates compliance.

In addition to specified technical criteria, CEC approval will also depend upon the CEC's evaluation of:

- Enforceability in terms of reasonably simple, reliable, and rapid methods of verifying compliance and application of energy efficiency features modeled by the ACM candidate compliance software and the inputs used to characterize those features by the software users.
- Dependability of the installation and energy savings of features modeled by the ACM candidate compliance software. The CEC will evaluate the probability that the measure will be installed and remain functional. The CEC shall also determine that the energy impacts of the features that the ACM candidate compliance software is capable of modeling will be reasonably and accurately reflected in real building applications of those features. It is important that the ACM candidate compliance software does not encourage the replacement of actual energy savings with theoretical energy savings due to tradeoffs allowed by the ACM candidate compliance software.

3.1 General Requirements

3.1.1 Scope

The compliance software must satisfy the requirements contained in this chapter.

The compliance software shall be capable of modeling at least 50 thermal zones.

The compliance software shall be capable of modeling at least 15 HVAC systems.

3.1.2 Calculation Methods

The compliance software shall calculate the annual consumption of all end uses in buildings, including fuel and electricity for:

- HVAC (heating, cooling, fans, and ventilation).
- Lighting (both interior and exterior).
- Receptacles and miscellaneous electric.
- Service water heating.
- Process energy uses.
- All other energy end uses that typically pass through the building meter.

The compliance software shall perform a simulation on an hourly time interval (at a minimum) over a one-year period (8,760 hours) with the ability to model changes in weather parameters, schedules, and other parameters for each hour of the year. This is achieved by specifying a 24-hour schedule for each day of the week plus holidays.

3.1.2.1 Calculating Design Loads

The compliance software shall be capable of performing design load calculations for determining required standard design HVAC equipment capacities and air and water flow rates, as described in this reference manual or using other accepted industry calculation methods showing equivalency.

3.1.2.2 Checking Simulation Output for Unmet Loads

The compliance software shall be capable of checking the annual simulation output for the proposed design to ensure that thermal zone conditions are maintained within the tolerances specified in Section 2.4: Unmet Load Hours. The compliance software shall post a compliance analysis error and inform the user of what zones violate the unmet load-hour criteria.

3.1.3 Climate Data

The compliance software shall perform simulations using the official CEC weather files and design conditions documented in Reference Appendices, Joint Appendix JA2.

The compliance software shall calculate solar radiation on exterior surfaces on an hourly basis from the values of direct normal irradiance and diffuse horizontal irradiance contained in the climate data, taking ground reflectance into account.

The compliance software shall be capable of simulating time-of-use rates and apply both demand and energy charges for each period of the rate schedule.

3.1.5 Long-term System Cost (LSC)

The compliance software shall be capable of converting site energy to LSC applying the CEC LSC multipliers for each hour of the simulation. See CEC Reference Appendices, Joint Appendix JA3.

3.1.6 Source Energy

The compliance software shall be capable calculating source energy for each hour of the simulation as described in 2.1.5 Source Energy.

3.1.7 Thermal Mass

The calculation procedures used in the compliance software shall account for the effect of thermal mass on loads due to occupants, lights, solar radiation, and transmission through building envelope on the amount of heating and cooling required to maintain the specified space temperature schedules and on variation in space temperature.

3.1.8 Modeling Space Temperature

The compliance software shall incorporate a dynamic simulation of space temperature that accounts for:

- Dynamics in change in heating and cooling setpoint temperatures.
- Dead band between heating and cooling thermostat settings.
- Temperature drift in transition to setback or setup thermostat schedules.
- Temperature drift in periods when heating or cooling capability are scheduled off.
- Temperature drift when heating or cooling capability of the system is limited by heating or cooling capacity, airflow rate, or scheduled supply air temperature.
- Indirectly conditioned thermal zones, where the temperature is determined by internal loads, heat transfer through building envelope, and heat transfer between thermal zones.

3.1.9 Heat Transfer Between Thermal Zones

The compliance software shall be capable of modeling heat transfer between a thermal zone and adjacent thermal zones.

The compliance software shall account for the effect of this heat transfer on the space temperature, space-conditioning loads, and resulting energy use in the thermal zone and adjacent thermal zones.

3.1.10 Control and Operating Schedules

The compliance software shall be capable of modeling control and operating schedules that can vary by:

- The hour of the day.
- The day of the week.
- Holidays, which are treated as a special day of the week.

The compliance software shall be capable of explicitly modeling all of the schedules specified in Appendix 5.4B of this manual.

3.1.10.1 Loads Calculation

The load calculations described in this chapter relate to the simulation engine, and not to the procedure used by the design engineer to size and select equipment.

3.1.10.2 Internal Loads

The compliance software shall be capable of calculating the hourly cooling loads due to occupants, lights, receptacles, and process loads.

The calculation of internal loads shall account for the dynamic effects of thermal mass.

The compliance software shall be capable of simulating schedules for internal loads in the form given in Appendix 5.4B.

The simulation of cooling load due to lights shall account for:

- The effect of the proportion of radiant and convective heat, which depends on the type of light and on the dynamic response characteristic.
- A portion of heat from lights going directly to return air. The amount depends on the type and location of fixture.

3.1.10.3 Building Envelope Loads

The compliance software shall calculate heat transfer through walls, roofs, and floors for each thermal zone, accounting for the dynamic response due to thermal characteristics of the particular construction as defined in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptor Reference.

The calculation of heat transfer through walls and roofs shall account for the effect of solar radiation absorbed on the exterior surface, which depends on orientation and absorptance of the surface.

The compliance software shall calculate heat transfer through windows and skylights, accounting for both temperature difference and transmission of solar radiation through the glazing.

Calculation of cooling load due to transmission of solar radiation through windows and skylights shall account for:

- The variation of thermal properties of the fenestration system with ambient temperature.
- Orientation (azimuth and tilt of surface).
- The effect of shading from overhangs, side fins, or exterior horizontal slats.

3.1.10.4 Infiltration

The compliance software shall be capable of simulating infiltration that varies by the time of day and day of the week. Schedules are provided in Appendix 5.4B.

3.1.11 Systems Simulation

3.1.11.1 General

The compliance software shall be capable of modeling:

- The standard design building systems defined in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptor Reference.
- The lighting, water-heating, HVAC, and miscellaneous equipment detailed in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptor Reference.
- All compulsory and required features, as detailed in Chapter 5: Nonresidential Building Descriptors Reference and Chapter 6: Multifamily Building Descriptor Reference.

The capability to model multiple zone systems shall allow at least 15 thermal zones to be served by one multiple-zone system.

The compliance software shall be capable of modeling plenum air return.

3.1.11.2 HVAC Zone Level Systems

The compliance software shall be capable of simulating the effect on space temperature and energy use of:

- Limited capacity of terminal heating devices.
- Limited capacity of terminal cooling devices.
- Limited rate of airflow to thermal zones.

3.1.11.3 HVAC Secondary Systems and Equipment

The compliance software shall be capable of simulating the effect on energy use and space temperature in thermal zones served by the HVAC system of:

- Limited heating capacity.
- Limited cooling capacity.

The simulation of HVAC systems shall account for:

- Temperature rise of supply air due to heat from supply fan, depending on the location of the fan.
- Temperature rise of return air due to heat from return fan.
- Temperature rise of return air due to heat from lights to return air stream.
- Fan power as a function of supply airflow in variable-air-volume systems.

3.1.11.4 HVAC Primary Systems and Equipment

The compliance software shall be capable of simulating the effect on energy use of limited heating or cooling capacity of the central plant system.

If the compliance software is not capable of simulating the effect of limited heating or cooling capacity of the central plant system on space temperature in affected thermal zones, then it shall issue a warning message when loads on the central plant system are not met.

3.1.11.5 Equipment Performance Curves

The compliance software shall be capable of modeling the part-load efficiency and variation in capacity of equipment as follows:

- Furnace efficiency as a function of part load.
- Boiler efficiency as a function of part load, supply hot water temperature, and return hot water temperature.
- Water-cooled compressors, including heat pumps and chillers, efficiencies as a function of part load, evaporator fluid, or air temperature and condensing fluid temperature.
- Air-cooled compressors, including heat pumps, direct expansion cooling and chillers, efficiencies as a function of part load, ambient dry-bulb temperature, and wet-bulb temperature returning to the cooling coil.
- Evaporative cooling system efficiency as a function of ambient wet-bulb temperature.
- Cooling tower efficiency as a function of range and ambient wet-bulb temperature.

3.1.11.6 Economizer Control

The compliance software shall be capable of modeling integrated air- and water-side economizers.

3.2 Special Documentation and Reporting Requirements

3.2.1 Building Envelope

3.2.1.1 Roof Radiative Properties

The user shall enter three-year aged roof reflectance and emittance for roofs that have been certified by the Cool Roof Rating Council. The compliance software shall report the product identification number(s) of any roofing products used on the building, so that aged reflectance and emittance can be verified by the code official.

3.2.2 Interior Lighting

3.2.2.1 Regulated Interior Lighting Power

Whenever any of the additional lighting power allowance for qualified lighting systems (the two rightmost columns in Table 140.6-C of the Energy Code) are claimed, the compliance software shall indicate on the compliance forms that verification is required.

3.2.2.2 Indoor Lighting Power (see Chapter 5.4.4: Interior Lighting)

Compliance software shall print all applicable lighting forms and report the lighting energy use and the lighting level (watts/ft^2) for the entire project. Compliance software shall report “no lighting installed” for nonresidential spaces with no installed lighting. Compliance software shall report “default residential lighting” for housing units of multifamily buildings and hotel/motel guest rooms.

Lighting power in unconditioned spaces does not receive performance standards compliance credit, but lighting in those spaces is required to meet the prescriptive requirements for regulated unconditioned spaces, such as commercial and industrial storage spaces, and parking garages. When these types of spaces are entered, the compliance software must report in the Special Features section that these spaces must comply with the prescriptive requirements for such spaces.

3.2.2.3 Design Illumination Set Point

Spaces that have low design illuminance levels, below the ranges specified in Appendix 5.4A, shall provide documentation showing the design illuminance to be used as the daylight illumination setpoint.

3.2.3 HVAC Exceptional Conditions

3.2.3.1 Equipment Sizing

When any proposed equipment size for secondary equipment or central plant equipment does not match the equipment size listed on construction documents, an exceptional condition shall be reported on compliance forms.

3.2.3.2 Process and Filtration Pressure Drop Allowance

Any nonzero values entered for supply fan process and filtration pressure drop are flagged as an exceptional condition in the compliance documentation.

3.2.3.3 Natural Ventilation Specified

When natural ventilation is specified by the user for the proposed design for Hotel/Motel guestrooms, the compliance software shall report an exceptional condition that the conditions in Section 120.1(c) of the Energy Code must be met. When natural ventilation is specified for common-use area in multifamily buildings, the compliance software shall report an exceptional condition that the conditions in Section 160.2(c) of the Energy Code must be met.

3.3 ASHRAE Standard 140-2023 Tests

This method of testing is provided for analyzing and diagnosing building energy simulation software using software-to-software and software-to-quasi-analytical-solution comparisons. The method allows different building energy simulation programs, representing different degrees of modeling complexity, to be tested by comparing the predictions from other building energy programs to the simulation results provided by the compliance software in question.

Compliance software must publish the results of ASHRAE Standard 140-2023 tests, but these tests are not part of the reference method.

The building energy simulation programs shall be tested according to ASHRAE Standard 140, except for Sections 12 of Standard 140. The required tests shall include Weather Drivers Tests (Section 6), Building Thermal Envelope and Fabric Load Tests (Section 7), Ground Coupled Slab-On-Grade Tests (Section 8), Space-Cooling Equipment Performance Tests (Section 9), Space-Heating Equipment Performance Tests ((Section 10), and Air-Side HVAC Equipment Performance Tests (Section 11), along with the associated reporting.

During testing, hidden inputs that are not normally accessible to the user shall be permitted. The hidden inputs are permitted to avoid introducing source code changes that are strictly used for testing.

The software vendor or third party, authorized by either the software vendor or the AHJ, shall publish on a publicly available website the following ASHRAE Standard 140 test results, input files, and modeler reports for each tested version of a building energy simulation program:

- Test results demonstrating the building energy simulation program were tested in accordance with ASHRAE Standard 140 Annex A3 and that meet or exceed the values for “The Minimum Number of Range Cases withing the Test Group to Pass” for all test groups in ASHRAE Standard 140, Table A3-14.
- Test results of the building energy simulation program and input files used for generating the ASHRAE Standard 140 test cases, along with the results of the other simulation programs included in ASHRAE Standard 140, Annexes B8 and B16.
- The modeler report in ASHRAE Standard140 Annex 2, Attachment A2.8. Report Blocks A and G shall be completed for results exceeding the maximum or falling below the minimum of the reference values shown in ASHRAE Standard 140 Table A3-1 through Table A3-13, and Report Blocks A and E shall be completed for any omitted results.

A software vendor of the simulation user interface or a third party authorized by the software vendor or the AHJ shall also be permitted to meet the requirements for this section.

If a certification program exists for building energy simulation program tested to ASHRAE Standard 140, the building energy simulation program shall be listed in the certification program.

4. Content and Format of Standard Reports

Consult the *Nonresidential and Multifamily Compliance Manual* for the reports required to be manually generated for any project. For nonresidential compliance, the PRF-01 report is generated by the compliance software. For residential compliance, the low-rise multifamily certification of compliance (LMCC) and the nonresidential and high-rise multifamily certification of compliance (NRCC) reports are generated by the compliance software.

5. Nonresidential Building Descriptors Reference

5.1 Overview

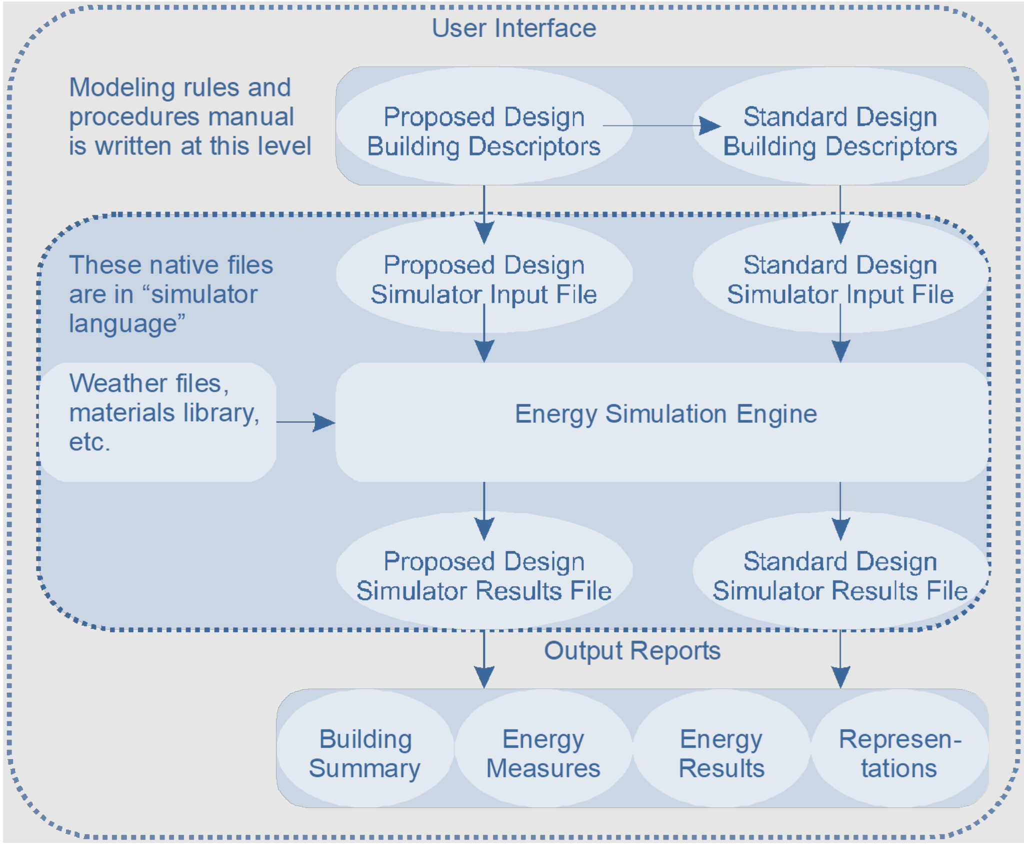
This chapter specifies, for each building descriptor, the rules that apply to the proposed design and to the standard design for nonresidential buildings and multifamily buildings as referenced in Chapter 6: Multifamily Building Descriptors Reference.

5.1.1 Definition of Building Descriptors

Building descriptors provide information about the proposed design and the standard design. In this chapter, the building descriptors are discussed in the generic terms of engineering drawings and specifications. By using generic building descriptors, this manual avoids bias toward one energy simulation engine. The building descriptors in this chapter are compatible with commonly used simulation software.

Each energy simulation program has a unique way of accepting building information. EnergyPlus™ uses a comma delimited data file called an *input data file* (IDF). DOE-2 uses BDL (building design language) to accept information. It is the responsibility of the compliance software to translate the generic terms used in this chapter into the "native language" of the simulation program. Figure 3: Information Flow illustrates the flow of information.

Figure 3: Information Flow



Source: California Energy Commission

5.1.2 Organization of Information

Building descriptors are grouped under objects or building components. A wall or exterior surface (an object) would have multiple building descriptors dealing with the geometry, thermal performance, and so forth. Each building descriptor contains the following pieces of information:

Building Descriptor Title

Applicability: Information on when the building descriptor applies to the proposed design.

Definition: A definition for the building descriptor.

Units: The units that are used to prescribe the building descriptor. A "list" indicates that a fixed set of choices applies, and the user shall be allowed to enter only one of the values in the list.

Input Restrictions: Any restrictions on information that may be entered for the proposed design.

Standard Design: This defines the value for the "standard design," or baseline building applied for this building descriptor. A value of "same as proposed" indicates that the building descriptor is neutral, that is, the value is set to match the proposed design value. In many cases, the value may be fixed or may be determined from a table lookup. In some cases, the input may not be applicable.

Standard Design: Existing Building: Standard design for existing buildings if different than for newly constructed buildings.

5.1.3 HVAC System Map

The Nonresidential HVAC system in the standard design depends on the predominant space function types of the building, the size of the building, and the number of floors. In buildings with different space function types on different floors, the standard design depends on the predominant space function type of each floor. Details about these systems are provided in subsequent chapters.

Many of the building descriptors have a one-to-one relationship between the proposed design and the standard design; for example, every wall in the proposed design has a corresponding wall in the standard design. For HVAC systems, however, this one-to-one relationship generally does not hold. The number and type of HVAC systems serving the proposed design and the standard design may be completely different in type and components.

The HVAC systems in the standard design are determined by Table 1: Nonresidential HVAC System Map, which is based on space type, system cooling capacity, number of above-grade floors, climate zone, conditioned floor area, and, for some spaces, process load, and laboratory exhaust rate. Table 2: System Descriptions, provides additional detail for each standard design system. Unless otherwise noted, all non-residential systems are set to meet the efficiency requirements for 3-phase equipment.

For Systems 1, 3, 7, 9, 10, and 11, each thermal zone shall be modeled with a respective HVAC system. For Systems 5, 6, 14, and 15 each floor shall be modeled with a separate HVAC system. Floors with identical thermal zones and occupancies can be grouped for modeling.

Table 1: Nonresidential HVAC System Map

Space Type	Above-Grade Floors	Climate Zone	System Cooling Capacity	Standard Design
Multifamily	(See NRMFACM Chapter 6)	(See NRMFACM Chapter 6)	(See NRMFACM Chapter 6)	(See NRMFACM Chapter 6)
Hotel/motel guestrooms	No limit	All	No limit	System 1 – RAC
Retail or grocery[1]	Buildings ≤ 2 floors	2-15	< 65 kBtu/h	System 3b – SZHP
Retail or grocery[1]	Buildings ≤ 2 floors	2-15	≥ 65 kBtu/h	System 7b – SZVAVHP
Retail or grocery[1]	Buildings ≤ 2 floors	1, 16	< 65 kBtu/h	System 3a – SZAC
Retail or grocery[1]	Buildings ≤ 2 floors	1, 16	≥ 65 kBtu/h	System 7c – SZVAVDFHP

Space Type	**Above-Grade Floors**	**Climate Zone**	**System Cooling Capacity**	**Standard Design**
Retail or grocery[1] and total building conditioned floor area < 25,000 ft^2	Buildings = 3 floors	2-15	< 65 kBtu/h	System 3b – SZHP
Retail or grocery[1] and total building conditioned floor area < 25,000 ft^2	Buildings = 3 floors	2-15	≥ 65 kBtu/h	System 7b – SZVAVHP
Retail or grocery[1] and total building conditioned floor area < 25,000 ft^2	Buildings = 3 floors	1, 16	< 65 kBtu/h	System 3a – SZAC
Retail or grocery[1] and total building conditioned floor area < 25,000 ft^2	Buildings = 3 floors	1, 16	≥ 65 kBtu/h	System 7c – SZVAVDFHP
School[2] and total building conditioned floor area ≤ 150,000 ft^2	Buildings ≤ 3 floors	2-15	< 65 kBtu/h	System 3b – SZHP
School[2] and total building conditioned floor area ≤ 150,000 ft^2	Buildings ≤ 3 floors	2-15	≥ 65 kBtu/h	System 7b – SZVAVHP
School[2] and total building conditioned floor area ≤ 150,000 ft^2	Buildings ≤ 3 floors	1, 16	< 65 kBtu/h	System 3c – SZDFHP
School[2] and total building conditioned floor area ≤ 150,000 ft^2	Buildings ≤ 3 floors	1, 16	≥ 65 kBtu/h	System 7c – SZVAVDFHP
School and total building conditioned floor area ≤ 150,000 ft^2	4 – 5 floors	2, 4, 8 – 16	No limit	System 15 – VAVAWHP
Warehouse and light manufacturing that do not include mechanical cooling in the proposed design[3]	No limit	All	No limit	System 9 – HEATVENT
Office in buildings with warehouse and light manufacturing space[3]	Buildings ≤ 3 floors	All	< 65 kBtu/h	System 3b – SZHP

Space Type	Above-Grade Floors	Climate Zone	System Cooling Capacity	Standard Design
Office in buildings with warehouse and light manufacturing space[3]	Buildings ≤ 3 floors	All	≥ 65 kBtu/h	System 7b – SZVAVHP
Office, financial institution, and library and total building area < 25,000 ft^2	Buildings ≤ 3 floors	1-15	< 65 kBtu/h	System 3b – SZHP
Office, financial institution, and library and total building conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	1-15	≥ 65 kBtu/h	System 7b – SZVAVHP
Office, financial institution, and library and total building conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	16	< 65 kBtu/h	System 3a – SZAC
Office, financial institution, and library and total building conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	16	≥ 65 kBtu/h	System 7c – SZVAVDFHP
Office, financial institution, and library and total building conditioned floor area < 25,000 ft^2	4 – 5 floors	All	No limit	System 15 – PVAVAWHP
Office, financial institution, and library and total building area 25,000 – 150,000 ft^2	≤ 5 floors	All	No limit	System 15 – PVAVAWHP
Covered process computer room with total process load ≤ 800kW	No limit	All	No limit	System 11 – CRAC Unit
Covered process computer room with total process load > 800kW	No limit	All	No limit	System 10 – CRAH Unit
Covered process laboratory with design maximum exhaust 20,000 cfm or less or meets an exception[5] and total building	No limit	All	No limit	System 7b – SZVAVHP

Space Type	Above-Grade Floors	Climate Zone	System Cooling Capacity	Standard Design
conditioned area less than 25,000 ft^2				
Covered process laboratory with design maximum exhaust 20,000 cfm or less or meets an exception[5] and total building conditioned floor area 25,000 ft^2 and less than 150,000 ft^2	No limit	All	No limit	System 5 – PVAV
Covered process laboratory with design maximum exhaust 20,000 cfm or less or meets exception[5] and total building conditioned floor area ≥ 150,000 ft^2	No limit	All	No limit	System 6 – VAV
Covered process laboratory design maximum exhaust greater than 20,000 cfm and does not meet exception[5] with total building conditioned floor area less than 150,000 ft^2	No limit	All	No limit	System 14a – ACSZVAV
Covered process laboratory design maximum exhaust greater than 20,000 cfm and does not meet an exception[5] with total building conditioned floor area 150,000 ft^2 or greater	No limit	All	No limit	System 14b – WCSZVAV
Covered process commercial kitchen for buildings that use System 6 – VAV	No limit	All	No limit	System 13a – BKITCHMAU
Covered process commercial kitchen for buildings that don't use System 6 – VAV	No limit	All	No limit	System 13b – PKITCHMAU
Healthcare facilities	No limit	All	No limit	Same as the Proposed Design

Space Type	Above-Grade Floors	Climate Zone	System Cooling Capacity	Standard Design
All other spaces in buildings with < 25,000 ft^2 conditioned floor area	Buildings ≤ 3 floors	All	< 65 kBtu/h	System 3a – SZAC
All other spaces in buildings with < 25,000 ft^2 conditioned floor area	Buildings ≤ 3 floors	All	≥ 65 kBtu/h	System 7a – SZVAVAC
All other spaces in buildings with < 25,000 ft^2 conditioned floor area	4 - 5 floors	All	No limit	System 5 – PVAV
All other spaces in buildings with < 25,000 ft^2 conditioned floor area	> 5 floors	All	No limit	System 6 – VAV
All other spaces in buildings with 25,000 – 150,000 ft^2 conditioned floor area	≤ 5 floors	All	No limit	System 5 – PVAV
All other spaces in buildings with 25,000 – 150,000 ft^2 conditioned floor area	> 5 floors	All	No limit	System 6 – VAV
All other spaces in buildings with > 150,000 ft^2 conditioned floor area	No limit	All	No limit	System 6 – VAV

Source: California Energy Commission

Notes:

1) “Retail or grocery” building space types include “Pharmacy Area,” “Retail Sales Area (Fitting Room),” “Retail Sales Area (Grocery Sales),” “Retail Sales Area (Retail Merchandise Sales),” “Concourse and Atria Area,” “Exercise/Fitness Center and Gymnasium Areas” and “Beauty Salon Area.” To qualify for this system, the building floor that includes these spaces must predominantly have a “Retail” function schedule group (FuncSchGrp), specified by Appendix 5.4A, and be part of a building with only three above-grade floors or less. If these are not met, the standard design system is determined using the “All other spaces” categories.
2) “School” building space types include “Classroom, Lecture, Training, Vocational Areas.” To qualify for this standard design system, the building floor that includes these spaces must predominantly have a “School” function schedule group (FuncSchGrp), specified by Appendix 5.4A, and be part of a building with only three above-grade floors or less. If these are not met, the standard design system is determined using the “All other spaces” categories.
3) Warehouse and light manufacturing spaces are those identified as having a “Warehouse” or “Manufacturing” function schedule group (FuncSchGrp), specified by Appendix 5.4A.
4) Office, financial institution, and library spaces include “Copy Room,” “Financial Transaction Area,” “Library, Reading Areas,” “Library, Stacks,” “Office (Greater than 250 square feet in floor area)," “Office (250 square feet in floor area or less),” “Videoconferencing Studio,” and “Waiting Area.” To qualify for this system, the building floor that includes these spaces must predominantly have an “Office” function schedule group (FuncSchGrp), specified by Appendix 5.4A. If these are not met, the standard design system is determined using the “All other spaces” categories.
5) Exceptions pertaining to covered process laboratory systems include:
i) Existing systems without heating or cooling that are altered,
ii) Systems in climate zone 7, 15
iii) Systems dedicated to vivarium spaces or spaces classified as biosafety level 3 or higher.

Table 2: System Descriptions

System Type	Description	Detail
System 1 – RAC	Residential air conditioner	Single-phase single-zone system with constant volume fan, no economizer, direct expansion cooling, and gas furnace heating.
System 2 – RESERVED		
System 3a – SZAC	Packaged single-zone air conditioner	Single-phase single-zone system with constant-volume fan, direct expansion cooling, and gas furnace heating.
System 3b – SZHP	Packaged single-zone heat pump	Single-phase single-zone system with constant-volume fan, direct expansion heat pump cooling and heating, and electric resistance supplemental heating.
System 3c – SZDFHP	Packaged single-zone dual-fuel heat pump	Single-zone system with constant-volume fan, direct expansion heat pump cooling and heating, and gas supplemental heating.
System 4 – Reserved		
System 5 – PVAV	Packaged VAV	Multi-zone packaged system with variable-air-volume fan, direct expansion cooling, hot water heating served by gas boiler, and hot water reheat terminal units served by a central gas boiler.
System 6 – VAV	Built-up VAV	Multi-zone built-up system with variable- air-volume fan, chilled water cooling provided by a central watercooled chiller and cooling tower, and hot water heating provided by central gas boiler.
System 7a – SZVAVAC	Packaged single-zone variable-air-volume air conditioner	Single-zone system with variable-air-volume fan, direct expansion variable-speed-drive cooling, and gas furnace heating. Integrated economizer for standard design cooling capacities ≥ 33 kBtu/h.
System 7b – SZVAVHP	Packaged single-zone variable-air-volume heat pump	Single-zone system with variable-air-volume fan, direct expansion heat pump cooling and heating, and electric resistance supplemental heating. Minimum fan speed ratio of 0.2 for laboratory spaces and 0.5 for all other spaces.

System Type	Description	Detail
System 7c – SZVAVDFHP	Packaged single-zone variable-air-volume dual-fuel heat pump	Single-zone system with variable-air volume fan, direct expansion heat pump cooling and heating, and gas supplemental heating.
System 8 – RESERVED		
System 9 – HEATVENT	Heating and ventilation only	Single-zone system with a constant volume fan and gas furnace heating.
System 10 – CRAH	Computer room air handler	Single-zone built-up system with variable-air-volume fan, chilled water cooling provided by a central water cooled chiller and cooling tower, and no heating.
System 11 – CRAC	Computer room air conditioner	Single-zone packaged system with variable-air-volume fan, direct expansion cooling, and no heating
System 12 – Reserved		
System 13a – BKITCHMAU	Built-up kitchen makeup air unit	Built-up single-zone makeup air unit with dedicated exhaust fan, chilled water cooling provided by a central water cooled chiller and cooling tower, and hot water heating provided by central gas boiler.
System 13b – PKITCHMAU	Packaged kitchen makeup air unit	Packaged single-zone makeup air unit with dedicated exhaust fan, direct expansion cooling, and gas furnace heating.
System 14a – ACSZVAV	Air-cooled single zone VAV	Single zone built-up 4 pipe system with variable-air-volume fan, chilled water provided by a dedicated air-cooled chiller, and hot water provided by a dedicated air-to-water heat pump. The air handler has a heat recovery coil as specified by Section 140.9(c)6 of the Energy Code. Each zone has a chilled water or hot water changeover coil with a 6-way valve for cooling or heating.
System 14b – WCSZVAV	Water-cooled single zone VAV	Single zone built-up 4 pipe system with variable-air-volume fan, chilled water provided by a central water-cooled chiller plant, and hot water provided by a dedicated air-to-water heat pump. The air handler has a heat recovery coil as specified by Section 140.9(c)6 of the Energy Code. Each zone has a chilled water or hot water changeover coil with a 6-way valve for cooling or heating.
System 15 – PVAVAWHP	Packaged VAV with AWHP heating	Multi-zone packaged system with variable-air-volume fan, direct expansion cooling, and hot water heating provided by an air to water

System Type	Description	Detail
		heat pump (AWHP). See Table 3: System 15 – PVAVAWHP: Standard Design Criteria for additional system details based on occupancy served and climate zone.

Source: California Energy Commission

Table 3: System 15 – PVAVAWHP: Standard Design Criteria

Design Criteria	Schools	Offices
Percentage of perimeter zone terminal units utilizing parallel fan powered boxes	All CZ: 100%	CZ 1 – 6, 16: 100% of heating capacity CZ 7-15: 25% of heating capacity
Ventilation System	CZ 2, 4, 11 – 16: HRV	CZ 1, 3, 5: HRV
Max system fan power	CZ 2: 15% lower than 140.4(c)1	CZ 3, 5: 15% lower than 140.4(c)1
Design leaving water temperature	CZ 2: ≤ 120 °F	No requirement
Minimum part load ratio	All CZ: 20%	All CZ: 20%
AWHP minimum operating temperature	All CZ: 17 °F	All CZ: 17 °F

The standard design systems serving mixed-use buildings are different from the standard design systems serving nonresidential space types. Also, spaces containing covered processes are served by dedicated standard design systems separate from systems serving other nonresidential space types. Examples include hotel/motel guestroom and related spaces located over retail and other similar conditions. For example, a 100,000 ft^2 building that has retail and restaurant on Floor 1, offices on Floors 2, 3, and 4, a 600-kW process load computer room on each office floor, and guestrooms on Floors 5, 6, and 7 would have the following systems in the standard design:

- System 13a or b – BKITCHMAU or PKITCHMAU serving the restaurant commercial kitchen zone
- Separate System 11 – CRAC systems serving each computer room
- Separate System 1 – RAC systems serving each guestroom space, with a System 6 – VAV system serving corridors and other non-guestroom spaces on each floor
- System 6 – VAV serving all other conditioned spaces, including retail spaces since the building has more than three floors, as well as the dining area of the restaurant.

The standard design building shall have only one central chilled and/or hot water plant, so if there are multiple systems that incorporate a central plant (for example, CRAH and VAVs), then a single plant shall serve all plant loads.

5.1.4 Additions and Alterations System Modification

For nonresidential additions and alterations to existing buildings, the standard design HVAC system and the proposed design system will be the same for all existing systems. For new and altered HVAC systems, the standard design system is determined as described in Chapter 5.1.4 Additions and Alterations System

Modification. In some cases when identifying the HVAC system, the characteristics for the entire building (existing plus any addition) must be considered. Therefore, the existing building floor area and number of floors must be entered. (See Chapter 5.2.2: Existing Building Classification.)

1. The building conditioned floor area and number of floors that are used in the HVAC system map is determined by the following rules.
    a. For an existing building that has both heating and cooling systems.
        i. Primary: If the change in cooling capacity of all new primary (plant) cooling equipment exceeds 50 percent of the total plant cooling capacity, the conditioned floor area and total above-grade floors of the entire building is used.
        ii. Non-Hydronic Secondary: If the change in cooling capacity of all new secondary cooling coils other than hydronic chilled water exceeds 50 percent of the total cooling capacity for the building, the conditioned floor area and total above-grade floors of the entire building is used.
        iii. Combined Secondary: If the combined cooling capacity of all (hydronic + non-hydronic) new secondary cooling coils exceeds 90 percent of the total building cooling capacity, the conditioned floor area and total above-grade floors of the entire building is used.

If none of the primary, non-hydronic secondary, or combined secondary condition descriptions apply, the conditioned floor area of only the addition and existing areas with new heating/cooling equipment and total above-grade floors of the entire building is used.

    b. For an existing building that has only heating-only systems.
        i. Primary: If the change in heating capacity of all new primary (plant) heating equipment exceeds 50 percent of the existing total plant heating capacity, the conditioned floor area and total above-grade floors of the entire building is used.
        ii. Non-Hydronic Secondary: If the change in heating capacity of all new secondary heating coils other than hydronic hot water or steam (if supported) exceeds 50 percent of the total heating capacity for the building, the conditioned floor area and total above-grade floors of the entire building is used.
        iii. Combined Secondary: If the combined heating capacity of all (hydronic + non-hydronic) new secondary heating coils exceeds 90 percent of the building heating capacity, the conditioned floor area and total above-grade floors of the entire building is used.
        iv. If none of these three conditions apply, the conditioned floor area of only the addition and existing areas with new heating equipment and total above-grade floors of the entire building is used.

New or replaced systems in added or altered areas of existing buildings are not subject to Section 140.4(a)2 requirements. New or replaced systems in altered areas of existing buildings must comply with Section 141.0(b)2Cii. In this case, the conditioned floor area and total above-grade floors determined in the step above are used as inputs to the revised system map below, when applicable. For all other systems Table 1: Nonresidential HVAC System Map is applicable.

Table 4: Nonresidential HVAC System Map (Alterations)

Space Type	Above-Grade Floors	Climate Zone	System Cooling Capacity	Standard Design
Retail or grocery	Buildings ≤2 floors	3-13 and 15	<65 kBtu/h	System 3b - SZHP
Retail or grocery	Buildings ≤2 floors	1,2, 14 and 16	<65 kBtu/h	System 3a - SZAC
Retail or grocery, conditioned area < 25,000 ft^2	Buildings =3 floors	3-13 and 15	<65 kBtu/h	System 3b - SZHP
Retail or grocery, conditioned area < 25,000 ft^2	Buildings =3 floors	1,2, 14 and 16	<65 kBtu/h	System 3a - SZAC
School, conditioned floor area < 150,000 ft^2	Buildings ≤ 3 floors	1-15	<65 kBtu/h	System 3b – SZHP
School, conditioned floor area < 150,000 ft^2	Buildings ≤ 3 floors	16	<65 kBtu/h	System 3b – SZAC
Office or financial institution, conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	3-13 and 15	<65 kBtu/h	System 3b – SZHP
Office or financial institution, conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	1,2, 14 and 16	<65 kBtu/h	System 3a - SZAC
Library, conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	1, 3-15	<65 kBtu/h	System 3b – SZHP
Library, conditioned floor area < 25,000 ft^2	Buildings ≤ 3 floors	2 and 16	<65 kBtu/h	System 3a - SZAC

5.1.5 Special Requirements for Additions and Alterations Projects

Compliance projects containing additions or alterations or both require that the user designate each building component (envelope construction assemblies and fenestration, lighting, HVAC, and water heating) as either new, altered, or existing. Many of the building descriptors in Chapter 5: Nonresidential Building Descriptors Reference of this manual do not have explicit definitions for the standard design when the project is an addition or alterations project or both. For these terms, the standard design rules for existing, altered components follow the same rule as the standard design rule for newly constructed buildings.

For example, the receptacle loads are prescribed for both the proposed design building and standard design building for a newly constructed buildings compliance project. For additions or alterations to an existing building, since the rules are not explicitly defined in the building descriptor in Chapter 5.3.3: Receptacle Loads, the same rules apply to the proposed design and standard design for the additions or alterations compliance project.

Building descriptors that are prescribed for the proposed and standard design models for newly constructed buildings projects are also prescribed for the proposed and standard design models for additions and alterations projects.

For additions and alterations projects, there are three modeling approaches that can be taken when modeling the existing building:

- Model the addition or altered portion alone. For this option, the addition or alteration is modeled as a stand-alone building, and the boundary or interface between the addition or alteration (or both) and the preexisting building is modeled as an adiabatic partition (an adiabatic wall, ceiling, roof, or floor).
- Model the entire existing building and any additions and alterations. For this option, the existing, unaltered components of the building would be modeled "as designed" (as specified by the user), with the standard design components modeled the same as the proposed design.
- Model part of the existing building and any additions and alterations. For this option, all components of the existing, unaltered building (HVAC, lighting, envelope, spaces) would have to be distinguished from the components that are added and altered. The existing building components would be modeled "as designed" (as specified by the user), with the standard design components modeled the same as the proposed design. Added or altered building components would follow the rules for additions and alterations.

When either Option 1 or Option 3 is used, the adiabatic partitions shall not be considered as part of gross exterior wall area or gross exterior roof area for the window/wall ratio (WWR) and skylight/roof ratio (SRR) calculations.

5.2 Project Data

This chapter specifies inputs for project-level information, including the location of the project and information on who is working on who is responsible for different portions of the building project.

5.2.1 General Information

The general information of the project identifies the basic information for where the project will be implemented and identifies a person to be responsible for different portions of the project. In a building project, the location of the project will help inform the climate zone applicable to the project.

The various roles that are identified can be used to coordinate between the design and modeling teams. By identifying a main lead for various parts of the building, questions regarding the design of specific building components can more quickly be answered.

Specifying the building project compliance type is important for developing the building model. The compliance type will inform assumptions made in the standard and proposed design. It is important to correctly identify the compliance type as this can have a major effect on modeling results.

Project Name

Applicability: All projects.

Definition: Name used for the project if one is applicable.

Units: Alphanumeric characters.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Project Owner

Applicability: All projects.

Definition: Owner(s) of the project or individual or organization for whom the building permit is sought should include name, title, organization, email, and phone number.

Units: Alphanumeric characters on each of two lines.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Envelope Designer

Applicability: All projects.

Definition: Person responsible for the building design; information should include name, title, organization, email, and phone number.

Units: Up to 50 alphanumeric characters on each of two lines.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Mechanical Designer

Applicability: All projects.

Definition: Person responsible for the mechanical design; information should include name, title, organization, email, and phone number.

Units: Up to 50 alphanumeric characters on each of two lines.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Lighting Designer

Applicability: All projects.

Definition: Person responsible for the lighting design; information should include name, title, organization, email, and phone number.

Units: Up to 50 alphanumeric characters on each of two lines.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Documentation Author

Applicability: All projects.

Definition: Person responsible for inputting building information and performing the compliance analysis; information should include name, title, organization, email, and phone number.

Units: Up to 50 alphanumeric characters on each of two lines.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Date

Applicability: All projects.

Definition: Date of completion of the compliance analysis or the date of its most recent revision.

Units: Date format.

Input Restrictions: Input is optional for the proposed design.

Standard Design: Not applicable.

Compliance Type

Applicability: All projects.

Definition: Type of compliance project (newly constructed buildings, partial compliance or additions and alterations).

Units: List:

- New Complete: Newly constructed building project assessing compliance of envelope, lighting, mechanical, domestic hot water systems, and when applicable photovoltaic and battery systems.
- New Envelope: Newly constructed building project, assessing compliance of building envelope systems only.
- New Mechanical: Newly constructed buildings project, assessing compliance of building mechanical systems only.
- New Envelope And Lighting: Newly constructed buildings project, assessing compliance of building envelope and lighting systems.
- New Envelope And Partial Lighting: Newly constructed buildings project, assessing compliance of building envelope systems. Compliance of lighting systems for some spaces are also assessed.
- New Envelope And Mechanical: Newly constructed buildings project, assessing compliance of building mechanical and envelope systems.
- New Envelope And Partial Mechanical: Newly constructed buildings project, assessing compliance of building envelope systems. Compliance of mechanical systems for some spaces are also assessed.

- New Mechanical And Lighting: Newly constructed buildings project, assessing compliance of building mechanical and lighting systems.
- New Mechanical And Partial Lighting: Newly constructed buildings project, assessing compliance of building mechanical systems. Compliance of lighting systems for some spaces are also assessed.
- New Lighting And Partial Mechanical: Newly constructed buildings project, assessing compliance of building lighting systems. Compliance of mechanical systems for some spaces are also assessed.
- Existing Alteration: Alteration of existing buildings project assessing compliance of the alteration envelope, lighting, mechanical, and domestic hot water systems.
- Existing Addition And Alteration: Alteration of existing buildings and addition to existing buildings project assessing compliance of addition and alteration envelope, lighting, mechanical and domestic hot water systems.
- Addition Complete: Additions to an existing building project assessing compliance of the addition envelope, lighting, mechanical and domestic hot water systems.
- Addition Envelope: Additions to an existing building project assessing compliance of the addition envelope systems.
- Addition Mechanical: Additions to an existing building project assessing compliance of the addition mechanical systems.
- Addition Envelope And Lighting: Additions to an existing building project assessing compliance of the addition envelope and lighting systems.
- Addition Envelope And Partial Lighting: Additions to an existing building project assessing compliance of the addition envelope systems. Compliance of lighting systems for some additions spaces are also assessed.
- Addition Envelope And Mechanical: Additions to an existing building project assessing compliance of the addition envelope and lighting systems.
- Addition Envelope and Partial Mechanical: Additions to an existing building project assessing compliance of the addition envelope systems. Compliance of mechanical systems for some additions spaces are also assessed.
- Addition Mechanical And Lighting: Additions to an existing building project assessing compliance of the addition mechanical and lighting systems.
- Addition Mechanical And Partial Lighting: Additions to an existing building project assessing compliance of the addition mechanical systems. Compliance of lighting systems for some additions spaces are also assessed.

Input Restrictions: As designed.

Standard Design: Same as proposed.

5.2.2 Existing Building Classification

The existing building classification provides general information on the building used for information and reporting purposes. The number of floors in the existing building and area of the building, including any additions, are required inputs.

Existing Building Number of Floors

Applicability: Additions and alterations.

Definition: Total number of floors of the building (For information and reporting purposes only).

Units: Integer

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Building: Same as the proposed design.

Existing Building Floor Area

Applicability: Additions and alterations.

Definition: Total floor area of an existing building, including any additions, if present (for information and reporting purposes only).

Units: ft^2.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Building: Not applicable.

5.2.3 Partial Compliance Model Input Classification

Earlier chapters of this reference manual have described the available partial compliance scenarios for newly constructed buildings or additions/alterations that address one or more but not all of the building systems. The compliance software that supports these scenarios must define the inputs for both the proposed design and the standard design for unpermitted portions of the building. “New” below refers to the particular partial compliance option for newly constructed buildings. “Addition” below refers to the particular partial compliance option for additions and/or alterations.

- New Envelope or Addition Envelope: The user specifies the project envelope systems, all spaces, space types, and thermal zones in the project as designed. The standard design rules are applied to the envelope systems of the standard design model. For all lighting and HVAC inputs, the proposed design values are prescribed and follow the rules for the standard design, including modeling the same HVAC systems determined using the HVAC system map in Chapter 5.1.3: HVAC System Map.
- New Mechanical or Addition Mechanical: The user specifies the project mechanical systems, and thermal zones in the project as designed. The standard design rules and system map are applied to the HVAC systems of the standard design model. This compliance option assumes that the building has already been permitted for envelope and lighting. The envelope and lighting systems for both the proposed design and the standard design are modeled as designed.
- New Envelope and Lighting or Addition Envelope and Lighting : The user specifies the project envelope systems, all spaces, space types, thermal zones, all lighting systems, and any daylighting in the project as designed. The standard design rules are applied to the envelope systems and the lighting systems of

the standard design model. For all HVAC inputs, the proposed design values are prescribed and follow the rules for the standard design, including modeling the same HVAC systems determined using the HVAC system map in Chapter 5.1.3: HVAC System Map.

- New Envelope and Mechanical or Addition Envelope and Mechanical: The user specifies the project envelope, all spaces, space types, thermal zones, and mechanical systems in the project as designed. The standard design rules and system map are applied to the envelope systems and HVAC systems of the standard design model. For all lighting inputs, the proposed design values are prescribed and follow the rules for the standard design model.
- New Envelope and Partial Lighting or Addition Envelope and Partial Lighting: This option is used for projects where the building envelope is defined and where the lighting systems in some of the spaces are defined. The user specifies the project envelope systems, all spaces, space types, thermal zones, and lighting systems for spaces with lighting systems defined and any daylighting in the project as designed. For spaces where the lighting system is not defined, the proposed design and standard design models are set to prescriptive lighting power limits. The standard design rules are applied to the envelope systems and the defined lighting systems of the standard design model. For all HVAC inputs, the proposed design values are prescribed and follow the rules for the standard design, including modeling the same HVAC systems determined using the HVAC system map in Chapter 5.1.3: HVAC System Map.
- New Mechanical and Lighting or Addition Mechanical and Lighting: The user specifies the project mechanical systems, all spaces, space types, thermal zones, all lighting systems, and any daylighting in the project as designed. The standard design rules and system map are applied to the lighting systems and HVAC systems of the standard design model. This compliance option assumes that the project has already been permitted for envelope compliance. The envelope systems for both the proposed design and the standard design are modeled as designed.
- New Mechanical and Partial Lighting or Addition Mechanical and Partial Lighting: The user specifies the project mechanical systems, thermal zones, lighting systems for spaces with lighting systems defined and any daylighting in the project as designed. The standard design rules and system map are applied to the defined lighting systems and HVAC systems of the standard design model. This compliance option assumes that the building has already been permitted for Envelope and Partial Lighting. The envelope systems, all spaces, space types, and permitted lighting spaces for both the proposed design and the standard design are modeled as designed.
- New Envelope and Partial Mechanical or Addition Envelope and Partial Mechanical: This option is used for projects where the building envelope id defined and where the mechanical systems in some of the spaces are defined. The user specifies the project envelope systems, all spaces, space types, thermal zones, and mechanical systems for spaces with mechanical systems defined as designed. For spaces where the mechanical system is not defined, the proposed design and standard models follow the rules for the standard design, including modeling the same HVAC systems determined using the HVAC system map in Chapter 5.1.3: HVAC System Map. For all lighting inputs, the proposed design values are prescribed and follow the rules for the standard design model. Building descriptors with inputs for both the proposed design and standard design that are restricted to prescribed values (for example,

equipment performance curves) follow the same rules for prescribed values for any of the partial compliance projects listed above.

5.2.4 Building Model Classification

The function of the building and building spaces affects a number of energy-related requirements including lighting, PV, battery, and HVAC requirements.

Space Classification

Applicability: All projects.

Definition: Appendix 5.4A lists the building classifications that are available under the Area Category method.

Units: List (See Appendix 5.4A).

Input Restrictions As designed.

Standard Design: Existing Building: Same as proposed.

5.2.5 Geographic and Climate Data

The following data needs to be specified or derived in some manner. Compliance software developers may use any acceptable method to determine the data. For California, city, state, and county are required to determine climate data from the available data in Reference Appendices, Joint Appendix JA2.

Zip Code

Applicability: All projects.

Definition: California postal designation.

Units: 5-digit number.

Input Restrictions: As designed.

Standard Design: Same as proposed.

Latitude

Applicability: All projects.

Definition: The latitude of the project site.

Units: Degrees (°).

Input Restrictions: Latitude from Reference Appendices, Joint Appendix JA2 based on zip code.

Standard Design: Same as proposed.

Longitude

Applicability: All projects.

Definition: The longitude of the project site.

Units: Degrees (°).

Input Restrictions: Longitude from Reference Appendices, Joint Appendix JA2 based on zip code.

Standard Design: Same as proposed.

Elevation

Applicability: All projects.

Definition: The height of the building site above sea level.

Units: Feet (ft).

Input Restrictions: Elevation from Reference Appendices, Joint Appendix JA2 based on weather station.

Standard Design: Same as proposed.

California Climate Zone

Applicability: All projects.

Definition: One of the 16 California climate zones.

Units: List (see Reference Appendices, Joint Appendix JA2).

Input Restrictions: One of the 16 California climate zones.

Standard Design: Same as proposed.

City

Applicability: All projects.

Definition: The city where the project is located.

Units: Alphanumeric string.

Input Restrictions: Representative city from Reference Appendices, Joint Appendix JA2.

Standard Design: Same as proposed.

Design Day Data

Applicability: All projects.

Definition: A data structure indicating design day information used for the sizing of the proposed system. This information may not necessarily match the information used in the annual compliance simulation.

Units: Data structure contains the following:

Design DB (0.4%), mean coincident wet-bulb, daily range, day of year.

Input Restrictions: The design day information is taken from one of the predefined California weather files for the location within the same climate zone as the location of the proposed building. (This is not input by the user.)

Standard Design: Not applicable.

Weather File

Applicability: All projects.

Definition: The hourly (that is, 8,760 hours per year) weather data to be used in performing the building energy simulations. Weather data must include outside dry-bulb temperature, outside wet-bulb temperature, atmospheric pressure, wind speed, wind direction, cloud amount, cloud type (or total horizontal solar and total direct normal solar), clearness number, ground temperature, humidity ratio, density of air, and specific enthalpy.

Units: Data file.

Input Restrictions: The weather file selected shall be in the same climate zone as the proposed design. Weather data must be based on the weather files found in CBECC.

Standard Design: Weather data shall be the same for both the proposed design and standard design.

Ground Reflectance

Applicability: All projects.

Definition: Ground reflectance affects daylighting calculations and solar gain. The reflectance can be specified as a constant for the entire period of the energy simulation or it may be scheduled, which can account for snow cover in the winter.

Units: Data structure: schedule, fraction.

Input Restrictions: Prescribed. The weather file determines the ground reflectance. The ground reflectance shall be set to 0.2 when the snow depth is 0 or undefined and set to 0.6 when the snow depth is greater than 0.

Standard Design: Same as proposed.

Local Terrain

Applicability: All projects.

Definition: An indication of how the local terrain shields the building from the prevailing wind. Estimates of this effect are provided in the ASHRAE Handbook of Fundamentals.

Units: List: the list shall contain only the following choices:

- Flat, open country
  - Exponent (α):0.14
  - Boundary layer thickness, δ (m): 270
- Rough, wooded country, Suburbs
  - Exponent (α): 0.22
  - Boundary layer thickness, δ (m): 370
- Towns and cities
  - Exponent (α): 0.33
  - Boundary layer thickness, δ (m): 460
- Ocean

- Exponent (α): 0.10
- Boundary layer thickness, δ (m): 210

- Urban, industrial, forest
  - Exponent (α): 0.22
  - Boundary layer thickness, δ (m): 370

The exponent and boundary layer are used in the following equation to adjust the local wind speed:

$$V_z = V_{met}\left(\frac{\delta_{met}}{Z_{met}}\right)^{\alpha_{met}}\left(\frac{Z}{\delta}\right)^{\alpha}$$

Where:

$\boldsymbol{Z}$ - altitude, height above ground (m)
$\boldsymbol{V_z}$ - wind speed at altitude $\boldsymbol{Z}$ (m/s)
$\boldsymbol{\alpha}$ - wind speed profile exponent at the site
$\boldsymbol{\delta}$ - wind speed profile boundary layer thickness at the site (m)
$\boldsymbol{Z_{met}}$ - height above ground of the wind speed sensor at the meteorological station (m)
$\boldsymbol{V_{met}}$ - wind speed measured at the meteorological station (m/s)
$\boldsymbol{\alpha_{met}}$ - wind speed profile exponent at the meteorological station
$\boldsymbol{\delta_{met}}$ - wind speed profile boundary layer thickness at the meteorological station. (m)

The wind speed profile coefficients — α, δ, α_{met}, and δ_{met} — are variables that depend on the roughness characteristics of the surrounding terrain. Typical values for α and δ are shown in the table above.

Input Restrictions: Parameters are prescribed.

Standard Design: The standard design terrain should be equal to the proposed design.

5.2.6 Site Characteristics

General site characteristics, including building shading and fuel source availability, are provided for the building. Building shading from external sources are not used for compliance calculations.

Shading of Building Site

Applicability: All projects.

Definition: Shading of building fenestration, roofs, or walls by surrounding terrain, vegetation, and the building itself.

Units: Data structure.

Input Restrictions: The default and fixed value are for the site to be unshaded. External shading from other buildings or other objects is not modeled for Title 24 compliance in the ACM. Building self-shading is accounted for using the detailed geometry method.

Standard Design: The proposed design and standard design are modeled with identical assumptions regarding shading of the building site.

Site Fuel Source

Applicability: All projects.

Definition: The fossil fuel source that is available at the site for water heating, space heating or other fuel purposes.

Units: List.

Input Restrictions: The following choices are available:

- Natural Gas
- Propane

Standard Design: Natural gas, if applicable.

5.2.7 Calendar

The calendar year entered in the compliance software is used to coordinate weather events from the weather files to specific days of the week. The schedule of holidays will also be coordinated to the calendar year.

Year for Analysis

Applicability: All projects.

Definition: The calendar year to be used for the annual energy simulations. This input determines the correspondence between days of the week and the days on which weather events on the weather tape occur and has no other impact.

Units: List: choose a year (other than a leap year).

Input Restrictions: Use year 2009.

Standard Design: Same calendar year as the proposed design.

Schedule of Holidays

Applicability: All projects.

Definition: A list of dates on which holidays are observed and on which holiday schedules are used in the simulations.

Units: Data structure.

Input Restrictions: The following 10 holidays represent the prescribed set. When a holiday falls on a Saturday, the holiday is observed on the Friday preceding the Saturday. If the holiday falls on a Sunday, the holiday is observed on the following Monday.

- New Year's Day — January 1
- Martin Luther King Day — Third Monday in January
- Presidents Day — Third Monday in February
- Memorial Day — Last Monday in May
- Independence Day — July 4

- Labor Day First Monday in September
- Columbus Day Second Monday in October
- Veterans Day November 11
- Thanksgiving Day Fourth Thursday in November
- Christmas Day December 25

Standard Design: The standard design shall observe the same holidays specified for the proposed design.

5.3 Thermal Zones

A *thermal zone* is a space or collection of spaces having similar space-conditioning requirements, has the same heating and cooling set point, and is the basic thermal unit (or zone) used in modeling the building. A thermal zone will include one or more spaces. Thermal zones may be grouped together, but systems serving combined zones shall be subject to efficiency and control requirements of the combined zones. Nonresidential buildings with identical floors served by like systems may be modeled with floor multipliers.

5.3.1 General Information

The general information is used to identify the various thermal zones included in the building project. This information will include whether the thermal zone is directly conditioned, unconditioned, or plenum, and the floor area of the thermal zone. The HVAC system(s) used to service the specific thermal zone is also identified.

Thermal Zone Name

Applicability: All projects.

Definition: A unique identifier for the thermal zone made up of 50 or fewer alphanumeric characters.

Units: Alphanumeric string.

Input Restrictions: None.

Standard Design: Same as proposed.

Thermal Zone Description

Applicability: All projects.

Definition: A brief description of the thermal zone that identifies the spaces which make up the thermal zone or other descriptive information. The description should tie the thermal zone to the building plans.

Units: Alphanumeric string.

Input Restrictions: None.

Standard Design: Same as proposed.

Thermal Zone Type

Applicability: All projects.

Definition: Designation of the thermal zone as a directly conditioned, unconditioned, or plenum. Plenum zones may be defined as either supply or return air paths for secondary systems.

Units: List: Conditioned, Unconditioned or Plenum.

Input Restrictions: The default thermal zone type is Conditioned.

Standard Design: The Conditioned and Unconditioned zones are identical for the proposed design and standard design. Plenum zones are considered Conditioned zones in the standard design.

System Name

Applicability: All projects.

Definition: The name of the HVAC system(s) that serves this thermal zone.

Units: Text, unique.

Input Restrictions: None.

Standard Design: The system(s) serving the zone is defined by Section 5.1.3.

Floor Area

Applicability: All projects.

Definition: The gross floor area of a thermal zone, including walls and minor spaces for mechanical or electrical services such as chases that may or may not be conditioned.

Units: Square feet (ft^2).

Input Restrictions: The floor area of the thermal zone is derived from the floor area of the individual spaces that make up the thermal zone.

Standard Design: Same as proposed design.

5.3.2 Interior Lighting

Inputs for interior lighting are specified at the space level. (See specification below.) In those instances, when thermal zones contain just one space, the inputs here will be identical to the inputs for the single space that is contained within the thermal zone.

For those instances when a thermal zone contains more than one space, the compliance software shall either:

- Model the lighting separate for each space and sum energy consumption and heat gain for each time step of the analysis, or
- Incorporate some procedure to sum inputs or calculate weighted averages such that the lighting power used at the thermal zone level is equal to the combination of lighting power for each of the spaces contained in the thermal zone.

In some cases, combining lighting power at the space level into lighting power for the thermal zone may be challenging and would have to be done at the level of each time step in the simulation. These cases include:

- A thermal zone that contains some spaces that have daylighting and others that do not.
- A thermal zone that contains spaces with different schedules of operation.
- A thermal zone that contains some spaces that have a schedule adjusted in some way for lighting controls and other spaces that do not.
- Combinations of the above.

5.3.3 Receptacle Loads

Inputs for receptacle and process loads are specified at the space level. (See specification below.) In those instances, when thermal zones contain just one space, the inputs here will be identical to the inputs for the single space that is contained within the thermal zone.

For those instances when a thermal zone contains more than one space, the compliance software shall either:

- Model the receptacle and process loads separate for each space and sum energy consumption and heat gain for each time step of the analysis, or
- Incorporate some procedure to sum inputs or calculate weighted averages such that the receptacle and process loads used at the thermal zone level are equal to the combination of receptacle and process loads for each of the spaces contained in the thermal zone.

When the spaces contained in a thermal zone have different schedules, combining receptacle and process loads from the space level may be challenging and would have to be done at the level of each time step in the simulation. See discussion above on lighting.

5.3.4 Occupants

Inputs for occupant loads are specified at the space level. (See specification below.) In those instances, when thermal zones contain just one space, the inputs here will be identical to the inputs for the single space that is contained within the thermal zone.

For those instances when a thermal zone contains more than one space, the compliance software shall either:

- Model the occupant loads separate for each space and the heat gain for each time step of the analysis, or
- Incorporate some procedure to sum inputs or calculate weighted averages such that the occupant loads used at the thermal zone level are equal to the combination of occupant loads for each of the spaces contained in the thermal zone.

When the spaces contained in a thermal zone have different occupant schedules, rolling up occupant loads from the space level may be challenging and would have to be done at the level of each time step in the simulation. Spaces with differences in full-load equivalent operating hours of more than 40 hours per week shall not be combined in a single zone. See discussion above on lighting.

5.3.5 Space Temperature Control

THERMAL ZONE THERMOSTAT SETPOINT TOLERANCE

Applicability: All thermal zones.

Definition: The number of degrees that the room temperature, when occupied, must be above the cooling setpoint, or below the heating setpoint, for the zone load to be considered 'unmet'.

Units: Degrees Fahrenheit (°F).

Input Restrictions: The prescribed value is +/-1°F.

Standard Design: Same as the proposed design.

THERMOSTAT TEMPERATURE SCHEDULE

Applicability: All thermal zones.

Definition: An hourly schedule of thermostat setpoints.

Units: Data structure: temperature schedule.

Input Restrictions: Prescribed.

The schedule is based on the predominant schedule group for the building floor or zone. See Chapter 2.3.3 space use classification considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: Schedules in the standard design shall be identical to the proposed design.

5.4 Space Uses

Each thermal zone discussed above may be subdivided into spaces. This chapter presents the building descriptors that relate to the space uses. Space uses and the defaults associated with them are listed in Appendix 5.4A. Every thermal zone shall have at least one space, as defined in this chapter. Daylit spaces should generally be separately defined by space type or orientation or both.

5.4.1 General Information

The general information is used to identify the various spaces included in each thermal zone. This information will include the area of each space as well as how the space will be used. The function of the space will inform certain standard design requirements such as lighting power density for the space.

SPACE FUNCTION TYPE

Applicability: All projects.

Definition: The space function type that defines occupancy, internal load, and other characteristics, as indicated in Appendix 5.4A.

The allowed space function types in area category are available from Appendix 5.4A. The building or space type determines the following standard design inputs:

- Number of occupants (occupant density)
- Equipment power density
- Lighting power density
- Hot water load
- Schedules (from Appendix 5.4B)

Units: List.

Input Restrictions: Only selections shown in Appendix 5.4A may be used. Additional inputs may be utilized to describe special space function cases that are needed to reflect special rules. Examples of additional inputs include:

- Whether the space has a process exhaust system subject to Section 140.9(b) or Section 140.9(c)
- Whether a space falls under the requirements of Section 140.9(c) and is a vivarium or has a specific biosafety level

Standard Design: Same as proposed design.

Standard Design: Existing Building: Same as proposed design.

VENTILATION SPACE FUNCTION

Applicability: All projects.

Definition: A unique identifier for ventilation requirements. A given function area may have different ventilation functions available, which define the design ventilation rate, minimum ventilation rates for the space if using demand control ventilation (DCV), and any exhaust air requirements.

Units: List (from Reference Manual Appendix 5.4A).

Input Restrictions: As designed (selection from list)

Standard Design: Same as proposed design.

Standard Design: Existing Building: Same as proposed design.

FLOOR AREA

Applicability: All projects.

Definition: The floor area of the space.

The area of the spaces that make up a thermal zone shall sum to the floor area of the thermal zone.

Units: Square feet (ft^2).

Input Restrictions: Area shall be measured to the outside of exterior walls and to the center line of partitions.

Standard Design: Area shall be identical to the proposed design.

Standard Design: Existing Building: Same as proposed design.

5.4.2 Infiltration

Infiltration of outside air into a building and leakage of air from inside of the building will affect the space-conditioning energy use of the building. There are several methods used to identify the air leakage or infiltration rate of the building.

Air Barrier

Applicability: All projects.

Definition: Air barrier specification that determines the infiltration rate.

Units: List.

- No air barrier
- Air barrier – not verified
- Air barrier – verified by visual inspection
- Air barrier – verified by air leakage testing
- *Input Restrictions:* As designed.

Standard Design: Not applicable.

Infiltration Method

Applicability: All projects.

Definition: Energy simulation programs have a variety of methods for modeling uncontrolled air leakage or infiltration. Some procedures use the effective leakage area, which is generally applicable for small, residential-scale buildings. The component leakage method requires the user to specify the average leakage through the building envelope per unit of area (ft^2). Other methods require the specification of a maximum rate, which is modified by a schedule. The airflow per unit of exterior wall area method shall be used.

Units: The infiltration method is prescribed. No input is provided.

Input Restrictions: The airflow per unit of exterior wall area calculation method is prescribed. A fixed infiltration rate shall be specified and calculated as a leakage per unit area of exterior envelope, including the gross area of exterior walls and fenestration but excluding roofs and exposed floors.

Standard Design: The infiltration method used for the standard design shall be the same as the proposed design.

Infiltration Data

Applicability: All projects.

Definition: Information needed to characterize the infiltration rate in buildings.

For the airflow per unit of exterior wall area calculation method, inputs are described below.

Units: Infiltration rate shall be calculated each hour using the following equation:

$$Infiltration\ Rate = I_{design} \cdot F_{schedule} \cdot (A + B \cdot |t_{zone} - t_{odb}| + C \cdot ws + D \cdot ws^2)$$

The infiltration is then found by multiplying the infiltration rate by the area of the exterior walls in the thermal zone.

Where:

$Infiltration\ Rate$ - zone infiltration airflow per unit of wall area (cfm/ft²)

$Infiltration$ - zone infiltration airflow (cfm/ft²)

I_{design}- zone infiltration airflow rate at reference conditions (cfm/ft²)

$F_{schedule}$- fractional adjustment from a prescribed schedule, consistent with HVAC availability schedules in Appendix 5.4B (unitless)

t_{zone} - zone air temperature (°F)

t_{odb} - outdoor dry bulb temperature (°F)

ws - the wind speed (mile/hr)

A - overall coefficient (unitless)

B - temperature coefficient (1/°F)

C - wind speed coefficient (hr/mile)

D - wind speed squared coefficient (hr²/mile²)

Input Restrictions:

The proposed design shall use the equation listed above, with coefficients A, B, and D set to 0. C shall be set to 0.10016 hr/mile (0.224 s/m). I_{design} shall be:

0.3696 cfm/ft² for buildings that do not have air barriers,
0.2352 cfm/ft² for buildings that have air barriers that are not verified,
0.1680 cfm/ft² for buildings that have air barriers verified by visual inspection
0.1344 cfm/ft² for buildings that have air barriers verified by whole building air leakage testing as described in Section 140.3(a)9Ci of the Energy Code.

For nonresidential spaces with operable windows that do not have mechanical system interlocks, the compliance software shall automatically increase the infiltration rate by 0.15 cfm/ft² whenever the outside air temperature is between 50°F and 90°F and when the HVAC system is operating.

Standard Design: The standard design shall use the equation listed above, with coefficients A, B, and D set to 0. C shall be set to 0.10016 hr/mile (0.224 s/m). I_{design} shall be 0.2352 cfm/ft². For Hotel/Motel Buildings in climate zone 7 and for relocatable public school buildings I_{design} shall be 0.3696 cfm/ft².

INFILTRATION SCHEDULE

Applicability: When an infiltration method is used that requires the specification of a schedule.

Definition: With the ACH method and other methods (see above), it may be necessary to specify a schedule that modifies the infiltration rate for each hour or time step of the simulation. Typically, the schedule is either on or off but can also be fractional.

Units: Data structure: schedule, fractional.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group for the building floor or zone. See Chapter 2.3.3: Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6: Multifamily Building Descriptions Reference. The infiltration schedule shall be set equal to 1 when the HVAC system is scheduled off and 0.25 when the HVAC system is scheduled on. This schedule is based on the assumption that when the HVAC system is on, it brings the pressure of the interior space above the pressure of the exterior, decreasing the infiltration of outside air. When the HVAC system is off, interior pressure drops below exterior pressure, and infiltration increases.

Standard Design:

The infiltration schedule for the standard design shall be scheduled the same as the proposed design.

5.4.3 Occupants

For space level information on occupancy, lighting, and plug load schedules, as well as occupant density and allowed lighting power density.

Occupant Density

Applicability: All projects.

Definition: The design egress occupant density assumed for simulation and minimum ventilation requirements of a space.

The occupancy density also affects hot water use requirements for the space.

Units: people/1,000 ft^2

Input Restrictions: This is determined based on the specified space function types defined in Appendix 5.4A and corresponding list of ventilation occupancy categories, as defined in Appendix 5.4C.

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as proposed.

Occupancy Fraction

Applicability: All projects.

Definition: The fraction of the design egress occupant density assumed for simulation and design ventilation requirements.

The occupancy fraction also affects hot water use requirements for the space.

Units: Unitless fraction.

Input Restrictions: Default of 0.5 as designed with a minimum value of 0.5 and a maximum value of 5.

Standard Design: 0.5.

Standard Design: Existing Buildings: 0.5.

Fixed Seating in Space

Applicability: All projects that have a space with designed occupancy (such as a theater or auditorium).

Definition: This is a flag that indicates the space has designed occupancy. If checked, this flag allows the user to override the default occupancy with values that comply with the California Building Code.

Units: Boolean.

Input Restrictions: As designed.

May not be used with multifamily living spaces, hotel/motel guest rooms, unoccupied, and unleased tenant area spaces. The default is false.

Standard Design: Same as proposed.

Standard Design: Existing Building: The number of occupants must be identical for both the proposed and standard design cases.

Occupant Heat Rate

Applicability: All projects.

Definition: The sensible and latent heat produced by each occupant in an hour.

This depends on the activity level of the occupants and other factors. Heat produced by occupants must be removed by the air-conditioning system as well as the outside air ventilation rate and can have a significant effect on energy consumption.

Units: Btu/h specified separately for sensible and latent gains.

Input Restrictions: The occupant heat rate is prescribed by Appendix 5.4A for nonresidential buildings and by Chapter 6: Multifamily Building Descriptors Reference for multifamily buildings.

Standard Design: The occupant heat rate for the standard design shall be the same as the proposed design.

Standard Design: Existing Building: Same as proposed.

Occupancy Schedule

Applicability: All projects.

Definition: The occupancy schedule modifies the number of occupants to account for expected operational patterns in the building. The schedule adjusts the heat contribution from occupants to the space on an hourly basis to reflect time-dependent usage patterns. The occupancy schedule can also affect other factors such as outside air ventilation, depending on the control mechanisms specified.

Units: Data structure: schedule, fractional.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group for the building floor or zone. See Chapter 2.3.3: Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6: Multifamily Building Descriptors Reference.

Standard Design: Occupancy schedules are identical for proposed and standard design buildings.

Standard Design: Existing Building: Same as proposed.

5.4.4 Interior Lighting

The building descriptors in this chapter are provided for each lighting system. Typically, a space will have only one lighting system but, in some cases, it could have two or more. Examples include a general and task lighting system in offices or hotel multipurpose rooms that have lighting systems for different functions. It may also be desirable to define different lighting systems for areas that are daylit and those that are not.

Lighting Classification Method

Applicability: Each space in the building.

Definition: Indoor lighting power is specified based on the area category for all space function types listed in Appendix 5.4A.

When lighting compliance is not performed, actual LPDs cannot be entered for the spaces; the LPDs of the building match the standard design.

Units: List.

Input Restrictions: None.

Standard Design: Same as proposed.

Standard Design: Existing Building: Same as proposed.

Table 5: Lighting Specification

Options: Lighting Classification Method	Area Category
Regulated lighting power types	General lighting power Additional lighting power

Source: California Energy Commission

Regulated Interior Lighting Power Density

Applicability: All projects when lighting compliance is performed.

Definition: Total connected lighting power density for all regulated interior lighting power

This includes the loads for lamps and ballasts. The total regulated interior lighting power density is the sum of general lighting power and applicable custom lighting power per unit of floor area in a space. Calculation of lighting power for conditioned spaces is done separately from unconditioned spaces.

Lighting in unconditioned spaces can be modeled, but total lighting power in unconditioned spaces is not enforced in the compliance software. Lighting in unconditioned spaces must follow prescriptive compliance and must be documented on appropriate compliance forms. No tradeoffs are allowed between lighting in conditioned spaces and lighting in unconditioned spaces.

Units: W/ft^2.

Input Restrictions: Proposed value is the sum of the proposed general lighting power and the proposed general lighting exceptional power within a conditioned space or a user input value if no interior lighting systems are modeled.

When lighting compliance is not performed, the lighting power may not be entered and is set equal to the lighting level of the standard design, which is set to the levels for the selected occupancy from Appendix 5.4A.

Standard Design: For spaces without special task lighting, wall display lighting, or similar requirements, this input will be the same as the general lighting power density. See the general lighting power building descriptor for details.

Standard Design: Existing Building: For alterations where fewer than 40 luminaires have been modified the standard design is the existing lighting condition before the alteration. If 40 or more luminaires have been modified, the prescriptive requirements for newly constructed buildings apply.

General Lighting Power

Applicability: All spaces or projects.

Definition: General lighting power is the power used by installed electric lighting that provides a uniform level of illumination throughout an area, exclusive of any provision for special visual tasks or decorative effect, and known as ambient lighting.

Units: Watts.

Input Restrictions: As designed.

For spaces without special task lighting, wall display lighting, or similar requirements, this input will be the same as the regulated lighting power.

Trade-offs in general lighting power are allowed between spaces. See Table 5: Lighting Specification for details.

Standard Design: General lighting power is the product of the lighting power densities for the space type from Appendix 5.4A and the floor areas for the corresponding conditioned spaces.

The standard design lighting power is modified by a factor of 1/1.20 (0.833) if the simplified geometry approach is used and if the visible transmittance of any fenestration in the space does not meet the prescriptive requirements established in Section 140.3 of the Energy Code.

Standard Design: Existing Building: When the lighting status is “existing” (and unaltered) for the space, the standard design is the same as the existing, proposed design.

When the lighting status is “altered” for the space, and at least 10 percent of existing luminaires have been altered:

- If the lighting status is “existing,” then the standard design LPD is the same as the proposed design.

- If the lighting status is “new,” then the standard design LPD is same as newly constructed buildings.
- If the lighting status is “altered,” then the standard design LPD is the same as newly constructed buildings.

Additional Lighting Power

Applicability: For all building types except multifamily buildings, space types listed in Appendix 5.4A. Some additional lighting power allowances are applicable only to certain space types. See Table 140.6-C of the Energy Code.

Definition: The Energy Code provides an additional lighting power allowance for qualified lighting systems. The additional lighting power allowance for qualified lighting systems is treated separately as “use-it-or-lose-it” lighting — the user receives no credit (standard design matches proposed), but there is a maximum power allowance for each item. The qualified lighting systems and the respective allowed additional lighting power allowance values are listed in the two rightmost columns of Table 140.6-C of the Energy Code.

Units: Data structure. This input has the following data elements — each data element corresponds to the additional lighting allowance of the functional area types listed in Table 140.6-C of the Energy Code.

Input Restrictions: As designed.

Standard Design: The standard design additional lighting power (ALP) is given by the following equation:

$$ALP_{std} = \sum_{i-1}^{13} \min\left(ALP_{prop,i}, ALPA_i \times ALPTQ_i\right)$$

Where:

ALP_{std}
The additional lighting power (ALP) of the standard design

$ALP_{prop,i}$
The proposed ALP of the allowance is in the data structure above. If there is no proposed lighting system in the proposed design serving as the qualified lighting system, the ALPprop,i should be assigned with a zero value (no allowance permitted and given). If there is a proposed lighting system serving as the qualified lighting system, the ALPprop,i should be assigned a value of one(1).

$ALPA_i$
The additional lighting power allowance (ALPA), which is the maximum allowed additional lighting power is indicated in the two rightmost columns in Table 140.6-C of the Energy Code.

$ALPTQ_i$
The additional lighting power task quantity (ALPTQ) for the i^{th} allowance, where the task area corresponds to the functional area with the additional lighting power allowance in Table 140.6-C of the Energy Code.

Standard Design: Existing Building: When the lighting status is “existing” (and unaltered) for the space, the standard design is the same as the existing, proposed design.

When the lighting status is “altered” for the space and at least 10 percent of existing luminaires have been altered:

- If the lighting status is “existing,” then the standard design LPD is the same as the proposed design.
- If the lighting status is “new,” then the standard design LPD is the same as for newly constructed buildings.
- If the lighting status is “altered,” then the standard design LPD is the same as for newly constructed buildings.

Additional Lighting Power Task Quantity

Applicability: Space types listed in Appendix 5.4A.

Definition: The area, length, or quantity associated with each of the additional lighting allowances in the ALP building descriptor.

Units: ft^2, linear ft of white board or chalk board, number of ATM(s), or number of illuminated mirror(s).

Input Restrictions: As designed but cannot exceed the floor area of the space.

Standard Design: Same as proposed.

Standard Design: Existing Building: Same as proposed.

Nonregulated Interior Lighting Power

Applicability: All projects.

Definition: For California, Section 140.6(a)3 of the Energy Code identifies excluded lighting.

Units: ft^2.

Input Restrictions: As designed.

The nonregulated lighting power should be cross-referenced to the type of exception and the construction documents. The default for nonregulated lighting power is zero.

Standard Design: The nonregulated interior lighting in the standard design shall be the same as the proposed design.

Standard Design: Existing Buildings: Same as proposed.

Lighting Schedules

Applicability: All projects.

Definition: Schedule of operation for interior lighting power used to adjust the energy use of lighting systems on an hourly basis to reflect time-dependent patterns of lighting usage.

Units: Data structure: schedule, fractional.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or zone. See Chapter 2.3.3: Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6: Multifamily Building Descriptors Reference.

Standard Design: The nonregulated interior lighting in the standard design shall be the same as the proposed design.

Standard Design: Existing Building: Same as proposed.

Fixture Type

Applicability: All interior light fixtures.

Definition: The type of lighting fixture, which is used to determine light heat gain distribution.

Units: List: one of three choices:

- Recessed with lens
- Recessed/downlight
- Not in ceiling

Input Restrictions: As designed.

Standard Design: Recessed/downlight.

Standard Design: Existing Building: Recessed/downlight.

Luminaire Type

Applicability: All interior light fixtures.

Definition: The type of lighting luminaire used to determine the light heat gain distribution

The dominant luminaire type determines the daylight dimming characteristics when there is more than one type of luminaire in the space.

Units: List:

- Linear fluorescent
- Compact fluorescent lamp (CFL)
- Incandescent
- Light-emitting diode (LED)
- Metal halide
- Mercury vapor
- High-pressure sodium

Input Restrictions: As designed.

Standard Design: LED.

Standard Design: Existing Building: LED.

Light Heat Gain Distribution

Applicability: All projects.

Definition: The distribution of the heat generated by the lighting system that is directed to the space, the plenum, the HVAC return air, or to other locations

This input is a function of the luminaire type, fixture type, and location. Luminaires recessed into a return air plenum contribute more heat to the plenum or the return air stream if the plenum is used for return air, while pendant-mounted fixtures hanging in the space contribute more heat to the space. Common luminaire type/space configurations are listed in Table 3, Chapter 18, 2009 *ASHRAE Handbook of Fundamentals*, summarized in Table 6: Light Heat Gain Parameters for Typical Operating Conditions. Typically, the data will be linked to a list of common luminaire configurations similar to Table 6: Light Heat Gain Parameters for Typical Operating Conditions so that the user chooses a luminaire type category, and heat gain is automatically distributed to the appropriate locations.

Units: List of luminaire types or data structure consisting of a series of decimal fractions that assign heat gain to various locations.

Input Restrictions: Heat gain distribution is fixed to Table 6: Light Heat Gain Parameters for Typical Operating Conditions values based on the luminaire, fixture, and distribution type.

Where lighting fixtures with different heat venting characteristics are used within a single space, the wattage weighted average heat-to-return-air fraction shall be used.

Standard Design: The standard design shall use the values in Table 6: Light Heat Gain Parameters for Typical Operating Conditions for recessed/downlight LED luminaires.

Standard Design: Existing Building: Same as newly constructed buildings.

Table 6: Light Heat Gain Parameters for Typical Operating Conditions

Based on Table 3, Chapter 18, 2009 ASHRAE Handbook of Fundamentals

Fixture Type	Luminaire Type	Return Type	Space Fraction	Radiative Fraction
Recessed with Lens	Linear Fluorescent	Ducted/Direct	1.00	0.67
Recessed with Lens	Linear Fluorescent	Plenum	0.45	0.67
Recessed/Downlight	Linear Fluorescent	Ducted/Direct	1.00	0.58
Recessed/Downlight	Linear Fluorescent	Plenum	0.69	0.58
Recessed/Downlight	CFL	Ducted/Direct	1.00	0.97
Recessed/Downlight	CFL	Plenum	0.20	0.97

Fixture Type	Luminaire Type	Return Type	Space Fraction	Radiative Fraction
Recessed/Downlight	Incandescent	Ducted/Direct	1.00	0.97
Recessed/Downlight	Incandescent	Plenum	0.75	0.97
Recessed/Downlight	LED	Ducted/Direct	1.00	0.97
Recessed/Downlight	LED	Plenum	0.20	0.97
Recessed/Downlight	Metal Halide	Ducted/Direct	1.00	0.97
Recessed/Downlight	Metal Halide	Plenum	0.75	0.97
Not in Ceiling	Linear Fluorescent	Ducted/Direct	1.00	0.54
Not in Ceiling	Linear Fluorescent	Plenum	1.00	0.54
Not in Ceiling	CFL	Ducted/Direct	1.00	0.54
Not in Ceiling	CFL	Plenum	1.00	0.54
Not in Ceiling	Incandescent	Ducted/Direct	1.00	0.54
Not in Ceiling	Incandescent	Plenum	1.00	0.54
Not in Ceiling	LED	Ducted/Direct	1.00	0.54
Not in Ceiling	LED	Plenum	1.00	0.54
Not in Ceiling	Metal Halide	Ducted/Direct	1.00	0.54
Not in Ceiling	Metal Halide	Plenum	1.00	0.54
Not in Ceiling	Mercury Vapor	Ducted/Direct	1.00	0.54
Not in Ceiling	Mercury Vapor	Plenum	1.00	0.54
Not in Ceiling	High Pressure Sodium	Ducted/Direct	1.00	0.54
Not in Ceiling	High Pressure Sodium	Plenum	1.00	0.54

Source: California Energy Commission

In this table, the *space fraction* is the fraction of the lighting heat gain that goes to the space; the *radiative fraction* is the fraction of the heat gain to the space that is due to radiation, with the remaining heat gain to the space due to convection.

Lighting Power Adjustment Factors (PAF)

Applicability: All projects.

Definition: Automatic controls that are not already required by the Energy Code and which reduce lighting power uniformly over the day can be modeled as *power adjustment factors.* Power adjustment factors represent the percentage reduction in lighting power that will approximate the effect of the control. Models account for such controls by multiplying the controlled watts by (1–PAF).

Eligible California power adjustment factors are defined in Table 140.6-A. Reduction in lighting power using the PAF method can be used only for nonresidential controlled general lights. Only one PAF can be used for a qualifying lighting system unless multiple adjustment factors are allowed in Table 140.6-A of the Energy Code. Controls for which PAFs are eligible are listed in Table 140.6-A of the Energy Code and include:

- Daylight continuous dimming plus off controls — daylight dimming controls that automatically shut off luminaires when natural lighting provides an illuminance level of at least 150 percent of the space requirement.
- Occupant sensing controls in offices larger than 250 square feet.
- Institutional tuning — lighting tuned to not use more than 85 percent of rated power, as specified by Section 140.6 of the Energy Code.
- Demand-responsive controls — demand-responsive lighting control that reduces lighting power consumption in response to a demand-response signal for qualifying building types.
- Clerestory fenestration – luminaires in daylit areas adjacent to the clerestory.
- Horizontal slats — interior or exterior horizontal slats on fenestration adjacent to daylit areas.
- Light shelves — clerestory fenestration with interior or exterior light shelves adjacent to daylit areas.

Note that clerestory fenestration is modeled using power adjustment factors and is not modeled directly by compliance software. Compliance software shall have a means of disregarding daylight through clerestory windows when using the PAF. If handled with a PAF, daylight controls in zones with clerestory windows should be disabled.

Units: List: eligible control types (see above) linked to PAFs

Input Restrictions: PAF shall be fixed for a given control and area type.

Standard Design: PAF is zero.

Standard Design: Existing Building: PAF is zero.

5.4.5 Daylighting Control

This group of building descriptors is applicable for spaces that have daylighting controls or daylighting control requirements.

California prescribes a modified version of the split flux daylighting methods to be used for compliance. This is an *internal daylighting method* because the calculations are automatically performed by the simulation engine. For skylit daylit areas (aka top-lighted areas) or sidelit daylit areas, California compliance prescribes an internal daylighting model consistent with the split flux algorithms used in many simulation programs. With this method the simulation model has the capability to model the daylighting contribution for each hour of the simulation and make an adjustment to the lighting power for each hour, considering factors such as daylighting availability, geometry of the space, daylighting aperture, control type, and the lighting system. The assumption is that the geometry of the space, the reflectance of surfaces, the size and configuration of the daylight apertures, and the light transmission of the glazing are taken from other building descriptors.

For daylight control using a simplified geometry approach, daylight control for both the primary daylit zone and secondary daylit zone (mandatory) must be indicated on the compliance forms. If the simplified geometry approach is used and the visible transmittance of fenestration does not meet prescriptive requirements, the standard design lighting power is reduced by 20 percent to represent increased energy usage for these building features. See Chapter 5.4.4 Interior Lighting.

Daylight Control Requirements

Applicability: All spaces with exterior fenestration.

Definition: The extent of daylighting controls in skylit and sidelit areas of the space.

Units: List.

Input Restrictions: For nonresidential spaces, when the installed general lighting power in the skylit, primary sidelit, or secondary sidelit daylit zone is 75W or greater, daylighting controls are required, as specified by the Title 24 mandatory requirements. Controls are not required if total glazing area is less than 24 ft^2 or for luminaires in sidelit daylit zones in retail merchandise sales and wholesale showroom areas.

For parking garages, when the installed general lighting power in the primary sidelit and secondary sidelit daylit zone exceeds 60W, daylighting controls are required, as specified by the Title 24 mandatory requirements. Luminaires located in daylit transition zones or dedicated ramps are not required to meet this requirement. Controls are not required if total glazing and openings are less than 36 ft^2.

Standard Design: The requirements are the same as proposed.

Standard Design: *Existing Buildings*: When lighting systems in an existing altered building are not modified as part of the alteration, daylighting controls are the same as the proposed design.

When an alteration increases the area of a lighted space, increases lighting power in a space, or when luminaires are modified in a space where proposed design lighting power density is greater than 85 percent of the standard design LPD, daylighting control requirements are the same as for newly constructed buildings.

Skylit, Primary, and Secondary Daylit Area

Applicability: All daylit spaces.

Definition: The floor area that is daylit.

The skylit area is the portion of the floor area that gets daylighting from a skylight. Two types of sidelit daylit areas are recognized. The primary daylit area is the portion that is closest to the daylighting source and receives the most illumination. The secondary daylit area is an area farther from the daylighting source, which still receives useful daylight.

The primary daylit area for side lighting is a band near the window with a depth equal to the distance from the floor to the top of the window and width equal to window width plus 0.5 times window head height wide on each side of the window opening. The secondary daylit area for side lighting is a band beyond the primary daylit area that extends a distance double the distance from the floor to the top of the window and width equal to window width plus 0.5 times window head height wide on each side of the window opening. Area beyond a permanent obstruction taller than 6 feet should not be included in the primary and secondary daylight area calculation.

The skylit area is a band around the skylight well that has a depth equal to 70 percent of the ceiling height from the edge of the skylight well. The geometry of the skylit daylit area will be the same as the geometry of the skylight. Area beyond a permanent obstruction taller than 50 percent of the height of the skylight from the floor should not be included in the skylit area calculation.

Double counting due to overlaps is not permitted. If there is an overlap between secondary and primary or skylit areas, the effective daylit area used for determining reference position shall be the area minus the overlap.

Units: ft^2.

Input Restrictions: Not a user input. The daylit areas in a space are derived using other modeling inputs like dimensions of the fenestration and ceiling height of the space.

Standard Design: The daylit areas in the standard design are derived from other modeling inputs, including the dimensions of the fenestration and ceiling height of the space. Daylit area calculation in the standard design is done after window to wall ratio and skylight to roof ratio rules in Chapter 5.5.7 Fenestration of this manual are applied.

Standard Design: Existing Buildings: Same as newly constructed buildings when skylights are added/replaced and general lighting altered.

Installed General Lighting Power in the Skylit Daylit Zone

Applicability: All spaces.

Definition: The installed lighting power of general lighting in the skylit daylit zone.

The skylit daylit zone shall be defined on the plans and be consistent with the definition of the skylit daylit zone in the Energy Code. Note that a separate building descriptor, fraction of controlled lighting, defines the fraction of the lighting power in the space that is controlled by daylighting.

Units: Watts.

Input Restrictions: As designed.

Standard Design: The installed lighting power for the standard design is the product of the skylit daylit area and the LPD for general lighting in the space.

Standard Design: Existing Buildings: Same as newly constructed buildings when skylights are added/replaced and general lights are altered.

Installed General Lighting Power in the Primary Daylit Zone

Applicability: All spaces.

Definition: The installed lighting power of general lighting in the primary daylit zone.

The primary daylit zone shall be defined on the plans and be consistent with the definition of the primary daylit zone in the Energy Code. Note that a separate building descriptor, fraction of controlled lighting, defines the fraction of the lighting power in the space that is controlled by daylighting.

Units: Watts.

Input Restrictions: As designed.

Standard Design: The installed lighting power for the standard design is the product of the primary daylit area and the LPD for general lighting in the space.

Standard Design: Existing Buildings: Same as newly constructed buildings when windows are added/replaced and general lights are altered.

Installed General Lighting Power in the Secondary Daylit Zone

Applicability: All spaces.

Definition: The installed lighting power of general lighting in the secondary daylit zone.

The secondary daylit zone shall be defined on the plans and be consistent with the definition of the secondary daylit zone in the Energy Code. Note that a separate building descriptor, fraction of controlled lighting, defines the fraction of the lighting power in the space that is controlled by daylighting.

Units: Watts.

Input Restrictions: As designed.

Standard Design: The installed lighting power for the standard design is the product of the secondary daylit area and the LPD for general lighting in the space.

Standard Design: Existing Buildings: Same as newly constructed buildings when windows are added/replaced and general lights are altered.

Reference Position for Illuminance Calculations

Applicability: All spaces or thermal zones, depending on which object is the primary container for daylighting controls.

Definition: The position of the two daylight reference points within the daylit space.

Lighting controls are simulated so that the illuminance at the reference position is always maintained at or above the illuminance setpoint. For step switching controls, the combined daylight illuminance plus uncontrolled electric light illuminance at the reference position must be greater than the setpoint illuminance before the controlled lighting can be dimmed or tuned off for stepped controls. Similarly, dimming controls will be dimmed so that the combination of the daylight illuminance plus the controlled lighting illuminance is equal to the setpoint illuminance.

Preliminary reference points for primary and secondary daylit areas are located at the farthest end of the daylit area aligned with the center of each window. For skylit area, the preliminary reference point is located at the center of the edge of the skylit area closest to the centroid of the space. In each case, the Z – coordinate of the reference position (elevation) shall be located 2.5 feet above the floor.

Up to two final reference positions can be selected from among the preliminary reference positions identified in for each space.

Units: Data structure.

Input Restrictions: The user does not specify the reference position locations; reference positions are automatically calculated by the compliance software based on the procedure outlined below. Preliminary reference positions are each assigned a relative daylight potential (RDP) which estimates the available illuminance at each position, and the final reference position selection is made based on the RDP.

Relative Daylight Potential: An estimate of daylight potential at a specific reference position. This is NOT used directly in the energy simulation, but it used to determine precedence for selecting the final reference points. The relative daylight potential is calculated as a function of effective aperture, azimuth, illuminance setpoint and the type (skylit, primary sidelit, or secondary sidelit) of the associated daylit zone. RDP is defined as:

$$RDP = C_1 \times EA_{dz} + C_2 \times SO + C_3$$

Where: C_1,C_2, and C_3 are selected from the following table.

Table 7: Illuminance Calculation

Illuminance Setpoint	Skylit Daylit Zone C1	Skylit Daylit Zone C2	Skylit Daylit Zone C3	Primary Sidelit Daylit Zone C1	Primary Sidelit Daylit Zone C2	Primary Sidelit Daylit Zone C3	Secondary Sidelit Daylit Zone C1	Secondary Sidelit Daylit Zone C2	Secondary Sidelit Daylit Zone C3
< 200 lux	3927	0	3051	1805	-0.40	3506	7404	-3.32	1167
> 200 lux < 1000 lux	12046	0	-421	6897	-7.22	475	1512	-2.88	-22
> 1000 lux	5900	0	-516	884	-5.88	823	212	-0.93	57

Illuminance Setpoint: This is defined by the user, subject to the limits specified in Appendix 5.4A, determined from the space type.

Source Orientation (SO): The angle of the outward facing normal of the daylight source's parent surface projected onto a horizontal plane, expressed as degrees from south. This is not a user input but is calculated from the geometry of the parent surface. For skylights, the source orientation is not applicable. For vertical fenestration, it is defined:

$$SO = |(180 - Azimuth)|$$

Where: Azimuth is defined as the azimuth of the parent object containing the fenestration associated with the preliminary reference point.

Effective Aperture (EA): For this calculation, effective aperture represents the effectiveness of all sources which illuminate a specific reference position in contributing to the daylight available to the associated daylit zone. In cases where daylit zones from multiple fenestration objects intersect, the effective aperture of an individual daylit zone is adjusted to account for those intersections according to the following rules:

- For skylit and primary sidelit daylit zones, intersections with other skylit or primary sidelit daylit zones are considered.
- For secondary sidelit daylit zones, intersections with any toplit or sidelit (primary or secondary) daylit zones are considered.

Effective aperture is defined as follows:

$$EA_{dz} = \left(VT_{fdz} \times A_{fdz} + \sum F_i \times VT_i \times A_i\right) / A_{dz}$$

Where:

$\boldsymbol{EA_{dz}}$ - Is the combined effective aperture of all daylight sources illuminating a specific daylit zone.
$\boldsymbol{VT_{fdz}}$ - Is the user specified visible transmittance of the fenestration object directly associated with the daylit zone.
$\boldsymbol{A_{fdz}}$ - Is the area of the fenestration object directly associated with the daylit zone.
$\boldsymbol{VT_i}$ - Is the user specified visible transmittance of the fenestration object associated with each intersecting daylit zone.
$\boldsymbol{A_i}$ - Is the area of the fenestration object directly associated with each intersecting daylit zone.
$\boldsymbol{F_i}$ - Is the fraction of intersecting area between the daylit zone in question and each intersecting daylit zone:
$\boldsymbol{F_i = A_{intersection} / A_{dzi}}$
$\boldsymbol{A_{dzi}}$ - Is the area of each intersecting daylit zone (including area that might fall outside a space or exterior boundary).
$\boldsymbol{A_{dz}}$ - Is the area of the daylit zone (including area that might fall outside a space or exterior boundary).

First Reference Position: Select the preliminary reference point with the highest relative daylight potential (RDP) from among all preliminary reference points located within either top or primary sidelit daylit zones. If multiple reference points have identical RDPs, select the reference point geometrically closest to the centroid of the space.

Second Reference Position: Select the preliminary reference point with the second highest RDP from amongst all remaining preliminary reference points located within either top or primary sidelit daylit zones. If multiple reference points have identical RDPs, select the reference point geometrically closest to the centroid of the space.

Standard Design: Reference positions for the standard design shall be selected using the same procedure as those selected for the proposed design.

Standard Design: Existing Buildings: When additions or alternations to the lighting in spaces trigger the daylighting control requirements, the reference positions shall be determined in the same manner as with newly constructed buildings.

Illumination Adjustment Factor

Applicability: All Daylit Spaces.

Definition: Recent studies have shown that the split flux interreflection component model used in many simulation programs overestimates the energy savings due to daylighting, particularly deep in the space. A set of two adjustment factors is provided, one for the primary daylit zone and one for the secondary daylit zone.

For simulation purposes, the input daylight illuminance setpoint will be modified by the illuminance adjustment factor as follows:

$$LightSetpoint_{adj} = LightSetpoint \times Adjustment\ Factor$$

Units: Unitless

Input Restrictions: Prescribed values for space type in Appendix 5.4A.

Standard Design: The standard design illumination adjustment factors shall match the proposed.

Standard Design: *Existing Buildings*: Same as newly constructed buildings when fenestration is added/replaced and general light is altered.

Fraction of Controlled Lighting

Applicability: Daylit Spaces.

Definition: The fraction of the general lighting power in the primary and skylit daylit zone, or secondary sidelit daylit zone that is controlled by daylighting controls.

Units: Numeric fraction

Input Restrictions: As designed when the daylight control requirements building descriptor indicates that mandatory daylighting controls are not required. If daylighting controls are required, input is restricted to 1.

Standard Design: When daylight controls are required according to the daylight control requirements building descriptor in either the primary daylit and skylit zone, or the secondary daylit zone, or both, the fraction of controlled lighting shall be 1. When the daylight control requirements building descriptor indicates that they are not required, the standard design shall match the proposed design.

Standard Design: Existing Buildings: Same as for newly constructed buildings when fenestration is added/replaced, and general light is altered.

Daylighting Control Type

Applicability: Daylit Spaces.

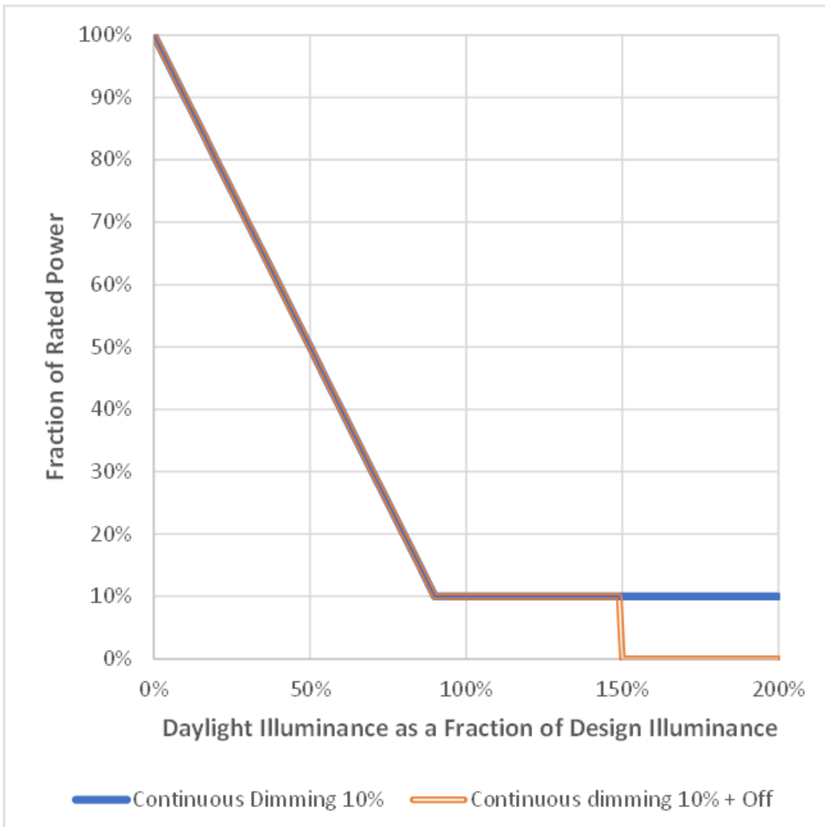
Definition: The type of control that is used to control the electric lighting in response to daylight available at the reference point.

Options:

- Stepped switching controls: The electric power input and light output vary in discrete, equally spaced steps.

- Continuous dimming controls: The fraction to rated power to fraction of rated output that is a linear interpolation of the minimum power fraction at the minimum dimming light fraction to rated power at full light output. See Figure 4: Example of Lighting Power Fraction Continuous Dimming and Continuous Dimming Plus OFF Daylighting Controls (with Minimum Dimming Fraction of 10 Percent).
- Continuous dimming + off controls: Same as continuous dimming controls except that these controls can turn all the way off when none of the controlled light output is needed. The OFF stage is implemented at a daylight illuminance of 150% or higher than design illuminance.

Figure 4: Example of Lighting Power Fraction Continuous Dimming and Continuous Dimming Plus OFF Daylighting Controls (with Minimum Dimming Fraction of 10 Percent)



Source: California Energy Commission

Units: List (see above).

Input Restrictions: Daylighting control type must be specified when fraction of controlled lighting is greater than zero. For parking garage with daylighting control, the users must use continuous dimming plus off control or stepped switching control to meet the mandatory requirement.

Standard Design: Parking garage in standard design uses continuous plus off daylighting control. All other spaces in standard design use continuous daylighting control.

Standard Design: Existing Buildings: Same as for newly constructed buildings when fenestration is added/replaced, and general lighting is altered.

Minimum Dimming Power Fraction

Applicability: Daylit spaces.

Definition: The minimum power fraction when controlled lighting is fully dimmed. Minimum power fraction = minimum power / full rated power.

Units: Numeric: fraction.

Input Restrictions: In proposed design if continuous daylighting control is used, the dimming fraction must be 0.1 or lower. No restriction if other control types are used.

Standard Design: Standard design uses a minimum dimming power fraction of 0.1.

Standard Design: Existing Buildings: Same as for newly constructed buildings when fenestration is added/replaced, and general lighting is altered.

Minimum Dimming Light Fraction

Applicability: Daylighting and dimming controls.

Definition: The minimum light output when controlled lighting is fully dimmed. Minimum light fraction = minimum light output / rated light output.

Units: Numeric: fraction.

Input Restrictions: No restrictions.

Standard Design: Standard design uses a minimum dimming light fraction of 0.1.

Standard Design: Existing Buildings: Same as for newly constructed buildings when fenestration is added/replaced, and general lighting is altered.

5.4.6 Receptacle Loads

Receptacle loads contribute to heat gains in spaces and directly use energy.

Receptacle Power

Applicability: All building projects.

Definition: Receptacle power is power for typical general service loads in the building. Receptacle power includes equipment loads normally served through electrical receptacles, such as office equipment and printers, but does not include either task lighting or equipment used for HVAC purposes. Receptacle power values are slightly higher than the largest hourly receptacle load that is actually modeled because the receptacle power values are modified by the receptacle schedule, which approaches but does not exceed 1.0.

Units: Total power (W) or the space power density (W/ft^2)

Compliance software shall also use the following prescribed values to specify the latent, radiative, and convective heat gain split. If the sum of these values is less than 1, the balance is assumed to be lost from the space.

Heat Gain Fractions:

Receptacle Power

- Radiative: 0.20
- Latent: 0.00
- Convective: 0.80

Gas Equipment Power

- Radiative: 0.15
- Latent: 0.00
- Convective: 0.00

Input Restrictions: Prescribed to values from Appendix 5.4A for nonresidential buildings.

For multifamily buildings, the rules established in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual apply.

Spaces with an information technology equipment (ITE) equipment power density that is greater than 20 W/ft^2 are considered computer rooms.

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as for newly constructed buildings.

Receptacle Schedule

Applicability: All projects.

Definition: Schedule for receptacle power loads used to adjust the intensity on an hourly basis to reflect time-dependent patterns of usage.

Units: Data structure: schedule, fraction.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as for newly constructed buildings.

UPS Efficiency

Applicability: Computer rooms and data centers with computer rooms.

Definition: The efficiency of the Uninterruptible Power Supply (UPS) systems in a computer room. This only applies to computer room process loads with an ITE equipment power density greater than 20 W/ft^2.

Units: Percentage, 0 to 100%.

Input Restrictions: For healthcare facilities, same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or zone. See Chapter 2.3.3 Space

Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: The UPS Efficiency shall match the requirements in Table 140.9-B.

Standard Design: Existing Buildings: Same as for newly constructed buildings.

5.4.7 Commercial Refrigeration Equipment

Commercial refrigeration equipment includes the following:

- Walk-in refrigerators
- Walk-in freezers
- Refrigerated casework

Refrigeration equipment is modeled as neutral plug loads, with the standard design power matching the proposed design and no heat added to or removed from the space where the equipment is located.

Refrigeration Modeling Method

Applicability: All buildings that have commercial refrigeration for cold storage or display

Definition: The method used to estimate refrigeration energy and to model the thermal interaction with the space where casework is located.

Title 24 defaults. With this method, the power density values provided in Appendix 5.4A are used; schedules are assumed to be continuous operation.

Units: List (see above).

Input Restrictions: The Title 24 defaults shall be used.

Standard Design: Title 24 defaults.

Standard Design: Existing Buildings: Same as for newly constructed buildings.

Refrigeration Power

Applicability: All buildings that have commercial refrigeration for cold storage or display.

Definition: Commercial refrigeration power is the average power for all commercial refrigeration equipment, assuming constant year-round operation. Equipment includes walk-in refrigerators and freezers, open refrigerated casework, and closed refrigerated casework. It does not include residential type refrigerators used in kitchenettes or refrigerated vending machines. These are covered under receptacle power.

Units: Total power (W) or the space power density (W/ft^2). The latent, radiative, and convective heat gain fractions are modeled as 0, resulting in no heat added to or removed from the space where the equipment is located.

Input Restrictions: With the Title 24 defaults method, the values in Appendix 5.4A are prescribed. These values are multiplied times the floor area of the rated building to estimate the refrigeration power.

Standard Design: Refrigeration power is the same as the proposed design when the Title 24 default method is used.

Standard Design: Existing Buildings: Same as for newly constructed buildings.

5.4.8 Elevators, Escalators and Moving Walkways

Elevators, escalators and moving walkways account for 3 percent to 5 percent of electric energy use in buildings. [1] Buildings up to about five to seven floors typically use hydraulic elevators because of their lower initial cost. Mid-rise buildings commonly use traction elevators with geared motors, while multifamily buildings typically use gearless systems where the motor directly drives the sheave. The energy-using components include the motors and controls as well as the lighting and ventilation systems for the cabs.

Elevators, escalators, and moving walkways are modeled as a plug loads, with the standard design power matching the proposed design.

Elevator & Escalator Power

Applicability: All buildings that have commercial elevators, escalators, or moving walkways.

Definition: The power for elevators, escalators and moving walkways are modeled as plug loads.

Units: Number of units.

Input Restrictions: The power values are prescribed as 10 kW per elevator and 3.93 kW per escalator or moving walkway for the proposed design.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

Elevator & Escalator Schedule

Applicability: All buildings that have commercial elevators, escalators, or moving walkways.

Definition: The schedule of operation for elevators, escalators, and moving walkways. This is used to convert elevator/escalator power to energy use.

Units: Data structure: schedule, state.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

5.4.9 Process Loads

Commercial gas and electric equipment includes the following:

---

1 Sachs, Harvey M., Opportunities for Elevator Energy Efficiency Improvements, American Council for an Energy Efficiency Economy, April 2005.

- Commercial kitchen or laboratory ovens
- Commercial kitchen fryers and grills
- Other equipment

The majority of commercial gas equipment is located in the space and may contribute both sensible and latent heat. Gas equipment is modeled by specifying the rate of average gas consumption or a fractional schedule that is prescribed in Appendix 5.4B which represents full load hours. The procedure consists of prescribed power and energy values for use with both the proposed and standard design buildings. No credit for commercial gas energy efficiency features is offered. For all electric buildings, the electric equipment power is the same as the gas equipment power but is modeled as electric load, see “Gas Equipment Schedule” for more details.

The prescribed average load values are provided in Appendix 5.4A. The full load schedules in Appendix 5.4B are used as the default.

Gas Equipment Power

Applicability: All spaces with commercial gas equipment.

Definition: Commercial gas power is the annual average power for all commercial gas equipment, such as gas-powered commercial cooking equipment, assuming constant year-round operation.

Units: Btu/h-ft^2.

Compliance software shall also use the following prescribed values to specify the latent heat gain fraction and the radiative/convective heat gain split.

For compliance software that specifies the fraction of the heat gain that is lost from the space, this fraction shall be prescribed at 0.

Gas Equipment Power Heat Gain Fractions:

Radiative = 0.15, Latent = 0, Convective = 0

Input Restrictions: The values in Appendix 5.4A are prescribed. However, these values may be overridden with a “0” value for buildings that are designed to use only electricity as the source.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Same as the proposed design.

Gas Equipment Schedule

Applicability: All spaces with commercial gas equipment.

Definition: The schedule of operation for commercial gas equipment. This is used to convert gas power to energy use. Since the gas equipment power is an annual average value the hourly energy use is calculated as follows.

$$GasEnergyUse_i = Power_{avg} \times \frac{8760}{FLH_{sch}} \times Schedule(i)$$

Where

$GasEnergyUse_i$ is the gas energy use per square foot of the building space at the i^{th} hour of the year

$Power_{avg}$ is the annual average gas equipment power in Btu/hr-ft^2

FLH_{sch} is the full load hour of the schedule in a year, and

$Schedule(i)$ is the schedule value at the i^{th} hour.

Units: Data structure: schedule, fractional.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

Gas Process Loads

Applicability Spaces with gas process loads.

Definition: Process load is the gas energy consumption in the conditioned space of a building resulting from an activity or treatment not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy. Process load may include sensible and/or latent components.

Compliance software shall model and simulate process loads only if the amount of the process energy and the location and type of process equipment are specified in the construction documents. This information shall correspond to specific special equipment shown on the building plans and detailed in the specifications.

Units: Data structure: Peak load (Btu/h-ft^2), radiant fraction, latent fraction, and loss fraction.

Input Restrictions: Compliance software shall receive input for total load, radiant fraction, latent fraction, and loss fraction for each zone in the proposed design. The radiant, latent, and loss fraction are defaulted to zero. The process load input shall be the peak of the process load (Btu/h-ft2) and the thermal zone where the process equipment is located. The modeled information shall be consistent with the plans and specifications of the building.

Standard Design: The standard design shall use the same gas process loads and sensible and latent contribution and radiative/convective split for each zone as the proposed design.

Standard Design: Existing Buildings: Same as newly constructed buildings.

Gas Process Load Schedule

Applicability: All buildings that have commercial gas equipment.

Definition: The schedule of process load operation. Used to convert gas power to energy use.

Units: Data structure: schedule, fractional.

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

ELECTRIC EQUIPMENT POWER

Applicability: All spaces with commercial electric equipment.

Definition: The average power for all commercial electric equipment, such as electric commercial cooking appliances, assuming constant year-round operation.

Units: W/ft².

Compliance software shall also use the following prescribed values to specify the latent heat gain fraction and the radiative/convective heat gain split.

For compliance software that specifies the fraction of the heat gain that is lost from the space, this fraction shall be prescribed at 0.

Electric Equipment Power Heat Gain Fractions:

Radiative = 0.15, Latent = 0, Convective = 0

Input Restrictions: The value is prescribed and derived from the gas equipment power value defined in Appendix 5.4A, converted to W/ft2. The electric equipment value will be “0” for buildings that have fossil fuel gas as an available source.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Same as the proposed design.

ELECTRIC EQUIPMENT SCHEDULE

Applicability: All buildings that have commercial electric equipment.

Definition: The schedule of operation for commercial electric equipment. This is used to convert the gas equipment power defined in Appendix 5.4A to hourly energy consumption. Since the gas equipment power is an annual average value the hourly energy use is calculated as follows.

$$ElecEquipUse_i = Power_{avg} \times \frac{8760}{FLH_{sch}} \times Schedule(i)$$

Where:

$ElecEquipUse_i$ is the electric energy use per square foot of the building space at the i^{th} hour of the year

$Power_{avg}$ is the annual average electric equipment power in W/ft^2

FLH_{sch} is the full load hour of the schedule in a year, and

$Schedule(i)$ is the schedule value at the i^{th} hour.

Units: Data structure: schedule, fractional.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group of the building floor or thermal zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

Electric Process Loads

Applicability: Spaces with electric process loads.

Definition: Process load is the electrical energy consumption in the conditioned space of a building resulting from an activity or treatment not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy.

Data center loads including transformers, uninterruptible power supplies, power delivery units, server fans and power supplies are considered receptacle loads, not process loads, and the equipment schedules are given in Appendix 5.4B.

Compliance software shall model and simulate process loads only if the amount of the process energy and the location and type of process equipment are specified in the construction documents. This information shall correspond to specific special equipment shown on the building plans and detailed in the specifications. The compliance software shall inform the user that the compliance software will output process loads including the types of process equipment and locations on the compliance forms.

Units: Data structure: load (kW).

For electric process loads, the radiative, latent, and loss fractions shall be defaulted by the compliance software to 0.0 resulting in a convective fraction of 1.0. The user may enter other values for the radiative/convective split, but the compliance software shall verify that the values add to 1.

Input Restrictions: Compliance software shall receive input for sensible and/or latent process load for each thermal zone in the proposed design. The process load input shall be the peak of the process load (W/h-ft^2) and the thermal zone where the process equipment is located. The modeled information shall be consistent with the plans and specifications of the building.

Standard Design: The standard design shall use the same process loads and radiative/convective split for each zone as the proposed design.

Standard Design: Existing Buildings: Same as newly constructed buildings.

Electric Process Load Schedule

Applicability: Spaces with electric process loads.

Definition: The schedule of electric process load operation.

Units: Data structure: schedule, fractional.

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

5.4.10 Water Heating Use

This chapter defines the water heating load (use rate) and system requirements on a space level.

Space Water Heating Use Rate

Applicability: All spaces.

Definition: The water heating use rate for a space in a building.

Units: Gal/h per person.

Input Restrictions: The values in Appendix 5.4A are prescribed.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

Space Water Heating Fuel Type

Applicability: All spaces.

Definition: A mapping that defines the standard design water heating fuel type for a space.

Units: List; gas or electric.

Input Restrictions: As designed.

Standard Design: Prescribed from the table in Appendix 5.4A.

Standard Design: Existing Buildings: Not applicable.

5.5 Building Envelope Data

5.5.1 Materials

Energy simulation programs commonly define construction assemblies by listing a sequence of material layers that make up the construction assembly. Appendix 5.5 has a list of standard materials that may be referenced by construction assemblies. Alternate methods may be used to define construction assemblies such as specifying the U-factor and optionally, a metric describing thermal mass such as heat capacity (HC). These alternate methods may not require identification of materials. When a material is defined, all of the properties listed below must be defined. Some materials listed in Appendix 5.5 are non-homogeneous, for instance, framing members with insulation in the cavity. The properties of each material layer can be found in ACM Appendix 5.5.

Material Name

Applicability: Opaque constructions.

Definition: The name of a construction material used.

Units: Text: unique.

Input Restrictions: Material name is a required input for materials not available from the standard list in ACM Appendix 5.5. The user may not modify entries for predefined materials.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Density

Applicability: Opaque constructions.

Definition: The density, mass per unit volume, of the construction material as documented in Appendix 5.5A.

Units: lb/ft^3.

Input Restrictions: Prescribed from Appendix 5.5.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Specific Heat

Applicability: Opaque constructions.

Definition: The specific heat capacity of a material is numerically equal to the quantity of heat that must be supplied to a unit mass of the material to increase its temperature by 1°F.

Units: Btu/lb·°F.

Input Restrictions: Prescribed from Appendix 5.5.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Thermal Conductivity

Applicability: All non-standard materials.

Definition: The thermal conductivity of a material of unit thickness is numerically equal to the quantity of heat that will flow through a unit area of the material when the temperature difference through the material is 1°F.

Units: Btu/lb·°F.

Input Restrictions: Prescribed from Appendix 5.5.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

THICKNESS

Applicability: All non-standard materials.

Definition: The thickness of a material.

Units: Inches.

Input Restrictions: Prescribed from Appendix 5.5.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

5.5.2 Construction Assemblies

For California compliance, construction assemblies for the proposed design shall be created by selecting from a library of building construction layers in ACM Appendix 5.5. The compliance software shall specify composite layers that consist of both framing and insulation. It shall use established methods defined in the ASHRAE Handbook of Fundamentals for calculating effective R-values of composite layers.

MASS WALLS

For mass walls, the user first chooses the mass layer from Appendix 5.5. After that, the user may select an insulating layer from Appendix 5.5 for outside and/or inside the mass wall.

BALLASTED ROOFS, VEGETATED ROOFS, CONCRETE PAVERS, AND OTHER MASS ROOFS

An additional layer may be added to the roof construction assembly when thermal mass is used above the roof membrane. This exception is intended to allow ballasted roofs, concrete pavers, and other massive elements to be explicitly modeled. To qualify, the weight of the stone ballast, the concrete pavers or other elements must exceed 25 lb/ft². The thickness, heat capacity, conductance and density of the additional mass layer shall be based on the measured physical properties of the material. If the surface properties of the additional mass material have been verified through the Cool Roof Rating Council (CRRC), the CRRC reported properties may be used for the proposed design. Otherwise, the mass layer shall be modeled with an aged reflectance of 0.10 and an emittance of 0.75.

ASSEMBLY NAME

Applicability: All projects.

Definition: The name of a construction assembly that describes a roof, wall, or floor assembly. The name generally needs to be unique so it can be referenced precisely by surfaces.

Units: Text.

Input Restrictions: Required input and name must be unique.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Specification Method

Applicability: All projects.

Definition: The method of describing a construction assembly. The common method is to describe the construction assembly as a series of layers, each layer representing a material. For slab-on-grade constructions, exterior insulation levels are specified, and the compliance software determines the corresponding F-factor from Reference Appendix JA4 tables.

Units: List: layers, F-factor.

Input Restrictions: The layers method shall be used for all above-grade constructions.

Standard Design: For each construction, the proposed design specification method shall be used.

Standard Design: Existing Buildings: Same as newly constructed buildings.

Layers

Applicability: All construction assemblies that use the layers method of specification

Definition: A structured list of material names that describe a construction assembly, beginning with the exterior finish and progressing through the assembly to the interior finish. Material names must be from the standard list (Appendix E) or defined (see above) ACM Appendix 5.5A.

Units: List: layers of construction assembly

Input Restrictions: The user is required to describe all layers in the actual assembly and model the proposed design based the layer descriptions.

Standard Design: See building descriptors for roofs, exterior walls, exterior floors, doors, fenestration, and below-grade walls.

Standard Design: Existing Buildings: Same as newly constructed buildings

5.5.3 Roofs

Roof Name

Applicability: All roof surfaces.

Definition: A unique name or code that identifies the roof and ties it to the construction documents submitted for energy code review. It is not mandatory to name roofs.

Units: Text.

Input Restrictions: Name must be unique.

Standard Design: N/A.

Standard Design: Existing Buildings: N/A.

Roof Type

Applicability: All roof surfaces.

Definition: A roof classification defined in the Energy Code. This descriptor can be derived from other building descriptors, and it may not be necessary for the compliance software user to specify it directly.

Units: List: metal building roofs, wood framed or other; residential or non-residential; steep or low-slope roof.

Input Restrictions: As designed for existing buildings.

Standard Design: All roofs in the standard design are modeled as wood-framed and other.

Standard Design: Existing Buildings: Same as proposed.

Roof Geometry

Applicability: All roofs.

Definition: Roof geometry defines the position, orientation, azimuth, tilt, and dimensions of the roof surface. The details of how the coordinate system is implemented may vary between compliance software programs. The data structure for surfaces is described in the reference section of this chapter.

Units: Data structure: surface.

Input Restrictions: There are no restrictions other than that the surfaces defined must agree with the building being modeled, as represented on the construction drawings or as-built drawings.

Standard Design: Roof geometry is identical in the proposed and standard design building designs.

Standard Design: Existing Buildings: Roof geometry will be identical in the proposed and standard design building designs. For alterations, roof geometry will be fixed based on one of the building prototypes.

Roof Solar Reflectance

Applicability: All opaque exterior roof surfaces exposed to ambient conditions.

Definition: The solar reflectance of a material. For roofing materials, the three-year aged reflectance value from CRRC testing should be used if available.

Units: Unitless.

Input Restrictions: Must be in the range of 0 to 1.

For roofs that are part of newly constructed buildings, if asphalt shingles or composition shingles are not rated by the CRRC, the default aged solar reflectance shall be equal to 0.08 for asphalt roofs and 0.10 for all other roof types. The default value may be overridden when roof materials are used that the CRRC has tested and are called for in the construction documents. In cases where the default value is overridden, the user is required to submit documentation identifying the test procedure that was used to establish the non-default values. If the aged CRRC reflectance is not known, the aged CRRC reflectance may be calculated from the initial CRRC reflectance using the following equation:

paged = 0.2 + β · (pinit – 0.2)ρ_{aged}

Where,

$\boldsymbol{\rho_{aged}}$ - the calculated aged reflectance

β - 0.65 for field-applied coatings, 0.7 for all other roof surfaces

$\boldsymbol{\rho_{init}}$ - the initial CRRC reflectance

As a compliance option, low-sloped roofs that use aggregate may specify an aged reflectance of 0.50 if the product meets the following criteria:

- Conforms to material standard ASTM D1863.
- Conforms to ASTM D448, size number equal between No.6 and No.7.
- Has a CRRC-tested initial solar reflectance that meets or exceeds 0.55 using the ASTM E1918 test procedure with aggregate passing a No. 4 sieve and is retained by a No. 8 sieve that conforms to ASTM D448, conducted by a CRRC-accredited independent laboratory meeting the requirement of Section 10-113(d)4 of the Energy Code.
- Has a label on bags or containers of aggregate stating that the materials conform to ASTM D1863 and ASTM D448.

Standard Design: For newly constructed buildings, the standard design reflectance is defined in Table 140.3-B for nonresidential buildings, Table 140.3-C for guest rooms of hotel/motel buildings containing guestrooms, Table 140.3-D for relocatable classroom buildings, and Table 170.2-A for multifamily buildings.

For alterations to more than 50 percent of the roof area or roof areas above 2,000 ft², the standard design shall be modeled as the more efficient of either the existing conditions or the values required for cool roofs under Section 141.0 and Section 180.2 of the Energy Code.

Standard Design: Existing Buildings: For alterations to more than 50 percent of the roof area or roof areas above 2,000 ft^2, the standard design shall be modeled as the more efficient of either the existing conditions or the values required for cool roofs under Section 141.0 and Section 180.2.

Roof Thermal Emittance

Applicability: All opaque exterior roof surfaces exposed to ambient conditions.

Definition: The thermal emittance of a material. For roofing materials, the three-year aged emittance value from CRRC testing should be used if available.

Units: Unitless.

Input Restrictions: Must be in the range of 0 to 1.

For roofs, newly constructed buildings: as designed, from CRRC values. If CRRC rating information is not available, the default thermal emittance shall be 0.85. Aggregate that meets the following criteria may specify a thermal emittance of 0.85:

- Conforms to material standard ASTM D1863.
- Conforms to ASTM D448, size number equal between No.6 and No.7.
- Has a CRRC-tested initial solar reflectance that meets or exceeds 0.55 using the ASTM E1918 test procedure with aggregate passing a No. 4 sieve and is retained by a No. 8 sieve that conforms to ASTM

D448, conducted by a CRRC accredited independent laboratory meeting the requirement of Section 10-113(d) 4 of the Energy Code.

- Has a label on bags or containers of aggregate stating that the materials conform to ASTM D1863 and ASTM D448.

Standard Design: For roofs, newly constructed buildings, the standard design thermal emittance shall be 0.75.

For alterations to more than 50 percent of the roof area or roof areas above 2,000 ft², the standard design shall be modeled as the more efficient of either the existing conditions or a thermal emittance of 0.85.

Standard Design: Existing Buildings: If the existing roof is unaltered, same as proposed. For alterations, the standard design is 0.85.

For alterations to more than 50 percent of the roof area or roof areas above 2,000 ft², the standard design shall be modeled as the more efficient of either the existing conditions or a thermal emittance of 0.80.

ROOF CONSTRUCTION

Applicability: All roofs.

Definition: A specification containing a series of layers that result in a construction assembly for the proposed design. The first layer in the series represents the outside (or exterior) layer and the last layer represents the inside (or interior) layer. See the building descriptors above for roof construction type.

Units: List: layers.

Input Restrictions: The area-weighted average of the roof construction assembly U-factors, defined by a series of layers, must be equal to or more efficient than the mandatory U-factor requirements of Section 120.7 and Section 160.1 of the Energy Code for newly constructed buildings, and Section 141.0 and Section 180.2 of the Energy Code for alterations. Note that these U-Factor requirements assume an exterior air film of R-0.17 and an interior air film of R-0.61. Each layer specified must be listed in the materials database in the ACM Appendix 5.5.

Newly constructed buildings

- Metal Building: U – 0.098
- Wood Framed and Others: U – 0.075

Additions and Alterations

- Roof / Ceiling Insulation: See Section 141.0(b)2Biii and Section 180.2(b)2B of the Energy Code

Appropriate R-values for insulation can be calculated using the formula below.

$$R_{insulation} = (1/UFactor) - R_{Layer(1)} - R_{Layer(2)} - R_{Layer(3)} - R_{Layer(n)}$$
$$R_{insulation} = R_{ins_{continuous}} + R_{ins_{framing}}$$

Ceilings that form the boundary between the modeled building of an additions and alterations project and the existing, un-modeled portion of the building may be modeled as adiabatic roofs (no heat transfer).

Standard Design: Roofs in the standard design are of the type "insulation entirely above deck." The insulation requirement is determined by climate zone. The standard design building roof construction shall be modeled as layers as defined. See Appendix 5.5for details.

For newly constructed buildings, the standard design roof type is wood framed and other, and the roof is a standing seam metal roof, with the R-value of continuous insulation adjusted to match the prescriptive standards for wood-framed and other roofs. The U-factor required for roof construction is defined in Table 140.3-B, 140.3-C, 140.3-D, or Table 170.2-A of the Energy Code. Programs that model a U-factor shall include an exterior and interior air film resistance. The standard design construction is based on JA4 Table 4.2.7 and assumes an exterior air film of R-0.17 and an interior air film of R-0.61.

The standard design construction shall include the following layers:

- Layer 1: Metal Standing Seam 1/16 in. (R - 0.00)
- Layer 2: Continuous Insulation (R - Based on Climate Zone)
- Layer 3: Open Framing + No Insulation (R - 0.00)

The value of the continuous insulation layer entirely above framing shall be set to achieve the following R-values:

Nonresidential Buildings: Continuous Insulation

- Climate Zones 6, 7, 8: R-21.34 (U – 0.047)
- All Other Climate Zones: R 35.78 (U – 0.028)

Multifamily Buildings and Hotel/Motel Guestrooms: Continuous Insulation

- Climate Zones 1, 2,4,8-16: R - 34.93 (U – 0.028)
- Climate Zone 7: R - 24.86 (U– 0.039)
- Climate Zones 3, 5, 6: R - 28.63 (U– 0.034)

For mixed-use buildings, the roof standard design requirements shall be determined by which space type (nonresidential or residential) is the majority of the floor area of the adjoining conditioned spaces.

For re-locatable classroom buildings, the standard design shall use the construction assembly corresponding to the most stringent of requirements in any climate zone, or R-28.63 continuous insulation.

For alterations, any approved roof type may be used. The U-factor in the standard design shall be modeled as the more efficient of either the existing conditions or the values stated in Section 141.0 and Section 180.2 of the Energy Code. Where applicable, selection shall be based on building type, assembly, and climate zone. A construction of layers shall be defined to yield an equivalent U-factor.

Standard Design: Existing Buildings: For existing buildings, if the roof component is not altered, the standard design roof construction shall match the proposed design roof construction of the existing building. If the roof is altered, the roof component shall meet the prescriptive requirements for newly constructed buildings for the roof type of the existing building.

The roof type of the existing building is either a metal building roof or a wood-framed or other roof. The standard design roof assemblies for altered roofs are shown below for the appropriate climate zones.

Alterations Roof Standard Design:

For alterations, any approved roof type may be used. The U-factor in the standard design shall be modeled as the more efficient of either the existing conditions or the values stated in Section 141.0 and Section 180.2 of the Energy Code. Where applicable, selection shall be based on building type, assembly, and climate zone. A construction of layers shall be defined to yield an equivalent U-factor.

5.5.4 Exterior Walls

WALL NAME

Applicability: All walls.

Definition: A unique name or code that relates the exterior wall to the design documents. This is an optional input since there are other acceptable ways to key surfaces to the construction documents.

Units: Text.

Input Restrictions: Must be unique.

Standard Design: None.

Standard Design: Existing Buildings: None.

WALL TYPE

Applicability: All walls.

Definition: One of four categories of above-grade wall assemblies used to determine minimum insulation requirements for walls. The five wall type categories are as follows:

1. Mass Light
2. Mass Heavy
3. Metal building
4. Metal framing
5. Wood framing and other walls

A mass light wall is defined as a wall with total heat capacity greater than 7 but less than 15 Btu/ft^2-. A mass heavy wall is defined as a wall with a total heat capacity of 15 Btu/ft^2-°F or greater. (Heat capacity is defined as the product of the specific heat in Btu/lb-°F, the thickness in ft, and the density in lb/ft^3.)

Units: List: mass light, mass heavy, metal building walls, metal framing walls, and wood framing and other walls

Input Restrictions: This input is required for existing buildings when any wall is altered. This input is not required for newly constructed buildings.

Standard Design: All walls in the standard design building are modeled as “metal framed.”

Standard Design: Existing Buildings: Same as proposed.

Wall Geometry

Applicability: All walls

Definition: Wall geometry defines the position, orientation, azimuth, and tilt of the wall surface. The data structure for surfaces is described in the reference section of this chapter.

Units Data structure: surface

Input Restrictions: As designed

Standard Design: Same as proposed

Standard Design: Existing Buildings: Same as proposed

Wall Fire Rating

Applicability: All walls in multifamily buildings.

Definition: The fire rating for the exterior walls in the building.

Units: hr (integer – typically, 1 hr, 2 hr).

Input Restrictions: This input is required for existing buildings when any wall is altered. This input is not required for newly constructed buildings.

Standard Design: Not required.

Standard Design: Existing Buildings: Same as proposed.

Wall Solar Reflectance

Applicability: All opaque exterior walls exposed to ambient conditions.

Definition: The solar reflectance of a material.

Units: Unitless ratio.

Input Restrictions: For walls and other non-roof surfaces, the value is prescribed to be 0.3.

Standard Design: For walls and other non-roof surfaces, the value is prescribed to be 0.3.

Standard Design: Existing Buildings: 0.3.

Wall Thermal Emittance

Applicability: All opaque exterior walls exposed to ambient conditions.

Definition: The thermal emittance of a material.

Units Unitless ratio.

Input Restrictions: For walls and other non-roof surfaces, the value is prescribed to be 0.9.

Standard Design: For walls and other non-roof surfaces, the thermal emittance is 0.9.

Standard Design: Existing Buildings: For walls and other non-roof surfaces, the thermal emittance is 0.9.

Wall Construction

Applicability: All walls that use the layers method.

Definition: A specification containing a series of layers that result in a construction assembly for the proposed design. The first layer in the series represents the outside (or exterior) layer and the last layer represents the inside (or interior) layer. See the building descriptors above for wall construction type.

Units: List: Layers.

Input Restrictions: The area weighted-average of the construction assembly U-factors, defined by a series of layers, must be equal to or more efficient than the mandatory U-factor requirements of Section 120.7 and Section 160.1 of the Energy Code for newly constructed buildings. Note that these U-Factor requirements assume an exterior air film of R-0.17 and an interior air film of R-0.68. Each layer specified, with the exception of composite layers, must be listed in the materials database in the ACM Appendix 5.5A.

Newly Constructed

Metal Building

- U – 0.113 nonresidential and multifamily

Metal Framed

- U – 0.151 nonresidential
- U – 0.148 multifamily

Light Mass Walls

- U – 0.440 nonresidential and multifamily

Heavy Mass Walls

- U – 0.690 nonresidential and multifamily

Wood Framed and Others

- U – 0.110 nonresidential
- U – 0.095 multifamily nominal 2x4 inch framing
- U – 0.069 multifamily 2x6 inch framing
- U – 0.102 multifamily all others

Spandrel Panels / Glass Curtain Walls

- U – 0.280 nonresidential and multifamily

Additions and Alterations

Metal Building

- U – 0.113 nonresidential and multifamily

Metal Framed

- U – 0.217 nonresidential and multifamily

Wood Framed and Others

- U – 0.110 nonresidential and multifamily

Spandrel Panels / Glass Curtain Walls

- U – 0.280 nonresidential and multifamily

Appropriate R-values for insulation can be calculated using the formula below.

$$R_{insulation} = (1/UFactor) - R_{Layer(1)} - R_{Layer(2)} - R_{Layer(3)} - R_{Layer(n)}$$
$$R_{insulation} = R_{ins_{continuous}} + R_{ins_{framing}}$$

Walls that form the boundary between the modeled building of an additions and alterations project and the existing, un-modeled portion of the building may be modeled as adiabatic walls (no heat transfer).

Standard Design: The U-factor required for wall construction of the standard design building is defined in Table 140.3-B, 140.3-C, 140.3-D, or 170.2-A of the Energy Code. Programs that model a U-factor shall use an exterior and interior air film resistance. The standard design construction is based on JA4 Table 4.3.3 and assumes an exterior air film of R-0.17 and an interior air film of R-0.68.

For metal framed walls, the standard design construction shall include the following layers:

Layer 1

- Stucco – 7/8 in.
- R - 0.18

Layer 2

- Building Paper
- R – 0.06

Layer 3

- Continuous Insulation
- R - Based on Climate Zone

Layer 4

- Closed Framing and No Ins.
- R – 0.65

Layer 5

- Gypsum Board – 1/2 in.
- R – 0.45

Standard Design: Existing Buildings: The value of the continuous insulation layer entirely outside framing shall be set to achieve the following R-values:

Nonresidential Buildings: Continuous Insulation

Climate Zones 1, 6, and 7

- R – 14.47

Climate Zones 2, 4, 5, and 8 – 16

- R – 15.99

Climate Zone 3

- R – 11.90

Multifamily Buildings and Hotel/Motel Guestrooms: Continuous Insulation

Climate Zones 1 - 6, and 8-16

- R – 12.30

Climate Zone 7

- R – 7.33

For mixed-use buildings that contain both nonresidential and residential spaces, walls adjacent to nonresidential spaces shall use the Nonresidential Buildings standard design construction, and walls adjacent to residential and multifamily spaces shall use the multifamily standard design construction.

For relocatable classroom buildings, the standard design shall use the construction assembly corresponding to the most stringent of requirements in any climate zone, or R-13.94 continuous insulation.

Table 8: Wall Construction

	CZ2,10-16	**CZ 1**	**CZ 4**	**CZ 3**	**CZ 5-9**
JA4 U-factor	0.170	0.196	0.227	0.278	0.440
Layer 1	4 in MW CMU, 115 lb/sf 4.3.6-B5	4 in MW CMU, 115 lb/sf 4.3.6-B5	4 in MW CMU, 115 lb/sf 4.3.6-B5	4 in MW CMU, 115 lb/sf 4.3.6-B5	8 in NW CMU, 125 lb/ft^2, partly grouted, reinforced with insulated cells 4.3.6-C10
Layer 2*	3” furring space with R-21 insulation and metal clips 4.3.14-V15 (equiv R-4.8 c.i.)	2.5” furring space with R-13 insulation and metal clips 4.3.14-R13 (equiv R-3.8 c.i.)	2” furring space with R-13 insulation and metal clips 4.3.14-N11 (equiv R-3.3 c.i.)	1.5” furring space with R-9 insulation and metal clips 4.3.14-J9 (equiv R-2.5 c.i.)	N/A
Layer 3	N/A	N/A	N/A	N/A	N/A
…	N/A	N/A	N/A	N/A	N/A
Layer n	N/A	N/A	N/A	N/A	N/A

Source: California Energy Commission

Table 9: Heavy Mass Wall (Heat Capacity >= 15 Btu/ft^2-F)

	CZ2,10-16	**CZ 1**	**CZ 4**	**CZ 3**	**CZ 5-9**	
JA4 U-factor	0.160	0.184	0.211	0.253	0.650	0.690
Layer 1	8 in. NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A10	8 in. NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A10	8 in. NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A10	8 in. NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A10	8 in NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A9	8 in. NW CMU, 125 lb/ft^2, solid grout, reinforced 4.3.5-A10

	CZ2,10-16	CZ 1	CZ 4	CZ 3	CZ 5-9	
Layer 2*	3” furring space with R-21 insulation and metal clips 4.3.14-V15 (equiv R-4.8 c.i.)	2.5” furring space with R-13 insulation and metal clips 4.3.14-R13 (equiv R-3.8 c.i.)	2” furring space with R-13 insulation and metal clips 4.3.14-N11 (equiv R-3.3 c.i.)	1.5” furring space with R-9 insulation and metal clips 4.3.14-J9 (equiv R-2.5 c.i.)	N/A	N/A
Layer 3	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A
Layer n	N/A	N/A	N/A	N/A	N/A	N/A

Source: California Energy Commission

Table 10: Metal Building Walls

	CZ15	CZ 2,4,5,8,9,10-14,16	CZ 1,3,6,7
JA4 U-factor	0.057	0.061	0.113
Layer 1	R-13 batt insulation draped over purlins and compressed	R-13 batt insulation draped over purlins and compressed	R-13 batt insulation draped over purlins and compressed Rlayer=8.85
Layer 2*	Second layer R-13 batt insulation	Second layer R-10 batt insulation	N/A
Layer 3	N/A	N/A	N/A
…	N/A	N/A	N/A
Layer n	N/A	N/A	N/A

Source: California Energy Commission

Table 11: Wood-Framed Walls

	CZ15	CZ 2,4,9-14,16	CZ 4	CZ 3
JA4 U-factor	0.042	0.059	0.102	0.110
Layer 1	2x4, 16” o.c., with R-13 batt ins	2x4, 16” o.c., with R-11 batt ins	2x4, 16” o.c. with R-13 batt ins	2x4, 16” o.c. with R-11 batt ins
Layer 2*	R-14 continuous insulation	R-8 continuous insulation	N/A	N/A

Source: California Energy Commission

5.5.5 Exterior Floors

Floor Name

Applicability: All floor surfaces.

Definition: A unique name or code that relates the exposed floor to the design documents.

Exposed floors include floors exposed to the outdoors and floors over unconditioned spaces, but do not include slab-on-grade floors, below grade floors, or interior floors.

Units: Text.

Input Restrictions: Must be unique.

Standard Design: None.

Standard Design: Existing Buildings: None.

FLOOR TYPE

Applicability: All exterior floor surfaces, optional.

Definition: The category that defines the standard design prescriptive floor requirements.

Units: List: mass or other.

Input Restrictions:

Standard Design: The standard design building floors shall be of type "other".

Standard Design: Existing Buildings: Same as proposed.

FLOOR GEOMETRY

Applicability: All exterior floors.

Definition: Floor geometry defines the position, orientation, azimuth, and tilt of the floor surface. The details of how the coordinate system is implemented may vary between compliance software programs. The data structure for surfaces is described in the reference section of this chapter.

Units: Data structure: surface.

Input Restrictions: As designed. Required input.

Standard Design: Standard design building floor geometry is identical to the proposed design.

Standard Design: Existing Buildings: Same as proposed.

Floor Construction

Applicability: All floors.

Definition: A specification containing a series of layers that result in a construction assembly for the proposed design. The first layer in the series represents the outside (or exterior) layer and the last layer represents the inside (or interior) layer. See the building descriptors above for floor construction type.

Units: List: Layers.

Input Restrictions: The area weighted-average of the floor construction assembly U-factors, defined by a series of layers, must be equal to or more efficient than the mandatory U-factor requirements of Section 120.7 and Section 160.1 of the Energy Code for newly constructed buildings, and Section 141.0 and Section 180.2 of the Energy Code for alterations. Note that these U-factor requirements assume an exterior air film of

R-0.17 and an interior air film of R-0.92. Each layer specified must be listed in the materials database in the ACM Appendix 5.5A.

Newly constructed buildings

Raised Mass Floors

- U – 0.269

Other Floors

- U – 0.071

Heated Slab Floors

- Climate Zone (see Section 120.7 and Section 160.1)

Additions and Alterations

Metal Building

- U – 0.113

Metal Framed

- U – 0.217

Wood Framed and Others

- U – 0.110

Spandrel Panels / Glass Curtain Walls

- U – 0.280

Appropriate R-values for insulation can be calculated using the formula below.

$$R_{insulation} = (1/UFactor) - R_{Layer(1)} - R_{Layer(2)} - R_{Layer(3)} - R_{Layer(n)}$$
$$R_{insulation} = R_{ins_{continuous}} + R_{ins_{framing}}$$

Floors that form the boundary between the modeled building of an addition and alteration project and the existing, un-modeled portion of the building may be modeled as adiabatic floors (no heat transfer).

Standard Design: The U-factor required for floor construction is defined in Table 140.3-B, 140.3-C, 140.3-D, or 170.2-A of the Energy Code. Programs that model a U-factor shall use an exterior and interior air film resistance. The standard design construction is based on JA4 Table 4.4.5 and assumes an exterior air film of R-0.17 and an interior air film of R-0.92.

For metal framed floors, the standard design construction shall include the following layers:

Layer 1

- Open Framing + No Ins.
- R – 0.00

Layer 2

- Continuous Insulation
- R – Based on Climate Zone

Layer 3

- Plywood – 5/8 in.
- R – 0.78

Layer 4

- Carpet and Pad – 3/4 in.
- R – 1.30

Standard Design: Existing Buildings: The value of the continuous insulation layer entirely above or below framing shall be set to achieve the following R-values:

Nonresidential Buildings: Continuous Insulation

- Climate Zones 1
  - R – 17.66
- Climate Zones 2, 11, and 14 -16
  - R – 22.47
- Climate Zones 3 – 10, 12, and 13
  - R – 10.91

Multifamily Buildings and Hotel/Motel Guestrooms: Continuous Insulation

- Climate Zones 1, 2, 14, and 16
  - R – 26.24
- Climate Zones 3 – 6, 8 – 13, and 15
  - R – 22.47
- Climate Zones 7
  - R – 10.91

The standard design floor that serves as the boundary between the modeled additions and alterations building and the existing, unmodeled portion of the building is modeled as an adiabatic floor, to match the proposed design. The standard design floor construction for existing buildings depends on the floor type.

5.5.6 Doors

Door Name

Applicability All exterior doors, optional input.

Definition A unique name or code that relates the door to the design documents submitted. Doors that are more than 50 percent glass are treated as windows and must be determined and entered by using the Fenestration building descriptors.

Units: Text: unique.

Input Restrictions: None.

Standard Design: None.

Standard Design: Existing Buildings: None.

Door Type

Applicability: All exterior doors, required input.

Definition: One of two door classifications of either: swinging or non-swinging. Non-swinging are generally roll-up doors. The prescriptive U-factor requirements depend on door type and climate. This building descriptor may be derived from other building descriptors, in which case a specific input is not necessary.

Units: List: swinging or non-swinging.

Input Restrictions: The door type shall be consistent with the type of door represented on the construction documents or as-built drawings.

Standard Design: The standard design building door type shall be the same as the proposed design.

Standard Design: Existing Buildings: Same as newly constructed buildings.

Door Geometry

Applicability: All exterior doors.

Definition: Door geometry defines the position and dimensions of the door surface relative to its parent wall surface. The azimuth and tilt (if any) of the door is inherited from the parent surface. The position of the door within the parent surface is specified through (X, Y) coordinates. The size is specified as a height and width (all doors are generally assumed to be rectangular in shape). The details of how the geometry of doors is specified may vary for each energy simulation program.

Units: Data structure: opening.

Input Restrictions: As designed.

Standard Design: Door geometry in the standard design building is identical to the proposed design.

Standard Design: Existing Buildings: Same as newly constructed buildings.

Door Construction

Applicability: All exterior doors.

Definition: The thermal transmittance of the door, including the frame.

Units: Btu/h·ft^2·°F.

Input Restrictions: The construction assembly must be equal to or more efficient than the mandatory U-factor requirements of Section 110.6 of the Energy Code for newly constructed buildings. There are no restrictions for alterations.

Standard Design: For newly constructed buildings, the U-factor required for door construction is defined in Table 140.3-B, 140.3-C, 140.3-D, or 170.2-A of the Energy Code.

- Nonresidential Buildings – U Factor:
  - Non-Swinging Doors:
    - Climate Zones 1, and 16
      - U – 0.50
    - Climate Zones 2 – 15
      - U – 1.45

- Swinging Doors:
  - Climate Zones 1 – 16
    - U – 0.70
- Multifamily Buildings and Hotel/Motel Guestrooms – U Factor:
  - Non-Swinging Doors:
    - Climate Zones 1, and 16
      - U – 0.50
    - Climate Zones 2 – 15
      - U – 1.45
  - Swinging Doors:
    - Climate Zones 1 – 16
      - U – 0.70
- Relocatable Public School Building (for all climate zones)
  - Non-Swinging Doors:
    - U-0.50
  - Swinging Doors:
    - U-0.70

Standard Design: Existing Buildings: For alterations, the U-factor in the standard design is either the same standard design as the newly constructed buildings standard design if the door is replaced, or the equal to the existing door construction, if the door is unaltered. Where applicable, selection shall be based on building type, assembly, and climate zone.

OPERABLE DOOR OPENING TYPE

Applicability: All exterior doors.

Definition: The opening type that determines whether interlocks with mechanical cooling and heating are required, as specified by Section 140.4(n) and Section 170.2(c)4L. If manual, then interlocks are required when operable windows are present in any nonresidential space, excluding multifamily and healthcare spaces and buildings. If self-closing or a glazed door, interlocks are not required and are not present in the standard design.

Units Btu/h·ft^2·°F.

Input Restrictions: List: Self-Closing, Manual, Glazed Door.

Standard Design: Same as Proposed.

5.5.7 Fenestration

Note that fenestration includes windows, doors that have 25 percent or more glazed area, and skylights. A skylight is fenestration that has a tilt of less than 60 degrees from horizontal.

FENESTRATION NAME

Applicability: All fenestration, optional input.

Definition: A unique name or code that relates the fenestration to the design documents and a parent surface.

Units: Text: unique.

Input Restrictions: None.

Standard Design: None.

Standard Design: Existing Buildings: None.

Fenestration Type (Vertical Fenestration)

Applicability: All vertical fenestration.

Definition: This is a classification of vertical fenestration that determines the thermal performance and solar performance requirement for vertical fenestration.

Units: List: Fixed, Operable, Curtain Wall, Glazed Doors.

Input Restrictions: As designed

Standard Design: Same as the proposed design

Standard Design: Existing Buildings: Same as newly constructed buildings

Fenestration Type (Skylights)

Applicability: All skylights

Definition: This is a classification of skylights that determines the thermal performance and solar performance requirement for vertical fenestration

Units List:

- Glass, Curb-mounted
- Glass, Deck-mounted
- Plastic, Curb-mounted
- Plastic, Deck-mounted

Input Restrictions: As designed

Standard Design: Same as the proposed design

Standard Design: Existing Buildings: Same as newly constructed buildings

Default Fenestration Type

Applicability: All fenestration that uses default thermal performance factors

Definition: This is a classification of fenestration that determines the thermal performance for fenestration using defaults from the Energy Code Section 110.6, Table 110.6-A. This is used for fenestration without National Fenestration Rating Council (NFRC) ratings or for fenestration for altered buildings that includes window films.

Units: List: fixed, operable, greenhouse/garden, doors, or skylight

Input Restrictions: As designed. The default value shall be fixed.

Standard Design: Not applicable

Default Glazing Type

Applicability: All fenestration that uses default thermal performance factors

Definition: This is a classification of fenestration that determines the thermal performance for fenestration using defaults from the Energy Code Section 110.6, Table 110.6-A. This is used for fenestration without NFRC ratings or for fenestration for altered buildings that includes window films.

Units: List: single pane, double pane, glass block

Input Restrictions: As designed. The default value shall be single-pane.

Glass block is only allowed if the default fenestration type is operable or fixed.

Standard Design: Not applicable.

Default Framing Type

Applicability: All fenestration that uses default thermal performance factors.

Definition: This is a classification of fenestration that determines the thermal performance for fenestration using defaults from the Energy Code Section 110.6, Table 110.6-A. This is used for fenestration without NFRC ratings or for fenestration for altered buildings that includes window films. This is also used for skylight products where the thermal performance is determined by the equations from the Reference Appendix NA6.

Units: List: metal, metal with thermal break, or nonmetal.

Input Restrictions: As designed. The default value shall be metal.

Standard Design: Not applicable.

Default Divider Type

Applicability: All double-pane fenestration that uses default thermal performance factors.

Definition: This is a classification of fenestration that determines the thermal performance for fenestration using defaults from the Energy Code Section 110.6, Table 110.6-A. This is used for fenestration without NFRC ratings or for fenestration for altered buildings that includes window films.

Units: List: no divider, true divided lite, divider between panes less than 7/16 inch, or divider between panes greater than or equal to 7/16 inch.

Input Restrictions: As designed. The default value shall be no divider.

Standard Design: Not applicable.

Default Tint Type

Applicability: All fenestration that uses default thermal performance factors.

Definition: This is a classification of fenestration that determines the thermal performance for fenestration using defaults from the Energy Code Section 110.6, Table 110.6-B. This is used for fenestration without NFRC ratings or for fenestration for altered buildings that includes window films.

Units: List: clear glazing, tinted glazing.

Input Restrictions: As designed. The default value shall be clear.

Standard Design: Not applicable.

DEFAULT OPERABLE CONFIGURATION

Applicability: All operable fenestration that uses default thermal performance factors.

Definition: This is a classification of fenestration that determines the visible transmittance (VT) for fenestration using defaults from the Energy Code Appendix NA6. This is used for fenestration without NFRC ratings, for fenestration for altered buildings that includes window films, or skylights.

Units: List: casement or awning, sliding.

Input Restrictions: As designed. The default value shall be sliding.

Standard Design: Not applicable.

FENESTRATION GEOMETRY

Applicability: All fenestration.

Definition: Fenestration geometry defines the position and dimensions of the fenestration surface within its parent surface and the identification of the parent surface. The orientation and tilt are inherited from the parent surface. The details of how the coordinate system is implemented may vary between compliance software programs.

Display Perimeter:

Display perimeter is the length of an exterior wall in a B-2 occupancy that immediately abuts a public sidewalk, measured at the sidewalk level for each floor that abuts a public sidewalk. The compliance software shall allow the user to specify a value for the length of display perimeter, in feet, for each floor or floor of the building. The user entry for display perimeter shall have a default value of zero. Note: Any non-zero input for display perimeter is an exceptional condition that shall be reported on the PRF-1 exceptional condition list and shall be reported on the ENV forms. The value for display perimeter is used as an alternate means of establishing maximum wall fenestration area in the standard design (Section 140.3 of the Energy Code).

The display perimeter shall be calculated separately for west-facing fenestration, and for non-west facing fenestration.

Floor Number:

The compliance software shall also allow the user to specify the display perimeter associated with each floor of the building.

Units: Data structure: opening

Geometry is defined relative to the parent surface and can include setbacks.

Inputs include:

Geometry of opening (window or skylight), parent surface, display perimeter (optional), percent of roof area that is not required to meet the skylight requirements in Section 140.3(a)6A of the Energy Code.

Input Restrictions: As designed

Specification of the fenestration position within its parent surface is required for the following conditions:

- Exterior shading is modeled from buildings, vegetation, or other objects; or
- If daylighting is modeled within the adjacent space.

Standard Design: The standard design calculates the window wall ratio (WWR) for each orientation and the overall window wall ratio for the building. The window wall ratio is the total fenestration area (including framing) divided by the gross exterior wall area (excluding wall area that is underground). Note that exterior wall area that is below grade, but has exposure to ambient conditions, and any associated fenestration, is included in the WWR calculation.

The standard design vertical fenestration area and horizontal fenestration area for spaces that are specified as computer rooms or data centers (with an ITE equipment power density greater than 20 W/ft^2) shall be zero.

For all other buildings, the geometry of the fenestration in the standard design shall be identical to the proposed design with the following exceptions:

Exception 1: Either the whole building window wall ratio or west window wall ratio exceeds 40 percent.

Exception 2: If display perimeter is entered, the fenestration area exceeds the greater of 40 percent of the gross wall area (excluding adiabatic walls) and six times the display perimeter.

Exception 1: The fenestration is adjusted based on the following conditions:

Case 1. $WWR_o > 0.40$, $WWR_w \leq 0.40$

In this case, the fenestration area of all windows is reduced by multiplying the fenestration area by the ratio $0.40/WWR_o$. The dimensions of each window are reduced by increasing the sill height so that the window height is modified by the multiplier (0.40/WWRo) so that the same window width is maintained.

Case 2: $WWR_o < 0.40$. $WWR_w > 0.40$

In this case, the fenestration area of all windows on the west orientation is reduced by multiplying the fenestration area by the ratio 0.40/WWRo. The dimensions of each window are reduced by multiplying the proposed window dimension by increasing the sill height so that the window height is modified by the multiplier (0.40/WWRo), so that the window width is maintained.

Case 3: $WWR_o > 0.40$. $WWR_w > 0.40$

If both the west window wall ratio and the overall window wall ratio exceed the prescriptive limit of 0.40, the fenestration areas must be reduced by:

Adjust the west window area multiplying the west window area by the ratio $0.4/WWR_w$.

Calculate the WWR of the north, east and south facades:

WWR_{nes} = Window $Area_{nes}$ / Gross Wall $Area_{nes}$

Adjust the window area of the windows on the north, east and south facades by the following ratio:

$WindowArea_{N,std} = WindowArea_{N,prop} \times 0.4 / WWR_{nes}$

$WindowArea_{E,std} = WindowArea_{E,prop} \times 0.4 / WWR_{nes}$

$WindowArea_{S,std} = WindowArea_{S,prop} \times 0.4 / WWR_{nes}$

Adjust each window geometry for the west façade by multiplying the window height by ($0.4/WWR_w$) by adjusting the sill height and by maintaining the same window width.
Adjust each window geometry for the north, east and south façade by multiplying the window height by ($0.4/WWR_{nes}$) by adjusting the sill height and by maintaining the same window width.

Exception 2: If the display perimeter is entered and the window area exceeds the prescriptive limit, the window area for the standard design is calculated by multiplying the proposed window area by the following ratio:

$WindowArea_{std} = 6 \times DisplayPerimeter$

The geometry of each window is modified by the following, and by modifying the sill height but not the head height position relative to the floor:

$WindowHeight_{std} = WindowHeight_{prop} \times (WindowArea_{std}/WindowArea_{prop})$

$WindowWidth_{std} = WindowWidth_{prop}$

The following rules apply for calculating geometry of skylights. For the calculation of the standard design skylight area, the gross roof area is defined as the total roof area, including skylights, that is directly over conditioned space.

The skylight area of the standard design is set:

- For buildings without atria or with atria having a height less than 55 feet over conditioned space, the smaller of the proposed skylight area and 5 percent of the gross roof area that is over conditioned space.
- For buildings with atria at a height of 55 ft or greater over conditioned spaces, the smaller of the proposed skylight area and 10 percent of the gross roof area that is over conditioned space.
- For buildings with atria or other roof area directly over unconditioned spaces, the smaller of the proposed skylight area or 5 percent of the roof area excluding the atria area and excluding any adiabatic walls, if present in the modeled building. The skylight area of the atria or roof area directly over unconditioned space is not included in the skylight area limit in this case.

The skylight area for atria over unconditioned space is not included in determining the skylight to roof ratio (SRR) for the building.

Depending on the following condition, adjustments to the SRR as described shall be made.

- For open spaces other than auditoriums, churches, movie theaters, museums and refrigerated warehouses, for buildings in climate zones 2 through 15, and when spaces have ceiling heights greater than 15 ft and floor areas greater than 5000 ft^2, the skylight area shall be the greater of 3 percent or the area required to provide daylight coverage through skylights or primary side lighting to 75 percent of the floor area in the space. See 5.4.5 Daylighting Control for detail description on primary daylit area and skylit daylit area.
- If the above condition is met and SRR ≤ 0.05, no adjustments are needed.
- If the condition is met and SRR > 0.05, skylight dimensions = Existing Dimension x [1- √ (0.05/SRR of Proposed Building)]
- If the condition is not met triggering the need for additional skylights, the standard design case shall be modeled with new skylights irrespective of the skylight location of the proposed case. The new skylights shall be distributed uniformly such that there is no overlapping of primary daylit areas from skylights or sidelights. The dimension of the new skylights shall be the same as the proposed design if calculated new SRR ≤ 0.05. If SRR > 0.05, skylight dimensions = existing dimension x [1- √ (0.05/SRRfof proposed building)].

Note that the adjustments to SRR are done after adjustments to WWR if any are completed.

For compliance software that cannot make the adjustments described above, the compliance software should enforce the proposed design to provide daylight coverage using skylights or primary side lighting to 75 percent of the space floor area.

Standard Design: Existing Buildings: For alterations of existing vertical fenestration or skylights, where no fenestration area is added, the fenestration geometry of the standard design shall be the same as the proposed for the existing building.

For additions of vertical fenestration or skylights, where the additional fenestration causes the fenestration area to exceed the limit of 40 percent window to wall ratio (WWR) for the building, 40 percent WWR for the west orientation of the building, 5 percent skylight to roof ratio (SRR) for existing buildings without atria 55 feet or higher, or 10 percent SRR for existing buildings with atria 55 feet or higher, the fenestration geometry for the standard design shall be adjusted from the proposed design according to the rules set forth under the standard design rules.

For additions of vertical fenestration and/or skylights, where the existing fenestration already exceeds any of these limits, the new fenestration shall be removed.

For additions of vertical fenestration and/or skylights that do not cause the fenestration area to exceed any of these limits, the fenestration geometry of the standard design shall be the same as the proposed design.

Skylight Requirement Exception Fraction

Applicability: All buildings with interior ceiling heights greater than 15 feet.

Definition: The fraction of floor area that is not required to meet the minimum skylight area requirement for spaces with high ceilings.

Identifying areas subject to Section 140.3 of the Energy Code:

When a proposed space has ceiling heights greater than 15 ft, with exterior surfaces having a tilt angle less than 60 degrees (roofs) and no more than three floors above grade, the user shall enter the fraction of the modeled space that is not required to meet the requirements of Section 140.3 of the Energy Code. If the proposed design has skylights, the user shall also indicate the area of the proposed design daylight area under skylights in this space. When the user enters a value greater than zero percent for the fraction of the space area that is not required to meet Section 140.3 of the Energy Code, the compliance software shall require that the user indicate at least one of the following exceptions:

- The building is not located in climate zone 1 or climate zone 16
- Designed general lighting is less than 0.5 W/ft^2
- Existing walls on plans result in enclosed spaces less than 5,000 ft^2
- Future walls or ceilings on plans result in enclosed spaces less than 5,000 ft^2 or ceiling heights less than 15 ft
- Plans or documents show that space is an auditorium, religious building of worship, movie theater, museum, or refrigerated warehouses

Units: Unitless fraction of area.

Input Restrictions: Must be in the range of 0 to 1 and should match the as-built drawings.

Standard Design: Same as the proposed design.

Standard Design: Existing Buildings: Not applicable.

FENESTRATION CONSTRUCTION

Applicability: All fenestration.

Definition: A collection of values that together describe the performance of a fenestration system.

The values that are used to specify the criteria are U-factor, SHGC, and VT. U-factor and SHGC inputs are whole-window values.

Units: Data structure: shall include at a minimum the following properties as specified by NFRC ratings:

U-factor: whole window U-factor (Btu/h ft^2 °F).

SHGC: whole window solar heat gain coefficient (unitless).

VT: visible transmittance (unitless).

Input Restrictions: For newly constructed buildings, performance information for fenestration shall be obtained from NFRC test results or shall be developed from procedures outlined in Section 110.6 of the Energy Code, as specified below. Values entered shall be consistent with the specifications and the construction documents.

For manufactured products:

- U-factor, SHGC, and VT shall be equivalent to NFRC rated values.

For products not rated by NFRC, U-factor, SHGC and VT shall be determined from CEC default tables (110.6 A and B).

For site-built products:

- U-factor, SHGC, and VT shall be equivalent to NFRC rated values.
- For products not rated by NFRC, up to 200 ft^2 of skylight area or alteration of any area in a skylight product may use center of glass properties and Reference Appendix NA6 equations to calculate U-factor, SHGC, and VT. Any site-built fenestration in excess of 200 ft^2 must use the default values in Table 110.6-A and 110.6-B.

For buildings with fenestration area that meets requirements for use of center-of-glass U-factor and SHGC, the fenestration overall U-factor, SHGC, and VT shall be determined by the following equations from the Reference Appendix NA6:

UT = C1 + (C2 · Uc)

SHGCT = 0.08 + (0.86 · SHGCc)

VTT = VTF · VTC

Where:

UT - U-factor is the total performance of the fenestration including glass and frame

C1 - Coefficient selected from Table NA6-5 in Reference Appendix NA6

C2 - Coefficient selected from Table NA6-5 in Reference Appendix NA6

UC - Center of glass U-factor calculated in accordance with NFRC 100 Section 4.5.3.1

SHGCT - Total SHGC performance including glass and frame SHGCC = Center of glass SHGC calculated in accordance with NFRC 200 Section 4.5.1.1

VTT - Is the total performance of the fenestration including glass and frame

VTF - 0.53 for projecting windows, such as casement and awning windows

VTF - 0.67 for operable or sliding windows

VTF - 0.77 for fixed or non-operable windows

VTF - 0.88 for curtain wall/storefront, site-built and manufactured non-curb mounted skylights

VTF - 1.0 for curb mounted manufactured skylights

VTC - Center of glass VT is calculated in accordance with NFRC 200 Section 4.5.1.1 or NFRC 202 for Translucent Products or NFRC 203 for Tubular Daylighting Devices and Hybrid Tubular Daylighting Devices or ASTM E972

For vertical fenestration the area weighted-average U-factors, must be equal to or more efficient than the mandatory U-factor requirements of Section 120.7 of the Energy code for newly constructed buildings. The area weighted-average of the construction assembly U-factors, must be equal to or more efficient than the mandatory U-factor requirements of Section 141.0(b)E of the Energy Code for altered buildings.

Newly Constructed Buildings

U-0.47

Additions and Alterations

U-0.58

For skylights, the default values shall be the alternate default U-factor and SHGC using default calculations specified above and in Reference Appendix NA6 or the U-factor and SHGC listed in Table 110.6-A and Table 110.6-B in the Energy Code.

Standard Design: For newly constructed buildings, the requirements for vertical fenestration U factor, SHGC, and visible light transmission by window or skylight type and framing type are specified in Table 140.3-B, C, or D of the Energy Code. For plastic skylights, SHGC of 0.50 is assumed.

Standard Design: Existing Buildings: The U-factor, SHGC, and VT in the standard design shall be modeled as design if unchanged, as the values stated in Table 141.0-A of the Energy Code when the existing window area is unchanged (different than the newly constructed buildings performance requirement), or Table 140.3-B, C, or D of the Energy Code for all other cases.

The standard design does not include window films.

External Shading Devices

Applicability: All fenestration.

Definition: Devices or building features that are documented in the construction documents and shade the glazing, such as overhangs, fins, shading screens, and setbacks of windows from the exterior face of the wall.

The Title 24 compliance software shall be capable of modeling vertical fins, horizontal slats, and overhangs. Recessed windows may also be modeled with side fins, horizontal slats, and overhangs.

Units: Data structure: surface.

Input Restrictions: No restrictions other than that the inputs must match the construction documents.

Standard Design: The standard design building is modeled without external shading devices.

Standard Design: Existing Buildings: No shading devices.

Internal Shading Devices

Applicability: All fenestration.

Definition: Curtains, blinds, louvers, or other devices that are applied on the room side of the glazing material.

Glazing systems that use blinds between the glazing layers are also considered internal shading devices. Glass coatings, components, or treatments of the glazing materials are addressed through the fenestration construction building descriptor.

Units: Not applicable – not modeled for compliance.

Input Restrictions: Not applicable – interior shading is not modeled for compliance.

Standard Design: Not applicable – interior shading is not modeled for compliance.

Standard Design: Existing Buildings: No interior shades.

Dynamic Glazing Present

Applicability: All fenestration that has dynamic glazing.

Definition: This is a flag used for reporting purposes only. Dynamic glazing is not modeled directly in compliance software.

Units: Boolean.

Input Restrictions: None.

Standard Design: False (not present).

Standard Design: Existing Buildings: Not Applicable.

5.5.8 Below-Grade Walls

Below-Grade Wall Name

Applicability: All projects, optional input.

Definition: A unique name that keys the below-grade wall to the construction documents.

Units: Text: unique.

Input Restrictions: None.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed.

Below-Grade Wall Geometry

Applicability: All projects.

Definition: A geometric construct that describes the dimensions and placement of walls located below grade. Below-grade walls have soil or crushed rock on one side and interior space on the other side. Some simulation models take the depth below grade into account when estimating heat transfer so the geometry may include height and width.

Units: Data structure: below-grade wall geometry.

Input Restrictions: As designed.

Standard Design: The geometry of below-grade walls in the standard design building is identical to the below-grade walls in the proposed design.

Standard Design: Existing Buildings: Same as proposed.

Below-Grade Wall Construction

Applicability: All projects, required input.

Definition: A specification containing a series of layers that result in a construction assembly for the proposed design. The first layer in the series represents the outside (or exterior) layer and the last layer represents the inside (or interior) layer. See the building descriptors above for below-grade wall construction type.

Units: Data structure: construction assembly.

The construction can be described as a C-factor which is similar to a U-factor, except that the outside air film is excluded, or the construction can be represented as a series of layers, like exterior constructions.

Input Restrictions: The construction assembly, defined by a series of layers, must be equal to or more efficient than the mandatory R-value and C-factor requirements of Section 120.7 of the Energy Code for newly constructed buildings, and Section 141.0 of the Energy Code for alterations. Note that these requirements only apply when the slab floor connected to the below-grade wall is heated.

For newly constructed buildings, the inputs shall agree with the construction documents. Values for the C-factor shall be taken from Table 4.3.5, 4.3.6, or 4.3.7 of Reference Appendices, Joint Appendix JA4.

For alterations there are no restrictions.

Standard Design: For newly constructed buildings, see Table 13: Standard Design Building Below-Grade Wall Construction Assemblies. The standard design building shall use default values for C-factor. The height shall be the same as specified in the proposed design.

For below-grade walls, the standard design construction shall include the layers described in Appendix 5.7 and in the table below.

For alterations, the C-factor in the standard design shall be modeled as the more efficient of either the existing conditions, or the values stated above for newly constructed buildings standard design.

For below-grade walls, the alteration standard design assembly shall include the appropriate existing layers.

Standard Design: Existing Buildings: Same as proposed.

Table 12: Standard Design Building Below-Grade Wall Construction Assemblies

Construction	Layer	Thickness (inch)	Conductivity (Btu/h ft°F)	Density (lb./ft²)	Specific Heat (Btu/lb°F)	R-value (ft²·°F ·h/Btu)	C-factor (Btu/ft²·°F ·h)
NR	115 lb./ft³ CMU, solid grout	8	0.45	115	0.20	0.87	1.140
R-7.5 c.i.	115 lb./ft³ CMU, solid grout	8	0.45	115	0.20	0.87	
	R-10 continuous insulation	1.8	0.02	1.8	0.29	7.50	
	Total assembly					8.37	0.119
R-10 c.i.	115 lb./ft³ CMU, solid grout	8	0.45	115	0.20	0.87	
	R-10 continuous insulation	2.4	0.02	1.8	0.29	10.00	
	Total assembly					10.87	0.092
R-12.5 c.i.	115 lb./ft³ CMU, solid grout	8	0.45	115	0.20	0.87	
	R-10 continuous insulation	3.0	0.02	1.8	0.29	12.50	
	Total assembly					13.37	0.075

Source: California Energy Commission

5.5.9 Slab Floors in Contact with Ground

These building descriptors apply to slab-on-grade or below-grade floors that are in direct contact with the ground.

Slab Floor Name

Applicability: All slab floors, optional.

Definition: A unique name or code that relates the exposed floor to the construction documents.

Units: Text: unique.

Input Restrictions: None.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Slab Floor Type

Applicability: All slab floors, required.

Definition: One of two types and two subtypes of floors in contact with ground:

1) Heated slab-on-grade floors,
2) Unheated slab-on-grade floors
3) Heated below-grade floors
4) Unheated below-grade floors.

Heated slab-on-grade floors include all floors that are heated directly in order to provide heating to the space. Unheated slab-on-grade floors are all other floors in contact with ground.

Units: List: restricted to the four selections listed above.

Input Restrictions: None.

Standard Design: The slab for type is unheated (either unheated slab-on-grade for slab-on-grade floors or unheated below-grade for below-grade floors).

Standard Design: Existing Buildings: Same as proposed.

Slab Floor Geometry

Applicability: All slab floors, required.

Definition: A geometric construct representing a slab floor in contact with the earth.

The geometric representation can vary depending on how the energy simulation compliance software models slabs-on-grade. Some models require that only the perimeter of the slab be entered. Other models divide the slab into a perimeter band within 2 ft of the edge and the interior portion or core area, such that the perimeter area and the core area sum to the total area of the slab.

Units: Data structure: surface.

This may include area, perimeter exposed.

Input Restrictions: None.

Standard Design: The geometry of the slab floor in the standard design building is identical to the slab floor in the proposed design.

Standard Design: Existing Buildings: Same as proposed.

Slab Floor Construction

Applicability: All slab floors, required.

Definition: A specification containing a series of layers that result in a construction assembly for the proposed design.

The first layer in the series represents the outside (or exterior) layer and the last layer represents the inside (or interior) layer. See the building descriptors above for slab floor construction type.

A description of how the slab is insulated (or not)

How the construction is described will depend on the energy simulation model. The construction can be represented by an F-factor that represents the entire construction (floor and insulation).

Simple models may include just an F-factor, representing an instantaneous heat loss/gain to outside air. The F-factor could be related to the configuration of insulation in the proposed design. Other slab loss models may require that the surface area of the slab floor be divided between the perimeter and the interior. The insulation conditions then define heat transfer between both outside air and ground temperature.

The insulation condition for slabs includes the R-value of the insulation and the distance it extends into the earth at the slab edge and how far it extends underneath the slab.

Units: F-factor from Reference Appendices, Joint Appendix JA4; this is one selection from list 1 and one selection from list 2. Note that some combinations from list 1 and list 2 are not allowed, see Reference Appendices, Joint Appendix JA4 Table 4.4.8 and Table 4.4.7 for details.

List 1:

- None / 12 in vertical
- 12 in horizontal / 24 in vertical
- 24 in horizontal / 36 in vertical
- 36 in horizontal / 48 in vertical
- 48 in horizontal / Fully insulated slab

List 2:

- R-0 / R-20 / R-45
- R-5 / R-25 / R-50
- R-7.5 / R-30 / R-55
- R-10 / R-35
- R-15 / R-40

The compliance software shall also provide the following slab insulation options:

- Horizontal+Vertical, R-5 vertical down to the horizontal insulation and R-5 horizontal insulation extending 4 feet inwards from the perimeter
- Horizontal+Vertical, R-10 vertical down to the horizontal insulation and R-7 horizontal insulation extending 4 feet inwards from the perimeter

These two combinations of slab insulation are mapped to an F-factor in Appendix 5.4B.

Input Restrictions: The construction assembly, defined by an F-factor, must be equal to or more efficient than the mandatory F-factor requirements of Section 120.7 of the Energy Code for newly constructed buildings, and Section 141.0 of the Energy Code for alterations.

For newly constructed buildings, F-factors shall be taken from Table 4.4.8 of Reference Appendices, Joint Appendix JA4 for heated slab floors and Table 4.4.7 for unheated slab floors. For all methods, inputs shall be consistent with the construction documents. For heated slab floors, the F-factor shall be determined by the mandatory R-value and installation requirements in Section 110.8 of the Energy Code. That information is used in Table 4.4.8 of Reference Appendices, Joint Appendix JA4 to determine the required F-factor. The same requirements apply for alterations.

Standard Design: Slab loss shall be modeled with the simple method (F-factor).

The standard design construction shall include the following layer:

Layer 1: Concrete 140lb/ft^3 – 6 in. (R - 0.44)

The standard design shall include no insulation, equivalent to an F-factor of 0.73.

For alterations, the F-factor in the standard design shall be modeled as the more efficient of either the existing conditions, or the values stated above for newly constructed buildings standard design.

Standard Design: Existing Buildings: Same as proposed.

5.5.10 Heat Transfer between Thermal zones

PARTITION NAME

Applicability: All partitions, optional.

Definition: A unique name or code that relates the partition to the construction documents.

Units: Text: unique.

Input Restrictions: The text should provide a key to the construction documents.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

PARTITION GEOMETRY

Applicability: All partitions.

Definition: A geometric construct that defines the position and size of partitions that separate one thermal zone from another.

The construct shall identify the thermal zones on each side of the partition. Since solar gains are not generally significant for interior partitions, the geometry of partitions is sometimes specified as an area along with identification of the thermal zones on each side.

Units: Data structure: surface with additional information identifying the two thermal zones that the partition separates.

Input Restrictions: No restrictions other than agreement with the construction documents.

Standard Design: The geometry of partitions in the standard design building shall be identical to the proposed design.

Standard Design: Existing Buildings: Same as proposed.

PARTITION CONSTRUCTION

Applicability: All partitions.

Definition: A description of the construction assembly for the partition.

Units: Data structure: construction assembly.

Input Restrictions: As designed.

Standard Design: Partitions in the standard design shall be steel framed walls with 5/8-inch gypsum board on each side. For walls, partitions in the standard design building shall be steel-framed walls with 5/8-inch gypsum board on each side. For interior floors and ceilings, standard design construction shall be a metal deck, 4 inches of heavyweight (140 lb./ft^3) concrete, and 3/4" thick carpet.

Standard Design: Existing Buildings: Same as proposed.

DEMISING PARTITION CONSTRUCTION

Applicability: All demising walls and demising partitions (ceilings, floors) that separate conditioned spaces from unconditioned spaces.

Definition: A description of the construction assembly for the partition.

Units: Data structure: construction assembly.

Input Restrictions: As designed.

Standard Design: For walls, when the proposed design demising partition is metal-framed or other, the standard design shall be a metal-framed wall meeting the mandatory U-factor requirements of Section 120.7 (b) of the Energy Code.

For walls, when the proposed design demising partition is wood-framed, the standard design shall be a wood-framed wall with the opaque portions of the wall meeting the mandatory U-factor requirements of Section 120.7 (b) of the Energy Code.

For windows in demising walls, the fenestration area shall equal the fenestration area of the proposed design. The window U-factor for fenestration in demising walls shall equal the fixed window prescriptive U-factor requirement of 5.5.7. Neither solar heat gain nor daylighting through interior demising windows will be modeled.

Demising ceiling partitions, separating conditioned space from unconditioned space and attics, shall be insulated to the same levels as exterior roofs in Chapter 5.5.3 Roofs. Demising floor partitions shall be insulated to the same levels as exterior floors in Chapter 5.5.5 Exterior Floors.

Standard Design: Existing Buildings: Demising ceiling partitions, separating conditioned space from unconditioned space and attics shall be insulated to the same levels as exterior roofs in Chapter 5.5.3 Roofs. Demising floor partitions shall be insulated to the same levels as exterior floors in Chapter 5.5.5 Exterior Floors.

5.5.11 Simplified Geometry Simulation Option

The compliance software may have an option to model a building with simplified two-dimensional (2D) geometry. This is an optional capability as an alternative to modeling the three-dimensional (3D) geometry of a building. If the compliance software only provides a 2D building model, the following features cannot be modeled:

- Daylighting controls and dimming
- Exterior shading or self-shading

All mandatory and prescriptive daylight controls must be present when submitting a compliance project using compliance software that only models a building with 2D geometry.

The compliance software must pass all reference method tests corresponding to 2D geometry to meet certification requirements as compliance software. Consult Appendix 3B of the *ACM Reference Manual* for additional information. The compliance software must pass the rule set implementation tests, and for the sensitivity tests that verify simulation accuracy, there are 2D tests specified for building envelope, but for other building components such as lighting and HVAC, the compliance software is compared against the results of the reference method, which uses a 3D geometry model.

The compliance software must have sufficient information to specify each exterior surface when modeling a building with 2D geometry. At a minimum, building surface azimuth, elevation, and area are required and the tilt, azimuth and area is specified for roof components. The model must use only vertical walls for the analysis. The model follows all other ACM requirements for space and zone definitions, lighting, and HVAC specifications, and follows the same rules for the standard design and proposed design constraints.

The model also requires the following explicit inputs from the user:

- Total Building Floor Count – the total number of floors
- Total Above Grade Floors – the total number of floors above grade, used in determination of multifamily classification

5.6 HVAC Zone Level Systems

This group of building descriptors relate to HVAC systems at the zone level. There is not a one-to-one relationship between HVAC components in the proposed design and the standard design since the standard design system is determined from building type, and size. The applicability of each building descriptor for each of the standard design systems is indicated in tables under the building descriptor standard design rules. Additions and alterations should follow the same requirements stated for newly constructed buildings proposed designs and newly constructed buildings standard designs unless otherwise noted in the descriptor.

5.6.1 General System Information

Count

Applicability: HVAC zone level systems.

Definition: The number of duplicate systems represented by the current system. All system attributes must be identical for multiple system assignment.

Units: None.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Design Supply Air Temperature (Cooling)

Applicability: HVAC zone level systems.

Definition: Design SAT in cooling for the zone.

Units: Deg F.

Input Restrictions: As Designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Design Supply Air Temperature (Heating)

Applicability: HVAC zone level systems.

Definition: Design SAT in heating for the zone.

Units: Deg F.

Input Restrictions: As Designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Net Cooling Capacity

Applicability: HVAC zone level systems.

Definition: Net cooling capacity of the zone system (one system if count>1), which includes all cooling to the zone but excludes any fan motor heat.

Units: Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design with adjustment to account for Standard Design fan heat. For all other cases, not applicable.

Net Heating Capacity

Applicability: HVAC zone level systems.

Definition: Net heating capacity of the zone system (one system if count>1), which includes all cooling to the zone but excludes any fan motor heat.

Units: Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design with adjustment to account for Standard Design fan heat. For all other cases, not applicable.

Supply Fan Capacity for Cooling

Applicability: HVAC zone level systems.

Definition: The supply fan flow rate when the zone requires cooling.

Units: cfm (for each mode).

Input Restrictions: Not applicable. The cooling airflow is set to be the same as the system design airflow.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Supply Fan Capacity for Heating

Applicability: HVAC zone level systems.

Definition: The supply fan flow rate when the zone requires heating.

Units: cfm (for each mode).

Input Restrictions: Not applicable. The heating airflow is set to be the same as the system design airflow.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Supply Temp Control

Applicability: HVAC zone level systems.

Definition: The method of controlling the system supply air temperature.

Units: List (Constant, reset by outside air, reset by demand).

Input Restrictions: No Supply Air Temperature Control.

Standard Design: No supply air temperature control.

5.6.2 Terminal Device Data

Terminal Type

Applicability: All thermal zones.

Definition: A terminal unit includes any device serving a zone (or group of zones collected in a thermal zone) that can vary airflow or reheat or recool or all three in response to the zone thermostat. This includes:

- None or Uncontrolled (applicable for single zone systems only)
- VAV reheat box
- VAV no-reheat box
- Series fan powered VAV box (with reheat)
- Parallel fan powered VAV box (with reheat)
- Dual duct mixing box (constant volume and VAV)
- Four-pipe VAV box
- Active Beam

Units: List (see above).

Input Restrictions: As designed.

Standard Design: See Chapter 5.1.3 HVAC System Map for a summary system types and terminal types used. All single-zone systems are assumed to use None or Uncontrolled.

For healthcare facilities, same as the Proposed Design.

Standard Design: Existing Buildings: Same as proposed design. For unaltered components; same as newly constructed buildings rules for new secondary systems or terminal units.

5.6.3 Terminal Heating

This group of building descriptors applies to proposed design systems that have reheat coils at the zone level. The building descriptors are applicable for standard design systems 5 and 6.

Terminal Heat Type

Applicability: Systems that have heating coils in the zone terminal unit.

Definition: The heating source for the terminal unit. This includes:

- Electric resistance
- Gas furnace
- Hot water

Units: List (see above).

Input Restrictions: For healthcare facilities electric resistance terminal heating is not allowed. For all others, as designed.

Standard Design: Hot water, when applicable.

For healthcare facilities, same as the Proposed Design except electric resistance is not allowed.

Terminal Heat Capacity

Applicability: Systems that have heating coils in the zone terminal unit.

Definition: The heating capacity of the terminal heating source.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: The compliance software shall automatically size the terminal heating gross capacity to be 25 percent greater than the design loads.

For healthcare facilities, same as the Proposed Design.

Reheat Delta T(ΔT_{reheat})

Applicability: Systems that have heating coils in the zone terminal unit.

Definition: This is an alternate method to enter the terminal heat capacity, which can be calculated as follows:

$$\Delta T_{reheat} = T_{reheat} - T_{cool\_supply}$$
$$\Delta T_{reheat} = Q_{coil} / 1.09 \times CFM$$

Where:

- $\Delta \boldsymbol{T_{reheat}}$ - Heat rise across the terminal unit heating coil F)
- $\boldsymbol{T_{reheat}}$ - Heating air temperature at design (F)
- $\boldsymbol{T_{cool\_supply}}$ - Supply air temperature at the heating coil (F)
- $\boldsymbol{Q_{coil}}$ - Heating coil load (Btu/h)
- $\boldsymbol{CFM}$ - Airflow (ft^3/min)

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed but may need to be increased if zone unmet load hours are greater than 150.

Standard Design: Method not used for standard design.

For healthcare facilities, same as the Proposed Design.

5.6.4 Terminal Cooling

This group of building descriptors applies to proposed design systems that have recool coils at the zone level. The building descriptors are applicable for standard design systems 14 and 15.

Terminal Cooling Type

Applicability: Systems that have heating coils in the zone terminal unit.

Definition: The cooling source for the terminal unit. This includes:

- Chilled Water

Units: List (see above).

Input Restrictions: As designed.

Standard Design: Chilled water, when applicable.

For healthcare facilities, same as the Proposed Design.

Terminal Cooling Capacity

Applicability: Systems that have heating coils in the zone terminal unit.

Definition: The Cooling capacity of the terminal heating source.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: The compliance software shall automatically size the terminal Cooling gross capacity to be 15 percent greater than the design loads.

For healthcare facilities, same as the Proposed Design.

5.6.5 Baseboard Heat

Baseboard Capacity

Applicability: All thermal zones.

Definition: Total heating capacity of the baseboard unit(s).

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Not applicable.

Baseboard Heat Control

Applicability: All thermal zones with baseboard heating.

Definition: Defines the control scheme of base board heating as controlled by a space thermostat.

Units: List (fixed as By Space Thermostat).

Input Restrictions: Controlled by space thermostat is the only type allowed if baseboard heating is used.

Standard Design: Not applicable.

Baseboard Heat Source

Applicability: All thermal zones with furnaces or baseboard heating at the zone.

Definition: Heating source.

Units: List

- Electric heat
- Gas furnace
- Hot water

Input Restrictions: Electric resistance baseboard shall not be used for healthcare facilities space heating unless it meets one of the exceptions to Section 140.4(g) in the Energy Code.

Standard Design: Not applicable, except for healthcare facilities, same as the Proposed Design.

5.6.6 Variable Refrigerant Flow (VRF) Zone Systems (Indoor Units)

The following inputs are required when zone systems are connected to a VRF system (condensing unit).

Acceptance Test Required

Applicability: VRF.

Definition: Flag if acceptance test is required.

Units: Boolean.

Input Restrictions: None.

Standard Design: Not applicable.

Supply Fan Capacity for Deadband

Applicability: VRF.

Definition: Identify the supply fan airflow rate in deadband (floating) mode.

Units: cfm (for each mode).

Input Restrictions: If the fan control is continuous, and if a multi-speed or variable speed fan is defined for the VRF fan coil, this will be set to the minimum fan flow. Otherwise, it is set to the design airflow.

If the fan control is Cycling, 0 cfm.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Auxiliary Power When On

Applicability: VRF.

Definition: The parasitic electrical energy use of the zone terminal unit when either terminal unit coil is operating.

Units: Watts or Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Auxiliary Power When Off

Applicability: VRF.

Definition: The parasitic electrical energy use of the zone terminal unit when the terminal unit coils are off.

Units: Watts or Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

Supply Fan Airflow Capacity Control

Applicability: VRF.

Definition: The supply fan airflow shall be capable of specifying one (constant volume), two, three, or variable speed control and power relationships for each fan unit.

Units: List: Subset of fan capacity control options: constant volume, two speed, three speed, and variable speed.

Input Restrictions: As designed. Minimum airflow capacity to be no less than 50% flow.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, not applicable.

5.6.7 Terminal Airflow

5.6.7.1 Variable Air Volume (VAV) Airflow

This group of building descriptors applies to proposed systems that vary the volume of air at the zone level.

Design Airflow

Applicability: Systems that vary the volume of air at the zone level.

Definition: The air delivery rate at design conditions.

Units: CFM.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For systems 5, 6, terminals and single zone systems the compliance software shall automatically size the terminal airflow to meet both:

- The standard design peak cooling load based on a supply-air-to-room-air temperature difference of 20°F for exterior zones or 15°F for interior zones, the required ventilation air from Table 120.1-A of the Energy Code, or makeup air, whichever is greater.
- The standard design peak heating load assuming a 95°F supply air temperature.

An exterior zone is a thermal zone that has any exterior walls and a non-zero amount of vertical exterior glazed fenestration (windows). Any zone that does not meet the definition of an exterior zone is an interior zone.

Terminal Minimum Airflow

Applicability: Systems that vary the volume of air at the zone level

Definition: The minimum airflow that will be delivered by a terminal unit.

Units: Unitless fraction of airflow

Input Restrictions: Input must be greater than or equal to the outside air ventilation rate.

For packaged VAV, built-up VAV, and built-up VAV with AWHP heating where the Control System Type Certified Guideline 36 Libraries specify that certified Guideline 36 libraries are not being used, the modeled minimum airflow shall be the maximum of 2 times the minimum airflow input and 2 times the minimum outside air ventilation rate.

For laboratories, users may input separate minimum rates for occupied and unoccupied. The unoccupied rates shall be used when the occupancy schedule indicates an occupancy fraction below 0.10.

Standard Design: For healthcare facilities, same as the Proposed Design. For systems 5 and 6, packaged VAV units and built-up VAV air handling units, set the minimum airflow to be the maximum of the minimum outside air ventilation rate or 10% of the design airflow.

For laboratories, the occupied minimum airflow fraction shall be fixed at a value equivalent to the greater of the proposed design occupied minimum exhaust requirements or the occupied minimum ventilation rate. The unoccupied minimum airflow fraction shall be 0.33 cfm/ft^2 less than the occupied minimum airflow fraction.

Terminal Heating Control Type

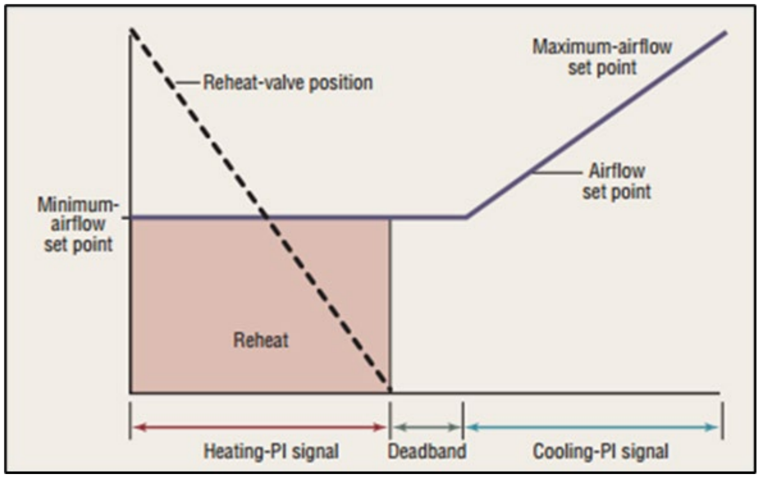
Applicability: VAV boxes with reheat

Definition: The control strategy for the heating mode.

Single Maximum:

In the single maximum control mode, the airflow is set to a minimum constant value in both the deadband and heating mode. This airflow can vary but is typically 30 to 50 percent of maximum. This control mode typically has a higher minimum airflow than the minimum used in the dual maximum below, resulting in more frequent reheat.

Figure 5: Single Maximum VAV Box Control



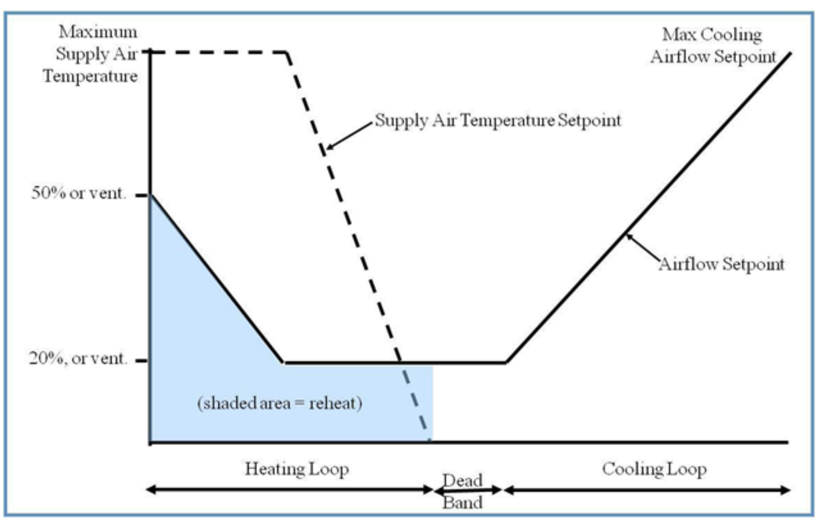
Source: California Energy Commission

Dual Maximum:

Raises the supply air temperature (SAT) as the first stage of heating and increases the airflow to the zone as the second stage of heating.

> The first stage of heating consists of modulating the zone supply air temperature setpoint up to a maximum setpoint no larger than 95°F while the airflow is maintained at the dead band flow rate.
>
> The second stage of heating consists of modulating the airflow rate from the dead band flow rate up to the heating maximum flow rate (50 percent of design flow rate or minimum ventilation rate whichever is greater).

Figure 6: Dual Maximum Control Sequence



Source: California Energy Commission

Units: List:

- Single maximum
- Dual maximum

Input Restrictions: Fixed at single maximum if control system type is not direct digital control (DDC) control to the zone level.

Standard Design: For healthcare facilities, same as the Proposed Design. For all other cases, dual maximum.

5.6.7.2 Fan Powered Boxes

Fan Powered Box Type

Applicability: Thermal zones that have fan powered boxes.

Definition: Defines the type of fan-powered induction box.

Units: List:

- Series
- Parallel

Input Restrictions: As designed.

Standard Design: Not applicable.

For healthcare facilities, same as the proposed design.

Terminal Fan Power

Applicability: Thermal zones that have fan powered boxes.

Definition: Rated power input of the fan in a fan-powered box.

Units: W/cfm.

Input Restrictions: As designed.

Standard Design: Not applicable.

For healthcare facilities, same as the Proposed Design.

Fan Powered Box Induced Air Zone

Applicability: Thermal zones that have fan powered boxes.

Definition: Zone from which a series or parallel fan-powered box draws its air.

Units: List: name of thermal zones included in the building model.

Input Restrictions: As designed.

Standard Design: Not applicable.

For healthcare facilities, same as the Proposed Design.

PARALLEL POWERED INDUCTION UNIT (PIU) INDUCTION RATIO

Applicability: Thermal zones that have fan-powered boxes.

Definition: Ratio of induction-side airflow of a fan-powered box at design heating conditions to the primary airflow.

Units: Ratio.

Input Restrictions: As designed.

Standard Design: Not applicable.

For healthcare facilities, same as the proposed design.

PARALLEL FAN BOX CONTROL METHOD

Applicability: Thermal zones that have parallel fan powered boxes.

Definition: The control scheme used to define when a parallel fan-powered box fans operate.

Units: List: Flow Fraction, Thermostat Offset.

Input Restrictions: None.

Standard Design: Not applicable.

For healthcare facilities, same as the proposed design.

PARALLEL FAN BOX FLOW FRACTION

Applicability: Thermal zones that have parallel fan powered boxes with 'Flow Fraction' control method.

Definition: If the primary airflow to the box is above this fraction, the parallel fan is off. If the fraction is set to 0, the fan will only run when there is a call for heating in the zone. Otherwise, the parallel box fan will run according to the system availability schedule, or if activated by night-cycle control.

Units: Ratio.

Input Restrictions: 0 to 1.

Standard Design: For System 15, 0.5.

For healthcare facilities, same as the proposed design.

5.6.8 Zone Exhaust

This group of building descriptors describes the rate of exhaust and the schedule or control for this exhaust. An exhaust system can serve one thermal zone or multiple thermal zones. Energy is summed for the exhaust system level, not the thermal zone level.

This chapter also contains unique inputs for kitchen exhaust systems that must meet requirements of Section 140.9 of the Energy Code.

Kitchen Exhaust Hood Length

Applicability: Exhaust fans in spaces of type kitchen, commercial food preparation.

Definition: The exhaust hood length.

Units: ft.

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Kitchen Exhaust Hood Style

Applicability: Exhaust fans in spaces of type kitchen, commercial food preparation.

Definition: The hood style as defined in Table 140.9-C of the Energy Code.

Units: List:

- Wall-mounted canopy
- Single island
- Double island
- Eyebrow
- Backshelf or Passover

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Kitchen Exhaust Hood Cooking Duty

Applicability: Exhaust fans in spaces of type kitchen, commercial food preparation.

Definition: The hood cooking duty as defined in Table 140.9-C of the Energy Code.

Units: List:

- Light-duty
- Medium-duty
- Heavy-duty
- Extra heavy-duty

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Exhaust Fan Name

Applicability: All thermal zones.

Definition: A reference to an exhaust fan system that serves the thermal zone.

Units: Text or other unique reference to an exhaust fan system defined in the secondary systems section.

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Exhaust Airflow Rate

Applicability: All thermal zones.

Definition: Rate of exhaust from a thermal zone.

Units: Cfm.

Input Restrictions: For nonresidential and hotel/motel spaces, Proposed exhaust airflow rate must meet the minimum exhaust requirements of Section 120.1(c)4 for applicable spaces in Table 120.1-B.

For laboratory spaces and zones, the design exhaust airflow rate is specified by the user, but a warning shall be posted if less than 1 cfm/ft^2.

Standard Design: Same as the proposed design but not above the maximum of the standard design exhaust rates listed in Appendix 5.4A for spaces that do not include covered processes. Exception for buildings with over 5,000 cfm of kitchen exhaust; the standard design is a function of the kitchen exhaust hood length, kitchen exhaust hood style, and kitchen exhaust hood cooking duty, and is determined by Title 24 Energy Code, Table 140.9-A.

For lab exhaust systems, the standard design exhaust flow rate is the same as the proposed.

For healthcare facilities, same as the Proposed Design.

Zone Exhaust Minimum Airflow Rate

Applicability: All laboratory zones.

Definition: Minimum rate of exhaust from a zone.

Units: cfm/ft^2.

Input Restrictions: As designed for non-process zones.

For laboratory zones, the exhaust airflow rate is the maximum of the hood scheduled exhaust airflow rate and the minimum ventilation rate. A warning is posted if the minimum exhaust rate is 2 ACH or less. Users shall have the capability to input separate rates for occupied and unoccupied.

Standard Design: For laboratory systems the occupied exhaust minimum airflow rate is the proposed design occupied minimum exhaust airflow rate. The unoccupied exhaust minimum airflow rate is the proposed design unoccupied minimum exhaust airflow rate.

Exhaust Fan Schedule

Applicability: All thermal zones.

Definition: Schedule indicating the pattern of use for exhaust air from the thermal zone.

Units: Data structure: schedule, fraction.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group for the building floor or zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

Exhaust schedules for commercial kitchen exhaust and laboratory processes are prescribed in Appendix 5.4B. For laboratory systems the compliance software shall automatically use either the manual sash control or auto sash control laboratory variable exhaust schedule or a volume-weighted interpolated average of the two schedules if only a fraction of the exhaust hoods have automatic sash control.

Standard Design: Same as the proposed design for non-covered process spaces.

Exhaust schedules for kitchen exhaust hoods are prescribed and specified in Appendix 5.4B.

For laboratory spaces, the standard design is variable volume. If the proposed laboratory space is fume hood intense (as defined in Table 140.9-D of the Energy Code) then the standard design will use a modified VAV schedule for hoods with sash controls, volume-weighted by the fraction of exhaust that is served by exhaust hoods with vertical-only sashes. If the proposed space is not fume hood intense then the standard design shall use the VAV exhaust schedule for manual sash control.

For healthcare facilities, same as the proposed design.

Exhaust Fan Fraction Sash Control

Applicability: Zones with laboratory exhaust hoods with vertical sashes.

Definition: The airflow-weighted fraction of exhaust hoods with vertical sashes that have automatic sash controls. This input is needed to appropriately model cases where only a fraction of the exhaust hoods that have automatic sash controls.

Units: Fraction.

Input Restrictions: As Designed (between 0 and 1).

Standard Design: 1 if sash controls are required for the laboratory space (per Table 140.9-D of the Energy Code).

For healthcare facilities, same as the Proposed Design.

Standard Design: Existing Buildings: As Designed (between 0 and 1).

Exhaust Source

Applicability: Zones with exhaust system.

Definition: The source of exhaust makeup air.

Units: List.

- Transfer From Adjacent Zones – assumes the exhaust makeup air is provided as outside air by a system either directly to the local zone or from adjacent zones by transfer openings. This option does not change the user's model or impact the simulation.
- Direct Outside Air – indicates a louver or other means of allowing untempered, outside air to enter from the exterior to make up for the exhaust. This results in the zone exhaust air to be modeled with an equivalent amount of outdoor air infiltrated into the zone in the simulation.

Input Restrictions: As designed, but if the total outside air brought into the building floor is less than the total exhaust air of the same building floor the compliance software should add infiltration to the zone with exhaust system.

Standard Design: Same as the Proposed Design.

Standard Design: Existing Buildings: As Designed.

5.6.9 Outdoor Air Ventilation

VENTILATION SOURCE

Applicability: All thermal zones.

Definition: The source of ventilation for a thermal zone. The choices are:

None (ventilaion not provided directly to the zone)tNatural (by operable openings)tForced (by fan)

Units: List: None, Natural, or Forced.

Input Restrictions: For hotel/motel guest rooms, can be 'Natural' or 'Forced'.

For all other occupancies, must be 'Forced'.

Standard Design: For hotel/motel guest rooms, same as the proposed.

For other occupancies, "Forced" if the proposed design is also "Forced", otherwise "None".

VENTILATION STANDARD

Applicability: Thermal zones with special ventilation requirements, such as a process space, which have no defined requirements in Title 24.

Definition: Minimum ventilation rates for:

Title 24 (default)
Other

Units: List: See above.

Input Restrictions: None.

User should be prepared to show justification for not using Title 24 ventilation source. If 'Other' is used, the user must enter a description of which standard applies, such as OSHPD3, Animal Shelter, etc.

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as proposed.

DESIGN VENTILATION RATE

Applicability: All thermal zones.

Definition: The quantity of ventilation air that is provided to the space for the specified thermal zone at the design condition.

Units: CFM.

Input Restrictions:

As defined by the user.

To accommodate transfer air requirements for makeup air for exhaust from other zones, the design ventilation rate may be between 95 percent and 110 percent of code required ventilation rates for a building floor before simulated energy usage is effected.

If any space ventilation rate is below 95% of the code required ventilation rate, additional ventilation must be provided to other spaces on the same building floor to meet the transfer air requirements, that is, the total design ventilation flow rates for all spaces on a building floor must be equal or greater than 95% of the code required ventilation rates.

If the ventilation source is natural ventilation for hotel/motel guestroom spaces, then the proposed design ventilation will be modeled as infiltration.

Standard Design: For labs and healthcare facilities, same as the Proposed Design.

If the total design ventilation rate of the building floor does not exceed 110% of the total ventilation requirement, then the standard design outside air ventilation rate shall be the same as the proposed. If the proposed ventilation rate exceeds the limit above, the standard design ventilation rate for each space shall be the proposed rate uniformly reduced such that the total ventilation air delivered to the building floor is equal to the maximum allowed ventilation air rate:

$\text{Design Ventilation Rate}_{std} = \text{Design Ventilation Rate}_{prop} \times (\text{BFVent}_{std} / \text{BFVent}_{prop})$

Where:

BFVent_{std} is the building floor ventilation requirement, as described in the descriptor below, and

BFVent_{prop} is the building floor design ventilation flow for the proposed design.

Standard Design: Existing Buildings: Same as the proposed, if unaltered. If space type is altered such that different ventilation rate requirements apply, the outside air ventilation rate should follow the same rules as for newly constructed buildings.

BUILDING FLOOR VENTILATION REQUIREMENT

Applicability: Internal variable, calculated for each building floor.

Definition: The total outside air ventilation airflow requirement for all spaces on a building floor.

This is calculated by summing the ventilation levels for each space and comparing it to the minimum required ventilation rate and the design exhaust airflow requirements.

Units: cfm (ft^3/min).

Input Restrictions: Not a user input; derived by summing the ventilation and exhaust airflows from all spaces on the building floor.

Standard Design: For labs and healthcare facilities, same as the Proposed Design.

For all other spaces:

This is calculated by the following procedure:

- Calculate the proposed ventilation for the building floor as the sum of design ventilation flow for each space included on a building floor, including all conditioned spaces except space designated as lab space.
- Calculate the proposed exhaust for the building floor as the sum of design exhaust flow for each space on the building floor, including all conditioned spaces except spaces designated as lab space.
- Calculate the code minimum ventilation requirement as the sum of all minimum required ventilation airflows, as defined by Appendix 5.4A, for all spaces in the building floor.
- Calculate the code minimum exhaust requirement as the sum of all minimum required exhaust airflows, as defined by Appendix 5.4A, for all spaces in the building floor.
- If the proposed exhaust is greater than the code minimum ventilation rate, then:
    - Total standard design building floor ventilation requirement shall be: Standard ventilation = Min (proposed ventilation, code minimum exhaust x 1.2)

Otherwise:

- Standard ventilation = Min (code minimum ventilation x 1.1, proposed ventilation)

MINIMUM VENTILATION RATE

Applicability: All thermal zones that have variable ventilation control.

Definition: The minimum quantity of ventilation air that must be provided to the space when it is occupied.

Units: cfm (ft^3/min).

Input Restrictions: As designed but not lower than code minimum (default value).

The default value shall be the conditioned floor area times the applicable ventilation rate from Appendix 5.4A unless the exception for designed occupancy is used where the larger of 15 cfm times the number of occupants or conditioned floor area times the applicable ventilation rate.

For spaces where demand control ventilation is installed, the minimum ventilation rate is specified by the greater of the rate in Table 120.1-A or 15 cfm times the scheduled occupancy for that hour.

For hotel/motel guestroom spaces where the proposed design ventilation source is natural ventilation, the minimum ventilation rate will be modeled as infiltration.

Standard Design: For labs and healthcare facilities, same as the Proposed Design.

For spaces where demand control ventilation is required, the minimum ventilation rate is specified by the greater of the rate in Appendix 5.4A or 15 cfm times the scheduled occupancy for that hour.

VENTILATION CONTROL METHOD

Applicability: All thermal zones

Definition: The method used to determine outside air ventilation needed for each hour in the simulation.

This information is reported to the system serving the zone. The method of controlling outside air at the system level in response to this information is discussed under secondary systems. Options at the zone level are:

- CO2 sensors in the space: The outside air is varied to maintain a maximum CO2 concentration in the space. This shall be approximated by multiplying the ventilation rate per occupant times the number of occupants for that hour. (When turnstile counts are used to automatically adjust ventilation levels based on occupancy, this method may also be used.)

Fixed ventilation rate: Outside air is delivered to the zone at a constant rate and is equal to the design ventilation rate (see above).

Units: List (see above)

Input Restrictions: As designed. If the space includes a design occupant density greater than or equal to 25 persons per 1,000 ft^2, and the system includes an airside economizer, or if the design airflow rate for the system exceeds 3,000 cfm, the input is restricted to CO2 sensors in the space.

Note: a classroom space greater than 750 ft^{2}must have an occupancy sensor for ventilation control and setback to meet the mandatory Title 24 Energy Code requirements of Section 120.2(e)3. This requirement should be indicated on the appropriate compliance form submittal.

Standard Design: For healthcare facilities, same as the Proposed Design.bIf the default occupancy for the specified space function from Appendix 5.4B is greater than or equal to 25 persons per 1,000 ft^2 and the system includes an airside economizer, set control method to CO2 sensors in the space. Otherwise, set to fixed ventilation rate.

DEMAND CONTROL VENTILATION (DCV) MINIMUM VENTILATION SCHEDULE

Applicability: All projects.

Definition: The DCV minimum schedule modifies the ventilation airflow rate for a given space based on the controllability of a ventilation system and the allowance of the energy standard for the space to modulate outdoor air. The schedule is dependent on the occupancy schedule for a space type and shall include a lower limit to airflow based on spaces where minimum ventilation air has a lower limit greater than 0.

Units: Data Structure: schedule, fractional.

Input Restrictions: The DCV minimum ventilation schedule is prescribed for California compliance based on a space type.

Standard Design: DCV minimum ventilation schedules shall be used in all spaces where DCV is a mandatory requirement. DCV minimum ventilation schedules can be different between the proposed and standard design buildings based on a proposed building adopting DCV control in spaces the energy standard does not require.

Standard Design: Existing Buildings: Same as proposed.

5.7 HVAC Secondary Systems

This group of building descriptors relate to the secondary HVAC systems. There is not a one-to-one relationship between secondary HVAC system components in the proposed and standard design since the standard design system is determined from building type, size, and number of floors. The standard design for a given building descriptor indicates the appropriate value for each applicable system type.

5.7.1 Basic System Information

HVAC System Name

Applicability: All system types.

Definition: A unique descriptor for each HVAC system.

Units: Text, unique.

Input Restrictions: When applicable, input should match the tags that are used on the plans.

Standard Design: None.

Standard Design: Existing Buildings: None.

System Type

Applicability: All system types.

Definition: A unique descriptor which identifies the HVAC system type. The System Type indicates the cooling and heat source, and whether the system serves a single zone or multiple zones.

Units: List from the choices below.

Input Restrictions:

PTAC – Packaged Terminal Air Conditioner

PTHP – Packaged Terminal Heat Pump

SZAC – Single-zone Air Conditioner

SZHP – Single-zone Heat Pump

SZDFHP – Single-zone Dual Fuel Heat Pump

PVAV* – Packaged Variable Air Volume (VAV) with Reheat

VAV* – Built-up VAV with Reheat

SZVAV-AC – Single Zone VAV Air Conditioner

SZVAV-HP – Single Zone VAV Heat Pump

SZVAV-DFHP – Single Zone VAV Dual Fuel Heat Pump

HV – Heating and Ventilation Only

CRAC – Computer Room Air Conditioner

CRAH – Computer Room Air Handler

FPFC – Four-pipe Fan Coil

WSHP – Water-source Heat Pump

SPVAC – Single package vertical air conditioner

SPVHP – Single package vertical heat pump

DOASVAV – Dedicated Outdoor Air System with Variable Air Volume Airflow

DOASCAV – Dedicated Outdoor Air System with Constant Air Volume Airflow

Chilled Beam – Active or Passive chilled beams

Dual Duct – Mixing box (constant volume and VAV)

* Choice includes series and parallel fan-powered boxes as zone terminal units

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, based on the prescribed system type in the HVAC system map (see Chapter 5.1.3 HVAC System Map).

SYSTEM CONFIGURATION

Applicability: Computer room air conditioner.

Definition: A unique descriptor which identifies the system class and configuration. This descriptor is used to determine the minimum system efficiency. The valid options are:

- Floor-Mounted (Downflow)
- Floor-Mounted (Upflow – Ducted)
- Floor-Mounted (Upflow - Nonducted)
- Floor-Mounted (Horizontal)
- Ceiling-Mounted (Ducted Discharge and Ducted Return)

- Ceiling-Mounted (Ducted Discharge and Free Air Return)
- Ceiling-Mounted (Free Air Discharge and Ducted Return)
- Ceiling-Mounted (Free Air Discharge and Free Air Return)

Units: None.

Input Restrictions: None.

Standard Design: When the standard design system is a computer room air conditioner the configuration is ‘Floor-Mounted (Downflow)’.

5.7.2 System Controls

5.7.2.1 Control System Type

Control System Type

Applicability: All HVAC systems that serve more than one control zone, as well as the hydronic systems that serve building HVAC systems.

Definition: The type of control system for multi-zone HVAC systems and their related equipment.

This input affects the proposed design system specification for zone level controls, supply air temperature reset controls, ventilation controls and fan and pump static pressure part-load curves. See the following building descriptors:

- Ventilation control method
- Terminal heating control type
- Pump part-load curve
- Fan part-load curve
- Optimal start

Units: List.

- Direct digital control (DDC) to the zone level – DDC systems with control to the zone level.
- Other – other control systems, including pneumatic and DDC systems without control to the zone level.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, DDC control to the zone level.

5.7.2.2 Schedules

Air Handler Schedule

Applicability: All systems that do not cycle with loads.

Definition: A schedule that indicates when the air handler operates continuously.

Units: Data structure: schedule, on/off.

Input Restrictions: For healthcare facilities, the schedule is the same as the proposed design. For all nonresidential buildings, the schedule is based on the predominant schedule group for the building floor or zone. See Chapter 2.3.3 Space Use Classification Considerations for details. For multifamily buildings, see Chapter 6 Multifamily Building Descriptors Reference.

The fan schedules and HVAC operations are defined so that the air handlers provide the necessary outside air 1 hour prior to scheduled occupancy.

Standard Design: Same as the proposed design.

Air Handler Fan Cycling

Applicability: All fan systems.

Definition: This building descriptor indicates whether the system supply fan operates continuously or cycles with building loads when the HVAC schedule indicates the building is occupied. (See night cycle control input for fan operation during unoccupied hours.) The fan systems in most commercial buildings operate continuously.

Units: List continuous or cycles with loads.

Input Restrictions: As designed if the HVAC system serves zones with a dedicated outside air source for ventilation; otherwise, continuous.

Standard Design: For healthcare facilities, same as the Proposed Design. For air-to-water residential air conditioner, cycles with loads; continuous for all other standard design system types.

Optimal Start Control

Applicability: Systems with the control capability for flexible scheduling of system start time based on building loads.

Definition: Optimal start control adjusts the start time of the HVAC unit such that the space is brought to setpoint just prior to occupancy. Modeling input is used for reporting only and does not affect simulation results.

Units: Boolean (Yes/No).

Input Restrictions: Fixed at yes if control system type is DDC to the zone level; otherwise, as designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, fixed at yes if control system type is DDC to the zone level.

Night-Cycle HVAC Fan Control

Applicability: All air systems – not applicable for zone systems.

Definition: The control of an HVAC system that is triggered by the heating or cooling temperature setpoint for thermal zones during periods when the heating, cooling and fan systems are scheduled to be off. For this control, the space is controlled to the setback or setup temperature only; this control is not equivalent to a night purge control. The choices are:

- Cycle on call from any zone
- Cycle on call from the primary control zone
- Stay off
- Cycle zone fans only (for systems with fan-powered boxes). Restart fans below given ambient temperature.
- Cycle on any cooling
- Cycle on any heating

Units: None.

Input Restrictions: For multi-zone systems, 'Cycle on call from any zone', except for systems with fan-powered boxes, where either 'Cycle on call from any zone' or 'Cycle zone fans only' is allowed. For DOAS, 'Stay off' unless the DOAS is identified as a heating or cooling system for any zone. For single-zone heating/cooling systems, 'Cycle on call from primary zone'.

Standard Design: For healthcare facilities, same as the Proposed Design. For multi-zone systems, 'Cycle on call from any zone'. For single-zone heating/cooling systems, 'Cycle on call from primary zone'.

Certified Guideline 36 Libraries

Applicability: Packaged VAV, built-up VAV and built-up VAV with AWHP heating with Control Type DDC to the zone.

Definition: Indicates whether certified ASHRAE Guideline 36 programming libraries are used in proposed HVAC control system design.

The input affects the proposed design system specification for zone level controls and fan static pressure part-load curves. See the following building descriptors:

- Terminal minimum airflow
- Fan part-load curve

Units: Boolean

Input Restrictions: None

Standard Design: Not applicable

5.7.2.3 Supply Air Temperature Control

Cooling Supply Air Temperature

Applicability: All cooling systems.

Definition: The supply air temperature setpoint at design cooling conditions.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, 15°F below the space temperature setpoint for interior zones that are served by multiple zone systems and for computer rooms without air containment (where space temperature equals return air temperature); for all other zones, 20°F below the space temperature. Setpoint

Heating Supply Air Temperature

Applicability: All heating systems.

Definition: The supply air temperature leaving the air handler when the system is in a heating mode (not the air temperature leaving the reheat coils in VAV boxes).

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, 95°F for all system types with heating, except 60°F for multiple zone systems; no heating for data centers and computer rooms.

Supply Air Temperature Control

Applicability: All cooling or heating systems or both.

Definition: The method of controlling the supply air temperature. Choices are:

- No control –For this scheme the coils cycle on/off based on control zone thermostat signal for heating/cooling. There is no controller to maintain a specific supply air temperature (SAT).
- Fixed - The coils cycle on/off to maintain a constant SAT setpoint.
- Warmest Reset – Resets the cooling supply air temperature of a central forced air HVAC system according to the cooling demand of the warmest zone.
- Outside air dry-bulb temperature –The SAT is adjusted based on the outdoor air temperature. The SAT is varied linearly between the max/min limits in proportion to the outside air max/mix limits, and constant above/below the outside air limits.
- Scheduled setpoint –The coils cycle on/off to maintain a SAT setpoint specified by schedules.

Units: List (see above).

Input Restrictions: Warmest zone reset controls not applicable for single-zone systems. Otherwise, as designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, for standard design systems 1 through 4 and 7 through 13, the SAT control is No Control. For systems 5, 6 and 15 the SAT control shall be reset by warmest reset.

Reset Schedule by Outdoor Air Temperature

Applicability: When the proposed design resets SAT by outside air dry-bulb temperature.

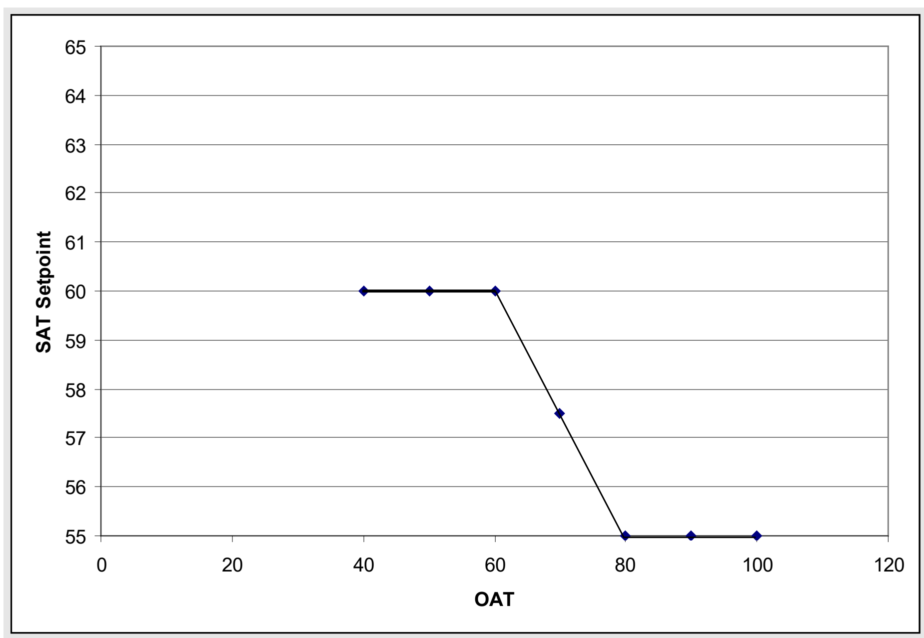
Definition: A linear reset schedule that represents the SAT setpoint as a function of outdoor air dry-bulb temperature.

This schedule is defined by at minimum the following four data points (see Figure 7: SAT Cooling Setpoint Reset Based on Outdoor Air Temperature (OAT)):

- The coldest supply air temperature
- The corresponding (hot) outdoor air dry-bulb setpoint
- The warmest supply air temperature
- The corresponding (cool) outdoor air dry-bulb setpoint

There may be one reset schedule for the system, or may be individual reset schedules for heating and cooling coils, as may be the case for DOAS systems.

Figure 7: SAT Cooling Setpoint Reset Based on Outdoor Air Temperature (OAT)



Source: California Energy Commission

Units: Data structure (two matched pairs of SAT and OAT, see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Dual Setpoint Supply Air Temperature Control

Applicability: All cooling and/or heating systems. This strategy is most applicable to ventilation only (DOAS) systems with tempering coils and/or heat recovery.

Definition: The maximum and minimum supply air temperature setpoints for the system. Cooling coils will be energized to maintain the system supply air temperature at the maximum setpoint, and heating coils will be energized to maintain the setpoint at the minimum temperature. If the mixed air temperature of the system is between these two values, the coils are not energized and the supply air temperature “floats” within this range.

Units: Data structure (a pair of minimum and maximum supply air temperatures).

Input Restrictions: As designed.

Standard Design: Same as proposed design for systems with DOAS.

5.7.3 Fan and Duct Systems

5.7.3.1 Standard Design Fan System Summary

The standard design fan system is summarized in this chapter. See Chapter 5.1.3 HVAC System Map, for the HVAC standard design system mapping. At the end of the Fans, General section below, the standard design fan power allowance and available credits is described. There are also sections on Supply, Return/Relief, and Exhaust systems with additional guidance.

5.7.3.2 Fans, General

The following descriptors are common to all fans.

FAN MODELING METHOD

Applicability: All fan systems.

Definition: Fans can be modeled in one of three ways. The simple method is for the user to enter the electric power per unit of flow (W/cfm). This method is commonly used for zonal equipment and other small fan systems. A more detailed method is to model the fan as a system whereby the static pressure, fan efficiency, part-load curve, and motor efficiency are specified at design conditions. A third method is to specify brake horsepower at design conditions instead of fan efficiency and static pressure. This is a variation of the second method whereby brake horsepower is specified in lieu of static pressure and fan efficiency. The latter two methods are commonly used for VAV and fan systems with significant static pressure.

Units: List power-per-unit-flow, static pressure, or brake horsepower.

Input Restrictions: As designed.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, power-per-unit-flow.

FAN CONTROL METHOD

Applicability: All fan systems with supply or relief fans or both.

Definition: A description of how the supply (and return/relief) fan(s) are controlled.

The options include:

- Constant volume
- Variable-flow, inlet, or discharge dampers

- Variable-flow, inlet guide vanes
- Variable-flow, variable speed drive (VSD)
- Variable-flow, variable pitch blades
- Two-speed
- Three-speed

For variable-speed fans, the fan control method determines which part-load performance curve to use.

Units: List (see above).

Input Restrictions: As designed. The user shall not be able to select VSD with static pressure reset if the building does not have DDC controls to the zone level.

Standard Design: For healthcare facilities, same as the Proposed Design. Based on the prescribed system type. Refer to the HVAC System Map in 5.1.3.

FAN BRAKE HORSEPOWER

Applicability: All fan systems.

Definition: The design shaft brake horsepower of a fan.

This input does not need to be supplied if the supply fan power (kW or W/cfm) is supplied.

Units: Horsepower (hp).

Input Restrictions: As designed. Required if the fan modeling method is 'brake horsepower', otherwise this input is calculated for other methods.

The compliance software shall apply the following rule to ensure the proposed design bhp is consistent with the user input motor nameplate horsepower.

The user entered brake horsepower for the proposed design is compared against the next smaller standard motor size, as defined by Table 13: Minimum Nominal Efficiency for Electric Motors (Percent), from the user entered supply fan nameplate motor horsepower. The proposed design supply fan brake horsepower (bhp) is set to the maximum of the user entered or calculated bhp and 95 percent of the next smaller motor horsepower:

Proposed bhp = max(User bhp, 95 percent ×MHPi-1)

Where User bhp is the user entered supply fan brake horsepower:

MHPi is the proposed (nameplate) motor horsepower

MHPi-1 is the next smaller motor horsepower from the Standard Motor Size table.

For example, if the user entered fan brake horsepower is 18 and the proposed motor horsepower is 25, the next smaller motor horsepower from the table above is 20, and 95 percent of the next smaller motor horsepower is 19. Then, the brake horsepower in the proposed model should be 19.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, not applicable (the standard design maps to a HVAC system type, which has a power-per-unit-flow allowance based on the components in the given system type).

Standard Design: Existing Buildings: Same as proposed if existing and unaltered.

Fan Motor Horsepower

Applicability: All fan systems.

Definition: The motor nameplate horsepower of the supply fan.

Units: List: choose from standard motor sizes: 1/12, 1/8, ¼, ½, ¾, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200

Alternatively, the nameplate horsepower can be entered as a numeric value.

Input Restrictions: As designed.

This building descriptor is required for all fan power modeling methods.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, set to the standard motor efficiency for the nominal motor size, from NEMA standards, for calculated supply fan input power.

Standard Design: Existing Buildings: Same as proposed if existing and unaltered.

Fan Total Static Pressure

Applicability: All fan systems using the static pressure method.

Definition: The design total static pressure for the supply fan. This includes both the internal and external static pressure drop for an air handler.

Units: Inches of water column (in. H20).

Input Restrictions: As designed.

The design static pressure for the supply fan does not need to be specified if the supply fan power index or brake horsepower (bhp) is specified.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, not applicable.

Standard Design: Existing Buildings: Same as proposed if existing and unaltered.

Fan Efficiency

Applicability: All fan systems using the static pressure method.

Definition: The efficiency of the fan at design conditions; this is the static efficiency and does not include motor losses.

Units: Unitless.

Input Restrictions: As designed.

The supply fan efficiency does not need to be specified if the supply fan brake horsepower (bhp) is specified.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, 65%.

Not applicable for the four-pipe fan coil system.

Standard Design: Existing Buildings: Not applicable.

Motor Efficiency

Applicability: All fans.

Definition: The full-load efficiency of the motor serving the fan.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: For healthcare facilities with total system fan power less than 1 kW and system is not a DOAS, same as the Proposed Design. For all others, determined from Table 13: Minimum Nominal Efficiency for Electric Motors (Percent) using the nameplate motor size.

Existing Buildings: Same as proposed.

Table 13: Minimum Nominal Efficiency for Electric Motors (Percent)

Motor Horsepower	Efficiency (%)
1	85.5
1.5	86.5
2	86.5
3	89.5
5	89.5
7.5	91.7
10	91.7
15	92.4
20	93.0
25	93.6

30	93.6
40	94.1
50	94.5
60	95.0
75	95.4
100	95.4
125	95.4
150	95.8
200	96.2
250	96.2
300	96.2
350	96.2
400	96.2
450	96.2
500	96.2

Source: California Energy Commission

MOTOR POSITION

Applicability: All fans.

Definition: The position of the supply fan motor relative to the cooling or heating air stream or both.

The choices are:

- in the air stream
- out of the air stream.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: In the air stream.

Fan Part-Flow Power Curve

Applicability: All variable flow fan systems.

Definition: A part-load power curve that represents the percentage full-load power draw of the supply fan as a function of the percentage full-load airflow.

The curve is typically represented as a quadratic equation with an absolute minimum power draw specified.

Units: Unitless ratio.

Input Restrictions: Prescribed, use curves in Appendix 5.7 based on fan control. When system 5, 6 or 15 is specified in the standard design and where the control system type specifies that certified guideline 36 libraries are not being used, the fan curve in the proposed design shall be fanVSDLimited SpResetPwrRatio_fCFMRatio.

The default fan curve shall be selected from Appendix 5.7 for the type of fan specified in the proposed design.

$$PLR = (a) + (b \times FanRatio) + (c \times FanRatio^2) + (d \times FanRatio^3)$$
$$PLR = PowerMin$$

Where:

$\boldsymbol{PLR}$ - Ratio of fan power at part load conditions to full load fan power
$\boldsymbol{PowerMn}$ - Minimum fan power ratio
$\boldsymbol{FanRatio}$ - Ratio of cfm at part-load to full-load cfm
$\boldsymbol{a, b, c, and\ d}$ - Constants from the table below

For exhaust fans modeled as zone fans, the part-flow power curve can be described by a curve from Appendix 5.7 for the type of fan specified, or as a linear curve.

Standard Design: For healthcare facilities with total system fan power less than 1 kW where system is not a DOAS, same as the Proposed Design. For all others, not applicable for standard design constant volume systems. The curve VSD with static pressure reset fans shall be used for variable volume systems. For exhaust fans, if a linear curve is used, the same fan curve, in the proposed design is used.

Fan Power Index

Applicability: Fan systems that use the power-per-unit-flow method.

Definition: The fan power (at the motor) per unit of flow.

Units: W/cfm.

Input Restrictions: As designed or specified in the manufacturers' literature.

Standard Design: For healthcare facilities with total system fan power greater than or equal to 1 kW and the system is not DOAS, power-per-unit-flow allowance based on the components in the proposed system according to 140.4(c)1 of the Energy Code. For healthcare facilities with DOAS and total system fan power less than 1 kW, 1.0 W/CFM. For all other health care facilities, same as Proposed Design.

For all other buildings:

- Residential air conditioner: 0.45 W/CFM

- Computer room air conditioner and computer room air handler systems: 0.58 W/CFM (approximate value of 27 W/kBtu-h of net sensible cooling capacity assuming design air flow rate is based on 20°F temperature differential between supply air and room air)
- System 15 – Parallel fan-powered box fan: 0.3 W/cfm.

Other systems: The fan electrical power input of the standard design will be based on which components are present in the given HVAC system type, and what the prescriptive fan power budget allows for each airflow range.

The standard design fan input electrical power will be determined by the system type and airflow range described in the table below:

Table 14: Total System Fan Power Allowance, in W/cfm by System Type

System No.	≤ 5,000 cfm	> 5,000 cfm; ≤ 10,000 cfm	> 10,000 cfm
3a – SZAC	0.802	0.780	0.748
3b – SZHP (no furnace)	0.744	0.720	0.676
3c – SZDFHP (with furnace)	0.802	0.780	0.748
7a – SZVAVAC	0.802	0.780	0.748
7b – SZVAVHP	0.744	0.720	0.676
7c – SZVAVDFHP (with furnace)	0.802	0.780	0.748
5 – PVAV	1.000	1.022	0.964
6 – VAV	0.977	1.013	0.947
9 – HEATVENT	0.616	0.620	0.605
15 – PVAVAWHP	1.000	1.022	0.964

Source: California Energy Commission

Standard Design: Existing Buildings: Same as proposed if existing and unaltered; otherwise use newly constructed buildings values with the following additional credits (includes supply and return/relief/exhaust):

Table 15: Additional System Fan Power Allowance, in W/cfm by System Type

System No.	≤ 5,000 cfm	> 5,000 cfm; ≤ 10,000 cfm	> 10,000 cfm
MZ-VAV (Systems 5 and 6)	0.205	0.174	0.159
All other (Systems 1, 3, 7, and 9)	0.209	0.182	0.162

Source: California Energy Commission

Fan Power Adjustment

Applicability: Any system with special requirements for filtration or other process requirements.

Definition: Additional system fan power related to application-specific filtration requirements or other process requirements.

An exceptional condition shall be included on compliance documentation when the user selects one of these adjustment conditions.

Units: List.

Input Restrictions: The user chooses one or more fan power adjustment credits from the list below. For the credits that are indicated as 'calculation required the user enters the pressure drop for each device.

Table 16: Adjustment Credits (Multi-zone VAV) (W/cfm)

Device	≤ 5,000 cfm	> 5,000 cfm; ≤ 10,000 cfm	> 10,000 cfm
Return of exhaust systems required by code to be fully ducted	0.089	0.100	0.116
Exhaust filters, scrubbers, or other exhaust treatment (calculation required, see note)	0.177	0.198	0.231
Particulate filtration credit: MERV 16 or greater and electronically enhanced filters	0.265	0.280	0.333
Carbon and other gas-phase air cleaners	0.176	0.188	0.224

Device	≤ 5,000 cfm	> 5,000 cfm; ≤ 10,000 cfm	> 10,000 cfm
(calculation required, see note)			
Biosafety cabinet (calculation required, see note)	0.177	0.198	0.231
Energy Recovery (included only if standard design requires heat recovery)	0.374	0.318	0.289

Source: California Energy Commission

Table 17: Adjustment Credits, All Other Fan Systems (W/cfm)

Device	≤ 5,000 cfm	> 5,000 cfm; ≤ 10,000 cfm	> 10,000 cfm
Return of exhaust systems required by code to be fully ducted	0.091	0.102	0.116
Exhaust filters, scrubbers, or other exhaust treatment (calculation required, see note)	0.179	0.202	0.232
Particulate filtration credit: MERV 16 or greater and electronically enhanced filters	0.264	0.292	0.342
Carbon and other gas-phase air cleaners (calculation required, see note)	0.177	0.197	0.231
Biosafety cabinet (calculation required, see note)	0.179	0.202	0.232
Energy Recovery (Included only if	0.381	0.329	0.293

Device	**≤ 5,000 cfm**	**> 5,000 cfm; ≤ 10,000 cfm**	**> 10,000 cfm**
standard design requires heat recovery)			
Single Zone VAV Systems that are capable of turning down to 50% of full load airflow at a maximum of 30% design wattage	0.070	0.100	0.089

For any row with "calculation require," include a field that allows the user to enter static pressure and multiply by the value in the cell. The value in the cell is based on 1.0 in. w.c. pressure drop.

Source: California Energy Commission

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as proposed for new HVAC equipment; not applicable for existing, unaltered systems.

Fan Energy Index (FEI)

Applicability: All fans with a motor nameplate horsepower greater than 1.00 hp or with an electrical input power greater than 0.89 kW.

Definition: FEI is a ratio of the baseline electrical power divided by the fan's actual electrical input power calculated in accordance with ANSI/AMCA 208-18 Annex C.

This input is currently only used for mandatory minimum efficiency checks.

Units: Unitless ratio.

Input Restrictions: As designed.

The applicable fan shall have a FEI of 1.00 or higher. The applicable fan used for a variable-air-volume system that meets the requirements of Section 140.4(c)2 shall have an FEI of 0.95 or higher. If the fan FEI does not meet one of the requirements above, the compliance run shall fail unless the fan meets one of the EXCEPTIONs to Section 120.10(a).

Standard Design: Not applicable.

Mult-speed Fan Power Ratio

Applicability: Two- and three-speed fans.

Definition: The ratio of part-load power to full-load power at the given fan flow.

Units: Unitless.

Input Restrictions: Not input. Same as standard design.

Standard Design:

Two-speed fans: 30 percent power at 50 percent flow.

Three-speed fans: 51 percent power at 66 percent flow, 12 percent power at 33 percent flow.

5.7.3.3 Supply Fans

The standard design HVAC systems have supply fans.

Supply Fan Power Ratio

Applicability: All fan systems.

Definition: The standard design fan power requirements apply to all fans that operate at design conditions. To apportion the fan power to the supply, return/relief fan and exhaust fans, a ratio is defined that is the ratio of supply fan power to total system fan power.

Units: Unitless ratio.

Input Restrictions: Not a user input.

This is the ratio of the supply fan power to total system fan power, which includes supply, return/relief, and exhaust fans in zones served by a proposed HVAC system. If the proposed design does not have a return, relief or exhaust fan in the zones served by the system, this ratio is 1.0.

Standard Design: Same as proposed.

Standard Design: Existing Buildings: Same as proposed.

Supply Fan Design Airflow

Applicability: All fan systems

Definition: The airflow rate of the supply fan(s) at design conditions.

This building descriptor sets the 100 percent point for the fan part-load curve.

Units: CFM (ft^3/min)

Input Restrictions: As designed*

* For systems with DX cooling coils, the airflow is typically between 250 and 500 cfm/$ton_{cooling}$. If the compliance software simulation engine limits the final calculated cfm/$ton_{cooling}$ to a certain range, the compliance software shall inform the user of this limitation.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others,

The program shall automatically size the airflow at each thermal zone to meet the loads. The design airflow rate calculation for exterior zones shall be based on a 20°F temperature differential between supply air and room air and a 15°F temperature differential for interior zones served by multiple zone systems. The design supply airflow rate is the larger of the flow rate required to meet space conditioning requirements and the required ventilation flow rate.

For multi-zone systems, the supply fan design airflow rate shall be the system airflow rate that satisfies the coincident peak of all thermal zones at the design supply air temperature.

For systems with cooling coils, a 115% multiplier is applied to the autosized airflow rate to be consistent with the cooling coil sizing multiplier.

Fan Position

Applicability: All supply fans.

Definition: The position of the supply fan relative to the cooling coil.

The configuration is either:

- draw through (fan is downstream of the coil) or
- blow through (fan is upstream of the coil).

Units List (see above).

Input Restrictions: As designed.

Standard Design: Draw through.

5.7.3.4 Return/Relief Fans

The standard design HVAC systems has a return or relief fan if any of the zone(s) in the proposed design are served by HVAC systems with return or relief fan. If the standard design is required to include exhaust air heat recovery, and the proposed design does not include a return and/or a relief fan, the standard design will be modeled with a return fan.

Plenum Zone

Applicability: Any system with return ducts or return air plenum.

Definition: A reference to the thermal zone that serves as return plenum or where the return ducts are located.

Units: Text, unique.

Input Restrictions: As designed.

Standard Design: Not applicable.

Return Air Path

Applicability: Any system with return ducts or return air plenum.

Definition: Describes the return path for air.

Can be:

- ducted return,

- via plenum zone(s), or
- direct-to-unit.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For standard design systems, the return air path shall be direct-to-unit.

Return/Relief Fan Power Ratio

Applicability: All thermal zones.

Definition: This is the ratio of the return or relief fan power divided by the total system fan power for the thermal zone. If the proposed design does not have a return or relief fan in the zones served by the system, this ratio is 0.0. This ratio is used to apportion the standard design fan power allowance to the standard design return/relief fan in a similar manner as the proposed design.

Units: Unitless ratio.

Input Restrictions: As designed, not a user input.

Standard Design: Same as proposed. When compliance scope does not include Mechanical, or includes Partial Mechanical and a zone is specified as 'HVAC Is Unknown', the return/relief fan power ratio shall be 0.

Standard Design: Existing Buildings: Same as proposed.

Return/Relief Fan Design Airflow

Applicability: All systems with a return or relief fan

Definition: The design airflow fan capacity of the return or relief fan(s).

This sets the 100 percent fan flow point for the part-load curve (see below).

Units: Cfm

Input Restrictions: As designed

Standard Design: For healthcare facilities, same as the Proposed Design. Otherwise, if the standard design has a return or relief fan, the design airflow will be equal to the standard design supply fan airflow less the system minimum outdoor air, or 90% of the standard design supply fan airflow, whichever is larger.

5.7.3.5 Exhaust Fans

The standard design shall track the proposed design exhaust flow rate up to the prescribed outside exhaust rate by space type (see Appendix 5.4A for the standard design maximum exhaust rate). Covered process exhaust includes garage ventilation, lab exhaust and exhaust from kitchens with over 5,000 cfm of exhaust. Rules for the standard design covered process exhaust rate and fan power are discussed in the following chapters.

Exhaust Fan Power Ratio

Applicability: All thermal zones.

Definition: This is the ratio of the proposed exhaust fan power included in zones served by a proposed HVAC system, divided by the total proposed system fan power, which includes: supply, return/relief, and exhaust fans. If the proposed design does not have exhaust fans in zones served by an HVAC system, this ratio is 0.

Units: Unitless ratio.

Input Restrictions: As designed, not a user input.

Standard Design: Same as proposed. When compliance scope does not include Mechanical, or includes Partial Mechanical and a zone is specified as 'HVAC Is Unknown', the exhaust fan power ratio for both the proposed and standard design systems will be based on the ratio of exhaust flow to total system flow (supply + exhaust), unless the exhaust fan power is defined for a covered process that does not depend on the proposed exhaust fan power ratio, in which case the standard design exhaust fan power is set to the covered process defined level.

Standard Design: Existing Buildings: Same as proposed.

Exhaust Fan Design Airflow

Applicability: All exhaust fan systems.

Definition: The rated design airflow rate of the exhaust fan system. This building descriptor defines the 100 percent flow point of the part-flow curve. Actual airflow is the sum of the flow specified for each thermal zone, as modified by the schedule for each thermal zone.

Units: Cfm.

Input Restrictions: As designed, but required if the space ventilation function results in a minimum exhaust rate to be provided. The total design exhaust flow capacity for building floor (conditioned space) shall not exceed the sum of building floor total outdoor airflow. The outdoor air can be brought into the building mechanically or drawn by the exhaust system through louvers at the zone. To specify air drawn through louvers users should set the exhaust air source as Direct Outside Air.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, same as proposed design unless the space ventilation function results in a minimum exhaust rate to be provided. In this case, the standard design shall be the code minimum exhaust. The design supply air ventilation rate for zone(s) may need to be adjusted by the compliance software, so that the total design outside air ventilation rate supplied to all zones on a floor equals the total exhaust fan design airflow for all zones on the floor.

Exhaust Fan Control Method

Applicability: All exhaust fan systems.

Definition: A description of how the exhaust fan(s) are controlled. The options include:

- Constant-flow, constant speed fan
- Variable-flow, constant speed fan
- Variable-flow, variable speed fan

For laboratories the options are:

- Constant-flow, constant speed fan with bypass damper
- Constant-flow, constant speed fan without bypass damper
- Variable-flow, constant speed fan with bypass damper
- Variable-flow, variable volume fan without bypass damper
- Variable-flow, variable volume fan with bypass damper

Units: List (see above)

Input Restrictions: As designed, when exhaust fan flow at the thermal zone level is varied through a schedule, one of the variable-flow options shall be specified.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others,

The standard design exhaust fan control shall be the same as the proposed design, but subject to the conditions described above.

For exhaust fans serving kitchen spaces, the fan control method is constant volume for fans with flow rate 5,000 cfm and below, and variable flow, variable speed drive for fans with flow rate greater than 5,000 cfm.

For exhaust fans serving laboratory spaces, the fan control method is variable-flow, constant speed fan with bypass damper. The airflow entering the exhaust fans is constant even though the exhausted conditioned airflow from the lab spaces varies in accordance with the larger of schedules of fume hood fraction, minimum ACH (circulation rate), and airflow required for heating and cooling. As exhaust airflow from the lab spaces decreases, bypass air correspondingly increases, and as a result, the airflow out of the stack is constant and the exhaust fan draws design power continuously when it is on.

Exhaust Fan Efficiency

Applicability: Any exhaust fan system that uses the static pressure method.

Definition: The efficiency of the exhaust fan at rated capacity.

This is the static efficiency and does not include losses through the motor.

Units: Unitless.

Input Restrictions: None.

Standard Design: For healthcare facilities covered process exhaust, same as the Proposed Design. For all other healthcare facility fans 65%.

For kitchen exhaust fans, the fan efficiency is 50%, while for lab exhaust it is 62%.

For all other exhaust fans, the standard design efficiency is 65%.

Exhaust Fan Power Index

Applicability: All exhaust systems.

Definition: The fan power of the exhaust fan per unit of flow.

This building descriptor is applicable only with the power-per-unit-flow method.

Units: W/CFM.

Input Restrictions: As designed. When an anemometer and/or contaminant controls are used in the proposed design the fan power is reduced by 0.2 W/cfm.

Standard Design: For healthcare facilities with total system fan power greater than or equal to 1 kW and the system is not DOAS, power-per-unit-flow allowance based on the components in the proposed system according to 140.4(c)1 of the Energy Code. For all other health care facilities, same as the Proposed Design.

For laboratory exhaust, where the building lab design exhaust flow exceeds 10,000 cfm, 0.65 W/cfm. If the user designates that the system includes scrubbers or other air treatment devices, the standard design exhaust fan power shall be 0.85 W/cfm.

For kitchen exhaust, 0.65 W/CFM.

For hotel/motel guestrooms, 0.58 W/CFM.

Exhaust Fan System Minimum Airflow Rate

Applicability: All laboratory exhaust fan systems.

Definition: Minimum rate of exhaust from a laboratory fan system.

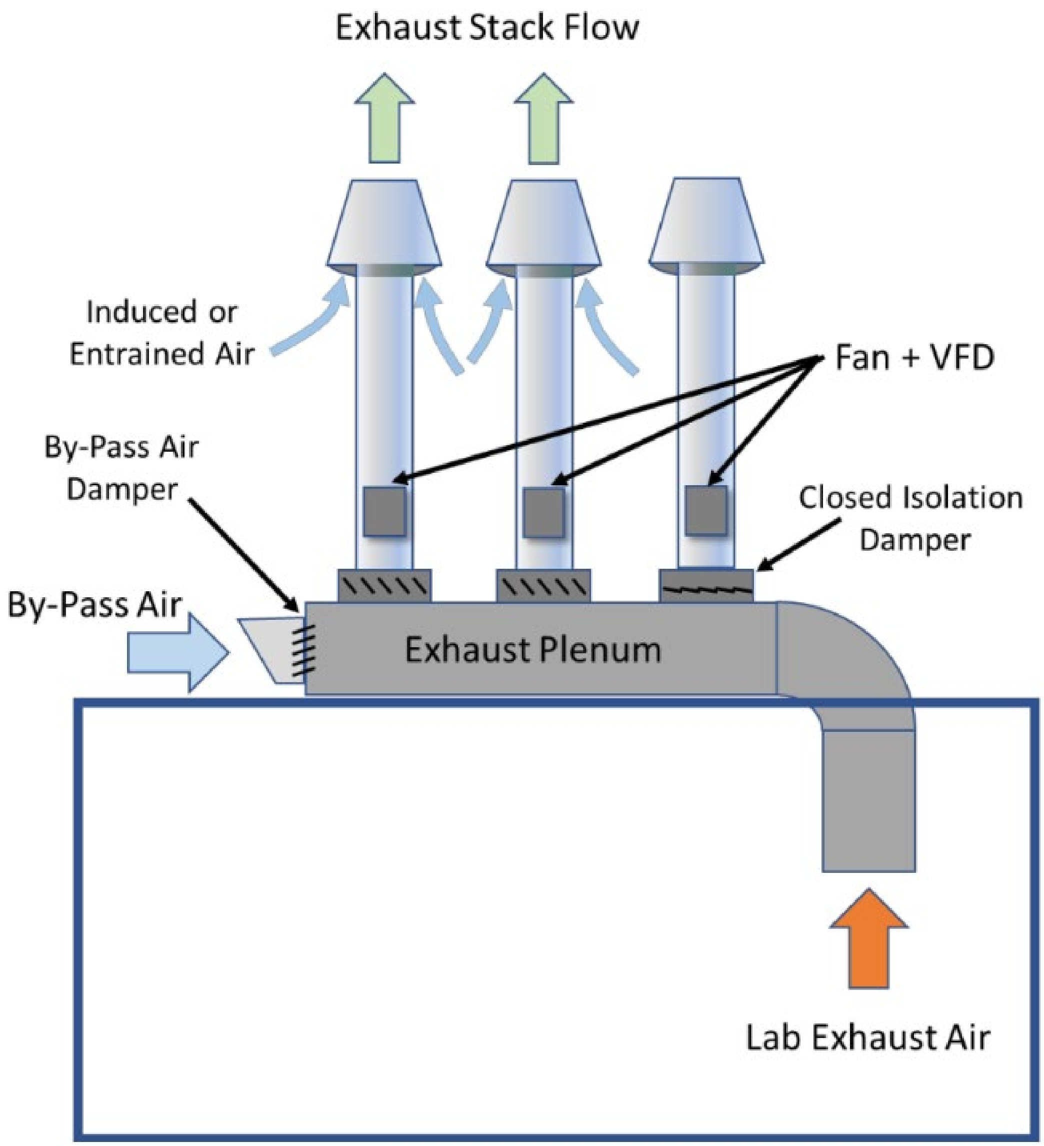
Units: Cfm.

Input Restrictions: As designed.

For laboratory zones, to maintain a minimum effluent discharge velocity or plume height, the minimum exhaust fan airflow rate may need to be greater than the sum of the zone exhaust air flow rates it serves and additional bypass air will be needed to meet the discharge velocity (see figure below). The exhaust fan system airflow rate is the maximum of the total zone exhaust airflow rates served by the exhaust fan system and the minimum fan system airflow rate. The difference between the sum of the zone exhaust airflow rates served by the exhaust fan system and the exhaust fan system airflow rate, is bypass air into the inlet of the exhaust fans. For induction fans that also have entrained airflow downstream of the fan, the entrained airflow shall be subtracted off the total stack airflow when defining the minimum exhaust flow rate. Users shall have the capability to input separate fan system minimum rates for high and low periods. High minimum periods correspond to times with wind speeds above user defined threshold velocities by wind direction for wind responsive control systems or above contaminant threshold concentration for contaminant monitoring control system.

Standard Design: For laboratory systems the occupied exhaust minimum air flow rate is the proposed design occupied minimum exhaust air flow rate. The unoccupied exhaust minimum air flow rate shall be 0.33 cfm/ft2 less than the occupied exhaust minimum airflow rate.

Figure 8: Laboratory Exhaust System



5.7.3.6 Garage Exhaust Fan Systems

When garage exhaust fan systems are modeled the fans shall be modeled as constant volume fans, with the fan power determined by whether or not the fan has CO controls.

Garage Exhaust Fan Rated Capacity

Applicability: All garage exhaust systems.

Definition: The rated design airflow rate of the garage exhaust fan system.

Units: Cfm.

Input Restrictions: As designed.

Standard Design: Same as proposed design.

Garage Exhaust Fan Control Method

Applicability: All garage exhaust fan systems.

Definition: The control method for the garage exhaust fan.

This input determines the fan power for the exhaust fan. No other fan inputs are required.

Units: List No CO control, or CO control.

Input Restrictions: None.

If constant volume is selected, proposed fan power is as designed.

If CO control is selected, proposed fan power is 12.5 percent of the design fan power.

Standard Design: Same as proposed.

5.7.3.7 Duct Systems in Unconditioned Space

Duct Leakage ECC Fan Power Adjustment

Applicability: Single zone, constant volume systems with ducts in unconditioned space, serving < 5000 ft^2 conditioned floor area.

Definition: Fan power energy usage adjusted based on the testing performed when ducts are in unconditioned spaces.

Units: List: Penalty, No Change Credit.

Input Restrictions: Not a user input.

If the ECC duct leakage testing isn’t done when required, or if the testing fails the duct leakage rate criteria the fan power is simulated with a 30% increase to represent increased energy usage from duct leakage.

Although testing is not required, if ECC testing is performed and leakage rates are verified, the fan power is simulated with a 14% decrease to represent decreased energy usage from low duct leakage.

For all other cases the fan power is simulated with no change.

Standard Design: No Change.

5.7.4 Outdoor Air Controls and Economizers

5.7.4.1 Outside Air Controls

Maximum Outside Air Ratio

Applicability: All systems with modulating outside air dampers.

Definition: The descriptor is used to limit the maximum amount of outside air that a system can provide as a percentage of the design supply air. It is used where the installation has a restricted intake capacity.

Units: Ratio.

Input Restrictions: 1.0 for 100% outdoor air systems. As designed for all systems above 33,000 Btu/h net cooling capacity. As designed up to 0.9 for other systems.

Standard Design: 1.0 for all systems above 33,000 Btu/h net cooling capacity; 0.9 for other systems.

Design Outside Airflow

Applicability: All systems with outside air dampers.

Definition: The rate of outside air that needs to be delivered by the system at design conditions. This input may be derived from the sum of the design outside airflow for each of the zones served by the system.

Units: Cfm.

Input Restrictions: As designed but no lower than the ventilation rate of the standard design.

Standard Design: For healthcare facilities, same as the Proposed Design.

For systems serving laboratory spaces, the system shall be 100 percent outside air.

Outdoor Air Control Method

Applicability: All HVAC systems that deliver outside air to zones.

Definition: The method of determining the amount of outside air that needs to be delivered by the system.

Each of the zones served by the system report their outside air requirements on an hourly basis. The options for determining the outside air at the zone level are discussed above. This control method addresses how the system responds to this information on an hourly basis. Options include:

> Average Flow - The outside air delivered by the system is the sum of the outside air requirement for each zone, without considering the position of the VAV damper in each zone. The assumption is that there is mixing between zones through the return air path.

Units: List (see above).

Input Restrictions: Average Flow.

Standard Design: Average Flow.

5.7.4.2 Air Side Economizers

Economizer Control Type

Applicability: All systems with an air-side economizer

Definition: An air-side economizer increases outside air ventilation during periods when system cooling loads can be reduced from increased outside airflow. The control types include:

No economizer: No air-side economizer.

Fixed dry-bulb: The economizer is enabled when the dry-bulb temperature of the outside air is equal to or lower than dry-bulb temperature fixed setpoint (e.g., 75°F).

Differential dry-bulb: The economizer is enabled when the dry-bulb temperature of the outside air is lower than the return air dry-bulb temperature.

Differential enthalpy: The economizer is enabled when the enthalpy of the outside air is lower than the return air enthalpy.

Differential dry-bulb and enthalpy: The system shifts to 100 percent outside air or the maximum outside air position needed to maintain the cooling SAT setpoint, when the outside air dry-bulb temperature is less than the return air dry-bulb temperature AND the outside air enthalpy is less than the return air enthalpy. This control option requires additional sensors.

Units: List (see above)

Input Restrictions: As designed

Standard Design: The control should be no economizer when the standard design net cooling capacity is less than 33,000 Btu/h and when the standard design cooling system is not a computer room system. Otherwise, the standard design shall assume an integrated fixed dry-bulb economizer.

If the following exceptions apply, the standard design system shall not include an economizer:

- Systems serving multifamily dwelling units or hotel/motel guestroom occupancies.
- Systems serving healthcare facilities with Standard Design net cooling capacity less than 54,000 Btu/h where ventilation is provided by a DOAS with heat recovery.
- When the proposed design includes a mechanical system for an individual computer room zone with an ITE design load under 18 kW and all other cooling systems in the proposed design do not have an economizer. If the compliance scope is Partial Mechanical this exception only applies if the computer room zone has a proposed system and all cooling systems included in the proposed mechanical scope (including the computer room) do not have economizers. If the computer room zone does not have a proposed system specified, both the proposed and standard design have an integrated fixed dry-bulb economizer.
- Single zone unitary air conditioner and heat pumps with rated cooling capacity less than 54,000Btu/hr if the compliance scope is Addition and/or Alteration.

For healthcare facilities, DOAS with heat recovery shall be assumed to have a fixed dry-bulb economizer.

ECONOMIZER INTEGRATION LEVEL

Applicability: Airside economizers.

Definition: This input specifies whether or not the economizer is integrated with mechanical cooling. It is up to the compliance software to translate this into software-specific inputs to model this feature. The input could take the following values:

- Non-integrated - The system runs the economizer as the first stage of cooling. When the economizer is unable to meet the load, the economizer returns the outside air damper to the minimum position and the compressor turns on as the second stage of cooling.

- Integrated - The system can operate with the economizer fully open to outside air and mechanical cooling active (compressor running) simultaneously, even on the lowest cooling stage.

Units: List (see above).

Input Restrictions: List non-integrated or integrated.

Standard Design: Integrated for systems above capacity 33,000 Btu/h net cooling capacity.

Economizer High Temperature Lockout

Applicability: Systems with fixed dry-bulb economizer.

Definition: The outside air setpoint temperature above which the economizer will return to minimum position.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: The required high temperature lockout is based on Table 140.4-G for fixed dry bulb device types. For computer rooms with containment, the economizer shall have a fixed dry-bulb high limit of 80°F.

- Climate Zones 1, 3, 5, 11-16 –75 °F
- Climate Zones 2, 4, 10 –73 °F
- Climate Zones 6, 8, 9 - 71 °F
- Climate Zone 7 - 69 °F

Economizer Low Temperature Lockout

Applicability: Systems with air-side economizers

Definition: A feature that permits the lockout of economizer operation (return to minimum outside air position) when the outside air temperature is below the lockout setpoint.

Units: Degrees Fahrenheit (F°)

Input Restrictions: As designed

Standard Design: Not applicable.

Economizer High Enthalpy Lockout

Applicability: Systems with differential enthalpy economizers.

Definition: The outside air enthalpy above which the economizer will return to minimum position.

Units: Btu/lb.

Input Restrictions: As designed.

The default is 28 Btu/lb (high altitude locations may require different setpoints.) The compliance software shall apply a fixed offset and add 2 Btu/lb to the user-entered value.

Standard Design: Not applicable.

5.7.4.3 Pumped Refrigerant Economizers

COMPUTER ROOM PUMPED REFRIGERANT ECONOMIZER

Applicability: Computer room air conditioner systems with pumped refrigerant economizers (PRE).

Definition: PRE systems provide partial cooling without the use of the computer room air conditioner system's compressor(s). If enabled, the economizer effect is embedded in PRE specific performance curves for cooling capacity and efficiency (Appendix 5.7).

Units: Boolean, true or false.

Input Restrictions: Only systems with PRE serving computer rooms may enable this function. No other economizer types may be used in combination with PRE and all other economizer inputs in this section are not applicable to PRE systems.

Standard Design: Not applicable.

5.7.5 Cooling Systems

5.7.5.1 General

This group of building descriptors applies to all cooling systems.

COOLING SOURCE

Applicability: All systems.

Definition: The type of cooling for the system.

Units: List

- chilled water,
- direct expansion (DX), or
- VRF.

Input Restrictions: As designed. When a system has a 'heat pump' heating coil type, the system shall also include a DX cooling coil. For VRF systems, the VRF coil type should be specified.

Standard Design: For healthcare facilities, same as the proposed design. For all others refer to the HVAC system map in Chapter 5.1.3 HVAC System Map for the prescribed type.

Standard Design: Existing Buildings: Same as proposed for existing, unaltered systems.

GROSS TOTAL COOLING CAPACITY

Applicability: All cooling systems.

Definition: The total gross cooling capacity (both sensible and latent) of a cooling coil or packaged DX system at AHRI conditions. The building descriptors defined in this chapter assume that the fan is modeled separately, including any heat it adds to the air stream. The cooling capacity specified by this building descriptor should not consider the heat of the fan.

Units: Btu/h.

Input Restrictions: As designed for systems with chilled water coils. For DX coils, calculated by program from net capacity.

For computer room air conditioner, (CRAC) gross total cooling capacity is equal to gross sensible cooling capacity.

For other packaged or VRF equipment with the fan motor in the air stream such that it adds heat to the cooled air, the compliance software shall calculate the net total cooling capacity as follows:

$$Q_{t,net,rated} = Q_{t,gross,rated} - Q_{fan,rated}$$

Where:

$\boldsymbol{Q_{t,net,rated}}$ – The net total cooling capacity of a packaged unit as rated by AHRI (Btu/h)
$\boldsymbol{Q_{t,gross,rated}}$ – The gross total cooling capacity of a packaged unit (Btu/h)
$Q_{fan,rated}$; - The heat generated by the fan and fan motor (if fan motor is in airstream) at AHRI rated conditions

For CRAC systems, the fan heat at AHRI 1360 rated conditions is calculated based on the user input fan power at rated conditions as follows:

$$Q_{fan,rated}(Btu/hr) = FanPower_{rated,user}(kW) \times 3412$$

For all other DX coils, the fan heat at rated conditions shall be accounted for by using the equation below:

$$Q_{fan,rated} = Q_{t,gross,rated} \times 0.0415$$

This equation is based on an AHRI rated fan power of 0.365 W/cfm, and a cooling airflow of 400 cfm/ton.

Standard Design: For healthcare facilities, the gross total cooling capacity is the same as the Proposed Design with an adjustment to account for fan heat of the Standard Design. For all others, the capacity of the systems in the standard design is determined from a sizing run. See Chapter 2.6.2. Sizing Equipment in Standard Design.

Gross Sensible Cooling Capacity

Applicability: Computer room air conditioner (CRAC).

Definition: The gross sensible cooling capacity of the coil or packaged equipment at AHRI 1360 rated conditions. The building descriptors defined in this chapter assume that the fan is modeled separately, including any heat it adds to the air stream. The cooling capacity specified by this building descriptor should be adjusted to calculate the net sensible cooling capacity, which includes the effect of fan motor heat.

The sensible heat ratio (SHR) used by some energy simulation tools can be calculated from the sensible cooling capacity and total cooling capacity:

SHR = sensible cooling capacity/total cooling capacity

Units: Btu/h.

Input Restrictions: Not input.

The compliance software calculates the gross sensible cooling capacity to account for the effect of fan motor heat as follows:

$$Q_{s,gross,rated} = Q_{s,net,rated} + Q_{fan,rated}$$

Where:

$Q_{s,net,rated}$: The AHRI rated net sensible cooling capacity (Btu/h)

$Q_{t,gross,rated}$: The AHRI rated gross sensible cooling capacity (Btu/h)

$Q_{fan,rated}$: The heat generated by the fan motor at AHRI rated conditions (Btu/h). Calculated as fan power at AHRI rated conditions times 3.412. See rated fan power building descriptor for details.

Because the rating condition of CRAC units is based on AHRI 1360 and the performance curves in Appendix 5.7, used by CRAC and other HVAC system types, are normalized to AHRI 210/240 conditions, the CRAC gross capacity must be adjusted as follows:

$$Q_{s,gross,sim} = \frac{Q_{s.gross.rated}}{Curve_{cap,temp}(AHRI\ 1360\ condition)}$$

Where:

$Q_{s,gross,sim}$: The simulated gross sensible cooling capacity (Btu/h)

$Curve_{cap,temp}$: The output of capacity adjustment curve as a function of temperature.

Standard Design: The capacity of the systems in the standard design is determined from a sizing run. See Chapter 2.6.2. Sizing Equipment in Standard Design.

Net Total Cooling Capacity

Applicability: All systems with DX coils except computer room air conditioners.

Definition: The total net cooling capacity (both sensible and latent) of a cooling coil or packaged DX system at AHRI rated conditions from manufacturers' literature. The cooling capacity specified by this building descriptor should account for fan heat.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Not applicable.

Net Sensible Cooling Capacity

Applicability: Computer room air conditioner (CRAC).

Definition: The net sensible cooling capacity of a computer room air conditioner at the AHRI 1360 rated condition from manufacturers' literature. The cooling capacity specified by this building descriptor should account for fan heat.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Not applicable.

Gross Total Cooling Capacity Curve

Applicability: All cooling systems.

Definition: A curve that represents the available total cooling capacity as a function of cooling coil and/or condenser conditions. The common form of these curves is given as follows:

$Q_{t,available} = CAP_{FT} \times Q_{t,adj}$

For air-cooled direct expansion:

$$CAP_{FT} = a + b(t_{wb}) + c(t_{wb})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{wb} \times t_{odb})$$

For water-cooled direct expansion:

$$CAP_{FT} = a + b(t_{wb}) + c(t_{wb})^2 + d(t_{wt}) + e(t_{wt})^2 + f(t_{wb} \times t_{wt})$$

For chilled water coils:

$$CAP_{FT} = a + b(t_{wb}) + c(t_{wb})^2 + d(t_{db}) + e(t_{db})^2 + f(t_{wb} \times t_{db})$$

Where:

- $\boldsymbol{Q_{t,available}}$ – Available cooling capacity at specified evaporator and/or condenser conditions (MBH)
- $\boldsymbol{Q_{t,adj}}$ – Adjusted capacity at AHRI conditions (Btu/h)
- $\boldsymbol{CAP_{FT}}$ – A multiplier to adjust $Q_{t,adj}$
- $\boldsymbol{t_{wb}}$ – The entering coil wet-bulb temperature (°F)
- $\boldsymbol{t_{db}}$ – The entering coil dry-bulb temperature (°F)
- $\boldsymbol{t_{wt}}$ – The water supply temperature (°F)
- $\boldsymbol{t_{odb}}$ – The outside air dry-bulb temperature (°F)

Note: If an air-cooled unit employs an evaporative condenser, t_{odb} is the effective dry-bulb temperature of the air leaving the evaporative cooling unit.

Compliance software may represent the relationship between cooling capacity and temperature in ways other than the equations given above.

Units: Data structure.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

Standard Design: Use the default curves or equivalent data for other models.

Coil Latent Modeling Method

Applicability: All DX cooling systems.

Definition: The method of modeling coil latent performance at part-load conditions.

Units: List.

Input Restrictions: One of the following values:

Bypass factor – used by DOE-2 based programs.

NTU-effectiveness – used by EnergyPlus™.

Standard Design: Same as proposed.

Rated Fan Power

Applicability: Computer room air conditioner (CRAC).

Definition: The power of the supply fan of the computer room air conditioner at the AHRI 1360 rated condition.

Units: kW.

Input Restrictions: Same as the reported value in the product document.

Standard Design: When the standard design system is a computer room air conditioner the rated fan power is 0.58 W/CFM (approximate value of 27 W/kBtu-h of net sensible cooling capacity assuming design air flow rate is based on 20°F temperature differential between supply air and room air).

5.7.5.2 Hydronic/Water-Source Cooling Coils

Design Water Flow rate

Applicability: Chilled water coils and water cooled DX coils.

Definition: The design flow rate of the chilled water coil or the condenser coil of a water-source heat pump.

Units: Gallons per minute (gpm).

Input Restrictions: None. Default based on gross capacity of the chilled water coil or heat rejection load of a water-source heat pump coil at the design deltaT of the attached hydronic loop.

Standard Design: For healthcare facilities, same as the Proposed Design. For all baseline systems with chilled water coils, default based on gross capacity at the design deltaT of the attached hydronic loop as follows.

$$FlowRate_{coil} = \frac{Capacity_{coil}}{500.19 \times \Delta T_{loop}}$$

Where:

- $FlowRate_{coil}$ – Chilled water coil water flow rate (gpm)
- $Capacity_{coil}$ – Chilled water coil gross capacity (Btu/h)
- ΔT_{loop} – the design deltaT of the attached hydronic loop (°F)

Design Pressure Drop

Applicability: Chilled water coils and water cooled DX coils.

Definition: The design pressure drop through the chilled water coil or the condenser coil of a water-source heat pump. For coils with water-source condensers, the pressure drop is used to calculate the simulated energy input ratio (EIR) by removing the power consumed by pumps from the rated Energy Efficiency Ratio (EER). For all other water coils, this property does not affect the simulation of the coil or fluid system, it is used as a reference or reporting only.

Units: Feet of water (ftH2O).

Input Restrictions: None. Default to 5ft.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.7.5.3 Direct Expansion

Energy Efficiency Ratio (EER/EER2)

Applicability: All DX cooling systems except variable refrigerant flow (VRF) systems.

Definition: The Energy Efficiency Ratio (EER) is the cooling efficiency of a direct expansion (DX) cooling system at AHRI rating conditions as a ratio of output over input in Btu/h per W, excluding fan energy. For all unitary and applied equipment where the fan energy is part of the equipment efficiency rating, the EER shall be adjusted as follows:

$$EER_{adj} = \frac{Q_{t,net,rated} + Q_{fan,rated}}{\frac{Q_{t,net,rated}}{EER} - \frac{Q_{fan,rated}}{3.413} - PumpPwr_{rated}}$$

Where:

$\boldsymbol{EER_{adj}}$ - The adjusted EER for simulation purposes

$\boldsymbol{EER}$ - The rated EER

$\boldsymbol{Q_{t,net,rated}}$ - The AHRI rated total net cooling capacity of a packaged unit (kBtu/h)

$\boldsymbol{Q_{fan,rated}}$ - The AHRI rated fan energy, specified in the gross total cooling capacity building descriptor (Btu/h).

$\boldsymbol{PumpPwr_{rated}}$ – The AHRI rated pump power (Watts). Only applicable to packaged water-source heat pumps

Units: Btu/h-W.

Input Restrictions: As designed, except that the user-entered value must meet mandatory minimum requirements of the Energy Code for the applicable equipment type. For packaged equipment with cooling capacity less than 65,000 Btu/h, specify the EER/EER2 along with the SEER/SEER2 when available from manufacturer's literature or AHRI certificate. For equipment with capacity above 65,000 Btu/h that are required to have a EER/EER2 rating, the EER/EER2 must be specified.

When EER/EER2 is not available for packaged equipment with SEER/SEER2 ratings (AHRI cooling capacity of 65,000 Btu/h or smaller), it shall be calculated as follows:

$$EER = MIN(-0.0194 \times SEER^2 + 1.0864 \times SEER, 13)$$

The default EER/EER2 shall be calculated by the equation above but constrained to be no greater than 13. For SEER2 rated systems, SEER2 is first converted to SEER using conversions listed below, and then SEER is used in the equation above for calculating EER. Evaporative cooling systems that pass the requirements of the Western Cooling Challenge may be modeled with an EER/EER2 as if the equipment were packaged unitary equipment. See Chapter 5.7.5 Evaporative Cooler.

A conversion factor is used to convert EER2 to EER ratings for modeling. For all cooling equipment the conversion factor is 1/0.96 to convert EER2 to EER. A conversion factor is used to convert SEER2 to SEER ratings for modeling. For split-system equipment the conversion factor is 1/0.95; for single-package equipment the conversion factor is 1/0.96; for small-duct high-velocity the conversion factor is 1.00; and for space-constrained equipment the conversion factor is 1/0.99 to convert SEER2 to SEER.

Standard Design: Use the minimum cooling efficiency (EER/EER2) from the Energy Code for the applicable equipment type.

Seasonal Energy Efficiency Ratio (SEER/SEER2)

Applicability: DX equipment with AHRI cooling capacity of 65,000 Btu/h or smaller

Definition: The seasonal energy efficiency ratio (SEER/SEER2) is a composite rating for a range of part-load conditions at specific ambient conditions.

Units: Btu/h-W.

Input Restrictions: As designed.

This input is required for packaged DX systems less than 65,000 Btu/h that are required to have a SEER/SEER2 rating. A conversion factor is used to convert SEER2 to SEER ratings for modeling. For split-system equipment the conversion factor is 1/0.95; for single-package equipment the conversion factor is 1/0.96; for small-duct high-velocity the conversion factor is 1.00; and for space-constrained equipment the conversion factor is 1/0.99 to convert SEER2 to SEER.

Standard Design: Use the minimum SEER. The standard design system 1 is assumed to use 1-phase power, otherwise the standard design uses 3-phase power.

Integrated Energy Efficiency Ratio (IEER)

Applicability: DX equipment with AHRI cooling capacity of 65,000 Btu/h or greater.

Definition: IEER is a composite rating for a range of part-load conditions and different ambient conditions. The rating is determined according to AHRI procedures. Equipment with this rating is subject to mandatory minimum requirements.

This input is currently only used for mandatory minimum efficiency checks.

Units: Btu/h-W.

Input Restrictions: As designed, the user-entered value must meet mandatory minimum requirements of the Energy Code for the applicable equipment type.

Standard Design: Not applicable.

Direct Expansion Cooling Efficiency Temperature Adjustment Curve

Applicability: DX equipment.

Definition: A curve that varies the cooling efficiency of a direct expansion (DX) coil as a function of evaporator conditions, and condenser conditions.

For air-cooled DX systems:

$$EIR_{FT} = a + b(t_{wb}) + c(t_{wb})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{wb})(t_{odb})$$

For water-cooled DX systems:

$$EIR_{FT} = a + b(t_{wb}) + c(t_{wb})^2 + d(t_{wt}) + e(t_{wt})^2 + f(t_{wb})(t_{wt})$$

$$P_{operating} = P_{rated}(EIR_{FPLR})(EIR_{FT})(CAP_{FT})$$

Where:

- $\boldsymbol{EIR_{FPLR}}$ - Part-load ratio based on available capacity (not rated capacity)
- $\boldsymbol{EIR_{FT}}$ - A multiplier on the EIR to account for the wet-bulb temperature entering the coil and the outdoor dry-bulb temperature, or the wet-bulb temperature entering the coil and the water supply temperature.
- $\boldsymbol{t_{wb}}$ - The entering coil wet-bulb temperature (F)
- $\boldsymbol{t_{wt}}$ - The water supply temperature (F)
- $\boldsymbol{t_{odb}}$ - The outside-air dry-bulb temperature (F)
- $\boldsymbol{P_{rated}}$ - Rated power draw at AHRI conditions (kW)
- $\boldsymbol{P_{operating}}$ - Power draw at specified operating conditions (kW)
- $\boldsymbol{CAP_{FT}}$ - A multiplier to adjust cooling capacity

Units: Data structure.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

For all systems except packaged DX units with cooling capacity equal to or less than 65,000 Btu/h, use default curves from Appendix 5.7. For packaged DX units with cooling capacity equal to or less than 65,000 Btu/h that have SEER/SEER2 ratings, the user inputs EER/EER2 and SEER/SEER2, or if EER/EER2 is not known, it is calculated using the equation in Energy Efficiency Ratio (EER/EER2) section. The compliance software generates the nine bi-quadratic equipment performance curve points (67, 95, 1.0*; 57, 82, $NEIR_{57,82}$; 57, 95, $NEIR_{57,95}$; 57,110,$NEIR_{57,110}$; 67, 82, $NEIR_{67,82}$; 67,110, $NEIR_{67,110}$; 77, 82, $NEIR_{77,82}$; 77, 95, $NEIR_{77,95}$; and 77,110, $NEIR_{77,110}$) based on SEER/SEER2 and EER/EER2 inputs and the following formulas.

*At ARI Test Condition, the curve output should be 1.0

$NEIR_{WBT,ODB}$ represents the normalized energy input ratio (EIR) for various entering wet-bulb (EWB) and outside dry-bulb (ODB) temperatures. The value represents the EIR at the specified EWB and ODB conditions to the EIR at standard ARI conditions of 67°F wet-bulb and 95°F dry-bulb. The COOL-EIR-FT curve is normalized at ARI conditions of 67°F entering wet-bulb and 95°F outside dry-bulb so NEIR67,95 is one or unity, by definition. For other EWB and ODB conditions, values of NEIR are calculated with Equation below.

$$NEIR_{EWB,ODB} = \frac{EIR_{EWB,ODB}}{EIR_{67,95}}$$

The energy input ratio (EIR) is the unitless ratio of energy input to cooling capacity. EIR includes the compressor and condenser fan, but not the supply fan. If the energy efficiency ratio EERnf (EER excluding the fan energy) is known for a given set of EWB and ODB conditions, the EIR for these same conditions is given by Equation below.

$$EIR_{EWB,ODB} = \frac{3.413}{EERnf_{EWB,ODB}}$$

If the EER (including fan energy) is known for a given set of EWB and ODB conditions, then the EERnf (no fan) can be calculated from Equation N2-1below.

Equation N2-1 $$EERnf_{EWB,ODB} = 1.0452 \times EER_{EWB,ODB} + 0.0115 \times EER_{EWB,ODB}{}^{2} + 0.000251 \times EER_{EWB,ODB}{}^{3}$$

The EER for different EWB and ODB conditions. These are given by the following equations.

Equation N2-2 $EER_{67,82} = SEER$

Equation N2-3 $EER_{67,95} = From\ Manufacuters\ Data$ [when available]

$EER_{67,95} = 10 - (11.5 - SEER) \times 0.83$ [Default for SEER < 11.5]

$EER_{67,95} = 10$ [default for SEER>11.5]

Equation N2-4 $EER_{67,110} = EER_{67,95} - 1.8$

Equation N2-5 $EER_{57,008} = 0.877 \times EER_{67,008}$

Equation N2-6 $EER_{77,008} = 1.11 \times EER_{67,008}$

A conversion factor is used to convert EER2 to EER ratings for modeling. For all air conditioners the conversion factor is 1/0.96 to convert EER2 to EER. A conversion factor is used to convert SEER2 to SEER ratings for modeling. For split-system equipment the conversion factor is 1/0.95; for single package equipment the conversion factor is 1/0.96; for small-duct high-velocity the conversion factor is 1.00; and for space-constrained equipment the conversion factor is 1/0.99 to convert SEER2 to SEER.

Standard Design: Use prescribed curves as described above.

NUMBER OF COOLING STAGES

Applicability: Single zone VAV systems and DX systems with multiple stages.

Definition: This applies to single zone VAV and any HVAC systems with multiple compressors or multiple discrete stages of cooling. This system is a packaged unit with multiple compressors and a two-speed or variable-speed fan.

Units: None (Integer).

Input Restrictions: As designed, but systems with more than 2 stages will be modeled with 2 stages.

Standard Design: The standard design shall be two for the single zone VAV baseline and packaged VAV baseline.

Total Cooling Capacity Ratio by Stage

Applicability: Single zone VAV systems and DX systems with multiple stages.

Definition: This provides the total cooling capacity of each cooling stage, at AHRI rated conditions. The capacity is expressed as an array, with each entry a fraction of the total rated cooling capacity for the unit. For example, if the stage cooling capacity is 4 tons (48,000 Btu/h) and the total cooling capacity is 8 tons (96,000 Btu/h), the capacity is expressed as “0.50” for that stage.

Units: Array of fractions.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, the default shall be (0.50, 1) for the single zone VAV baseline.

Condenser Type

Applicability: All direct expansion systems including heat pumps.

Definition: The type of condenser for a DX cooling system.

The choices are:

Air-cooled
Water-cooled

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, based on the prescribed system type.

Refer to the HVAC System Map in Chapter 5.1.3 HVAC System Map

Crank Case Heater kW

Applicability: Air conditioners.

Definition: The capacity of the electric resistance heater in the crank case of a direct expansion (DX) compressor. The crank case heater operates only when the compressor is off.

Units: Kilowatts (kW).

Input Restrictions: Where applicable, the value is prescribed to be 10 W per ton (rated net cooling capacity).

Standard Design: Where applicable, the value is prescribed to be 10 W per ton (rated net cooling capacity).

Crank Case Heater Shutoff Temperature

Applicability: All air source heat pumps and air conditioners.

Definition: The outdoor air dry-bulb temperature above which the crank case heater is not permitted to operate.

Units: Degrees Fahrenheit (°F).

Input Restrictions: Where applicable, the value is prescribed to be 50°F.

Standard Design: Where applicable, the value is prescribed to be 50°F.Supplementary DX Cooling Unit

Applicability: Required when no cooling system is specified, or can be added by the user when a zone has excessive unmet cooling load hours.

Definition: A supplementary DX cooling system that only operates when the thermostat cooling setpoint is not maintained by the proposed space conditioning equipment.

Units: None.

Input Restrictions: The compliance software shall define the following prescribed system characteristics:

Cooling capacity – Auto-sized by compliance software.

System airflow – Auto-sized by compliance software.

Fan power – None, system is assumed to cycle on fan/compressor only when cooling is needed.

Efficiency – Minimum value specified by the Energy Code for a packaged DX system, based on the calculated net cooling capacity and assuming 3-phase equipment. No adjustment of efficiency for rated fan heat because system fan cycles on only when cooling coil is energized.

Economizer - none

Design supply air temperature - 55°F

Supply air temperature control - None

Standard Design: Not applicable. With the exception of a qualified heating only system which is modeled with a system sized to meet the cooling load.

Net Sensible Coefficient of Performance (NSenCOP)

Applicability: Computer room air conditioner (CRAC)

Definition: A dimensionless ratio of the Net Sensible Cooling Capacity to the total power input (excluding reheaters and humidifiers) at AHRI 1360 rated conditions. NSenCOP must be adjusted as follows to determine the simulated COP:

$$COP_{sim} = \frac{Q_{s,net,rated} + Q_{fan,rated}}{\frac{Q_{s,net,rated}}{NSenCOP} - Q_{fan,rated}} \times Curve_{EIR,temp}(AHRI\ 1360\ condition)$$

Where:

COP_{sim}: The coefficient of performance for simulation purposes

$Q_{s,net,rated}$: The net sensible cooling capacity, see the corresponding descriptor.

$Q_{fan,rated}$: The heat generated by the fan and fan motor at AHRI 1360 rated conditions (Btu/h). Which is calculated as fan power at AHRI 1360 rated conditions times 3.412. See the rated fan power building descriptor.

$Curve_{EIR,temp}$: The output of Energy Input Ratio (EIR) adjustment curve as a function of temperature.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: Federal minimum efficiency for floor-mounted (downflow) configuration.

5.7.5.4 Evaporative Cooler

This is equipment that cools without the use of a vapor compression cycle. This equipment is not applicable for the standard design.

A supplementary DX cooling unit will be added to the zone if evaporative cooling is the only cooling source. See Chapter 5.7.5 Direct Expansion.

Evaporative Cooling Type

Applicability: Systems with evaporative cooling.

Definition: The type of evaporative cooler, including:

direct
indirect

An integrated cooler can operate together with compressor or chilled water (CHW) cooling. A non-integrated cooler will shut down the evaporative cooling whenever it is unable to provide 100 percent of the cooling required.

Units: List, see above.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Direct Stage Effectiveness

Applicability: Systems with evaporative cooling.

Definition: The effectiveness of the direct stage of an evaporative cooling system. Effectiveness is defined as:

$$Direct_{EFF} = \frac{T_{db} - T_{direct}}{T_{db} - T_{wb}}$$

Where:

$\boldsymbol{Direct_{EFF}}$ - The direct stage effectiveness
$\boldsymbol{T_{db}}$ - The entering air dry-bulb temperature
$\boldsymbol{T_{wb}}$ - The entering air wet-bulb temperature
$\boldsymbol{T_{direct}}$ - The direct stage leaving dry-bulb temperature

Units: Numeric (0 ≤ EFF ≤1).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Indirect Stage Effectiveness

Applicability: Systems with evaporative cooling.

Definition: The effectiveness of the indirect stage of an evaporative cooling system. Effectiveness is defined as:

$$Indirect_{EFF} = \frac{T_{db} - T_{indirect}}{T_{db} - T_{wb}}$$

Where:

- $\boldsymbol{Indirect_{EFF}}$ - The indirect stage effectiveness
- $\boldsymbol{T_{db}}$ - The entering air dry-bulb temperature
- $\boldsymbol{T_{wb}}$ - The entering air wet-bulb temperature
- $\boldsymbol{T_{indirect}}$ - The indirect stage leaving dry-bulb temperature

Units: Numeric (0 ≤ EFF ≤1).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Evaporative Cooling Performance Curves

Applicability: Systems with evaporative cooling.

Definition: A curve that varies the evaporative cooling effectiveness as a function of primary air stream airflow. The default curves are given as:

$$PLR = \frac{CFM_{operating}}{CFM_{design}}$$

$$EFF_{FFLOW} = a + b(PLR) + c(PLR)^2$$

Where:

- $\boldsymbol{PLR}$ - Part load ratio of airflow based on design airflow
- $\boldsymbol{EFF_{FFLOW}}$ - A multiplier on the evaporative cooler effectiveness to account for variations in part load
- $\boldsymbol{CFM_{operating}}$ - Operating primary air stream airflow (cfm)

- CFM_{design} - Design primary air stream airflow (cfm)

Units: Data structure.

Input Restrictions: User may input curves or use default curves. If defaults are overridden, the compliance software must indicate that supporting documentation is required on the output forms.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

AUXILIARY EVAPORATIVE COOLING POWER

Applicability: Systems with evaporative cooling.

Definition: The auxiliary energy of the indirect evaporative cooler fan, and the pumps for both direct and indirect stages.

Units: Watts.

Input Restrictions: As designed.

Standard Design: Not applicable.

DEWPOINT EFFECTIVENESS

Applicability: Systems with indirect evaporative cooling.

Definition: The effectiveness of the evaporative cooler based on dewpoint depression. This is an optional input which determines the maximum leaving air temperature based on dewpoint depression rather than wet-bulb depression. The leaving air temperature calculated with the dewpoint effectiveness will be the entering temperature minus the difference between the entering dry-bulb and dewpoint temperatures multiplied by the effectiveness,

$$T_{indirect} = T_{db} - \left(T_{db} - T_{dp}\right) \times \ Dewpoint_{EFF}$$

Where:

- $Dewpoint_{EFF}$ - The dewpoint effectiveness
- T_{db} - The entering air dry-bulb temperature
- T_{dp} - The entering air dewpoint temperature
- $T_{indirect}$ - The indirect stage leaving dry-bulb temperature

The actual leaving temperature will be the warmer of the two temperatures calculated from the wet-bulb and dewpoint effectiveness values.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: Not applicable.

Secondary Fan Flow Rate

Applicability: Systems with indirect evaporative cooling.

Definition: The flow rate of any integrated fan providing air to the secondary (wet) side of the indirect evaporative cooler.

Units: cfm.

Input Restrictions: As designed.

Standard Design: Not applicable.

Secondary Fan Total Efficiency

Applicability: Systems with indirect evaporative cooling.

Definition: The overall efficiency of any integrated fan providing air to the secondary (wet) side of the indirect evaporative cooler. This efficiency includes that of the fan, motor and drive.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: Not applicable.

Secondary Fan Static Pressure

Applicability: Systems with indirect evaporative cooling.

Definition: The total static pressure of any integrated fan providing air to the secondary (wet) side of the indirect evaporative cooler.

Units: inH2O.

Input Restrictions: As designed.

Standard Design: Not applicable.

Secondary Air Source

Applicability: Systems with indirect evaporative cooling.

Definition: The primary source of air supplied to the secondary (wet) side of the indirect evaporative cooler. If return is selected and the air system return air cannot meet the airflow desired by the evaporative cooler, the difference will be made up using outdoor air.

Units: List. The options are

- Return
- Outdoor

Input Restrictions: As designed.

Standard Design: Not applicable.

5.7.5.5 Four-Pipe Fan Coil Systems

This chapter contains building descriptors required to model four-pipe fan coil systems.

Additional HVAC components (chiller, boiler, pumps) are needed to fully define this system. If a water-side economizer is specified with this system, refer to 5.8.4 Water-side Economizers for a list of applicable building descriptors.

Capacity Control Method

Applicability: Four-pipe fan coil systems.

Definition: The control method for the fan coil unit used to meet zone heating or cooling loads.

The following choices are available:

- Constant Speed Fan, Variable Fluid Flow - The fan speed produces a fixed air flow rate whenever the unit is scheduled on. The hot/chilled water flow rate is varied so that the unit output matches the zone heating/cooling requirement.
- Cycling Fan - The fan is cycled to match unit output with the load.
- Variable Speed Fan, Constant Fluid Flow - The water flow rate is at full flow and the fan speed varies to meet the load.
- Variable Speed Fan, Variable Fluid Flow - both air and water flow rates are varied to match the load.

Units: List (with choices above).

Input Restrictions: Not a user input. It comes from building descriptors for fan control and chiller loop flow control.

Standard Design: Not applicable.

Rated Gross Capacity

Applicability: Four-pipe fan coil systems.

Definition: The gross cooling capacity of the cooling coil.

Units: Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, the same as the Proposed Design with an adjustment to account for fan heat of the Standard Design. For all others, not applicable.

Cooling Coil Design Flow rate

Applicability: Four-pipe fan coil systems and chilled beams.

Definition: The design flow rate of the cooling coil

Units: Gallons per minute (gpm).

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.7.5.6 Chilled Beams

Active and passive chilled beam systems may be modeled as four-pipe fan coils or similar system type if the compliance software does not explicitly support chilled beams. In this case, the FPFC fan flow rate is based on the induced airflow rate of the beam and modeled with no fan power.

Chilled Beam Name

Applicability: Chilled beams.

Definition: A unique name designating the chilled beam.

Units: None.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the proposed design. For all others, not applicable.

Chilled Beam Type

Applicability: Chilled beams.

Definition: Specification of the beam as active or passive.

Units: List:

Active

Passive

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the proposed design. For all others, not applicable.

Design Cooling Capacity

Applicability: Chilled beams.

Definition: The designed cooling capacity of the chilled beam.

Units: Btu/h.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Design Chilled Water Temperature

Applicability: Chilled beams.

Definition: The minimum supplied chilled water temperature to the beam.

This is typically at least 2°F higher than the space dewpoint temperature at design conditions, to prevent condensation.

Units: °F.

Input Restrictions: Not a user input. Based on building descriptors for chiller loop control.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Maximum Chilled Water Temperature

Applicability: Chilled beams.

Definition: The maximum supplied chilled water temperature to the beam. This allows for chilled water temperature reset at the source.

Units: °F.

Input Restrictions: Should be equal to or greater than the design chilled water temperature.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Active Beam Maximum Primary Flow Rate

Applicability: Chilled beams.

Definition: The design flow rate of the active fan.

Units: Cfm.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Active Beam Induced Air Rate

Applicability: Active chilled beams.

Definition: The rate at which induced air is drawn through the chilled beam.

The total airflow across the beam is the sum of the maximum primary flow rate and the active beam induced airflow rate.

Units: Cfm.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, Not applicable.

Chilled Beam Heating Capacity

Applicability: Chilled beams.

Definition: The heating capacity of the chilled beam.

Units: Btu/h.

Input Restrictions: None; defaults to 1 if no heating.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Chilled Beam Heating Source

Applicability: Chilled beams.

Definition: Defaults to electric resistance, whether there is heating provided by the beam or not.

Units: None.

Input Restrictions: Electric resistance.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.7.6 Heating Systems

5.7.6.1 General

Heating Source

Applicability: All systems that provide heating.

Definition: The source of heating for the heating coils. The choices are:

Hot water
Electric resistance
Electric heat pump
Gas furnace
VRF

Units: List (see above).

Input Restrictions: As designed. Electric heat pumps may have an additional coil to be used as supplemental heat. See section below. Electric resistance heating system shall not be used for healthcare facilities space heating unless it meets one of the exceptions to Section 140.4(g) in the Energy Code.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, based on the prescribed system type. Refer to Chapter 5.1.3 HVAC System Map. For Alterations, see 5.1.4 Additions and Alterations System Modification.

Gross Heating Coil Capacity

Applicability: All systems with a heating coil.

Definition: The heating capacity of a heating coil or packaged heat pump at AHRI conditions.

For packaged or VRF equipment that has the fan motor in the air stream such that it adds heat to the supply air, the compliance software shall calculate the net heating capacity as follows:

Net Heating Capacity = CapTotGrossRtd + FanHtRtd

Where:

- Net Heating Capacity - The net total heating capacity of a packaged unit as rated by AHRI (Btu/h)
- CapTotGrossRtd - The gross heating capacity of a packaged unit (Btu/h)
- FanHtRtd - The heat generated by the fan. See ‘Gross Cooling Capacity’

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, the gross total cooling capacity is the same as the Proposed Design with an adjustment to account for fan heat of the Standard Design. For all other cases, the capacity is auto sized, see Chapter 2.6.2 Sizing Equipment in the Standard Design.

Standard Design: Existing Building: Same as proposed if unaltered

5.7.6.2 Hydronic/Water-Source Heating Coils

Design Water Flow rate

Applicability: Hot water coils and water-cooled DX coils.

Definition: The design flow rate of the hot water coil or the condenser coil of a water-source heat pump.

Units: Gallons per minute (gpm).

Input Restrictions: None. Default based on gross capacity of the hot water coil or cooling heat rejection load of a water-source heat pump coil at the design deltaT of the attached hydronic loop.

Standard Design: For healthcare facilities, same as the Proposed Design. For baseline systems with hot water coils, default based on gross capacity at the design deltaT of the attached hydronic loop as follows.

$$FlowRate_{coil} = \frac{Capacity_{coil}}{500.19 \times \Delta T_{loop}}$$

Where:

$FlowRate_{coil}$ – Hot water coil water flow rate (gpm)

$Capacity_{coil}$ – Hot water coil gross capacity (Btu/h)

ΔT_{loop} – the design deltaT of the attached hydronic loop (°F)

Design Pressure Drop

Applicability: Hot water coils and water-cooled DX coils.

Definition: The design pressure drop through the hot water coil or the condenser coil of a water-source heat pump.

Units: Feet of water (ftH2O).

Input Restrictions: None. Default to 5ft.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.7.6.3 Furnace

FURNACE FUEL HEATING EFFICIENCY

Applicability: Systems with a furnace.

Definition: The full load thermal efficiency of either a gas or oil furnace at design conditions. The compliance software must accommodate input in either thermal efficiency (Et) or annual fuel utilization efficiency (AFUE). Where AFUE is provided, Et shall be calculated as:

$$E_t = 0.0051427 \times (AFUE \times 100) + 0.3989$$

Where:

$\boldsymbol{AFUE}$ - The annual fuel utilization efficiency (%)
$\boldsymbol{E_t}$ - The thermal efficiency (fraction)

Units: Fraction.

Input Restrictions: As designed.

Standard Design: Use the minimum heating efficiency from the Energy Code for the applicable equipment type and capacity.

FURNACE FUEL HEATING PART LOAD EFFICIENCY CURVE

Applicability: Systems with a furnace.

Definition: An adjustment factor that represents the percentage of full load fuel consumption as a function of the percentage full load capacity. This curve shall take the form of a quadratic equation as follows:

$$Fuel_{partload} = Fuel_{rated} \times FHeatPLC$$

$$FHeatPLC = a + b(Q_{partload}/Q_{rated}) + c(Q_{partload}/Q_{rated})^2$$

Where:

$\boldsymbol{FHeatPLC}$ - The fuel heating part load efficiency curve
$\boldsymbol{Fuel_{rated}}$ - The fuel consumption at part load conditions (Btu/h)
$\boldsymbol{Q_{partload}}$ - The capacity at part load conditions (Btu/h)
$\boldsymbol{Q_{rated}}$ - The capacity at rated conditions (Btu/h)

Units: Data structure.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

Standard Design: Use prescribed curves as described above.

FURNACE IGNITION TYPE

Applicability: Systems that use a furnace for heating.

Definition: The method used to start combustion in fuel-fired furnaces. The options are:

- Intermittent Ignition Device
- Pilot Light

Units: List (see above).

Input Restrictions: As designed.

Standard Design: Intermittent Ignition Device.

Furnace Fuel Heating Pilot

Applicability: Systems that use a furnace with pilot light ignition for heating.

Definition: The fuel input for a pilot light on a furnace.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Zero (pilotless ignition).

Furnace Fuel Heating Fan/Auxiliary

Applicability: Systems that use a furnace for heating.

Definition: The fan energy in forced draft furnaces and the auxiliary (pumps and outdoor fan) energy in fuel-fired heat pumps.

Units: Kilowatts (kW).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.7.6.4 Electric Heat Pump

Electric Heat Pump Supplemental Heating Source

Applicability: All heat pumps.

Definition: The auxiliary heating source for a heat pump heating system.

The common control sequence is to lock out the heat pump compressor when the supplemental heat is activated. Other building descriptors may be needed if this is not the case. Choices for supplemental heat include:

- Electric resistance
- Gas furnace
- Hot water

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, refer to the HVAC system map in Chapter 5.1.2 HVAC System Map for the prescribed type.

Electric Heat Pump Heating Efficiency

Applicability: All heat pumps except AWHPs.

Definition: The heating efficiency of a heat pump at AHRI rated conditions as a dimensionless ratio of output over input. The compliance software must accommodate user input of either the coefficient of performance (COP) or the heating season performance factor (HSPF/HSPF2). Where HSPF/HSPF2 is provided, COP shall be calculated as:

$$COP = (0.2778 \times HSPF) + 0.9667$$

For all unitary and applied equipment where the fan energy is part of the equipment efficiency rating, the COP shall be adjusted as follows to remove the fan energy:

$$COP_{adj} = \frac{\frac{HCAP_{rated} - Q_{fan,rated}}{3.413}}{\frac{HCAP_{rated}}{COP \times 3.413} - \frac{Q_{fan,rated}}{3.413}}$$

Where:

- $\boldsymbol{COP_{adj}}$ — The adjusted coefficient of performance for simulation purposes
- $\boldsymbol{COP}$ — The AHRI rated coefficient of performance
- $\boldsymbol{HCAP_{rated}}$ — The AHRI rated heating capacity of a packaged unit (Btu/h)
- $\boldsymbol{Q_{fan,rated}}$ – The heat generated by the fan at AHRI rated conditions. See Gross Cooling Capacity

Units: Unitless.

Input Restrictions: As designed. A conversion factor is used to convert HSPF2 to HSPF ratings for modeling. For split system, small-duct high-velocity, and space-constrained equipment, the conversion factor is 1/0.85 to convert HSPF2 to HSPF. For single-package equipment, the conversion factor is 1/0.84 to convert HSPF2 to HSPF.

Standard Design: Minimum heating efficiency form the Energy Code for the applicable equipment type.

Air to Water Heat Pump Rated Efficiency

Applicability: All AWHPs.

Definition: The heating efficiency of the AWHP (COP_H) at full-load conditions.

Units: COP.

Input Restrictions: As designed.

Must meet minimum efficiency requirements.

Standard Design: 3.29.

Standard Design: Existing Buildings: Same as proposed design if unaltered. Same as newly constructed buildings rules if altered or replacement.

Electric Heat Pump Heating Capacity Adjustment Curve(s)

Applicability: All heat pumps.

Definition: A curve or group of curves that represent the available heat-pump heating capacity as a function of evaporator and condenser conditions. The default curves are given as:

$$Q_{available} = CAP\_FT \times Q_{rated}$$

For air-cooled heat pumps:

$$CAP\_FT = a + b(t_{odb}) + c(t_{odb})^2 + d(t_{odb})^3$$

For water-cooled heat pumps:

$$CAP\_FT = a + b(t_{db}) + d(t_{wt})$$

Where:

> $\boldsymbol{Q_{available}}$ — Available heating capacity at present evaporator and condenser conditions (kBtu/h)
> $\boldsymbol{t_{db}}$ — The entering coil dry-bulb temperature (°F)
> $\boldsymbol{t_{wt}}$ — The water supply temperature (°F)
> $\boldsymbol{t_{odb}}$ — The outside-air dry-bulb temperature (°F)
> $\boldsymbol{Q_{rated}}$ — Rated capacity at AHRI conditions (in kBtu/h)

Units: Data structure.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

Standard Design: Use prescribed curves as described above.

Electric Heat Pump Heating Efficiency Adjustment Curve(s)

Applicability: All heat pumps except AWHPs.

Definition: A curve or group of curves that varies the heat pump heating efficiency as a function of evaporator conditions, condenser conditions and part-load ratio. The default curves are given as:

$$PLR = \frac{Q_{operating}}{Q_{available}(t_{db}, t_{odb/wt})}$$

$$EIR_{FPLR} = a + b(PLR) + c(PLR)^2 + d(PLR)^3$$

Air-Source Heat Pumps:

$$EIR_{FT} = a + b(t_{odb}) + c(t_{odb})^2 + d(t_{odb})^3$$

Water-Source Heat Pumps:

$$EIR_{FT} = a + b(t_{wt}) + d(t_{db})$$

$$P_{operating} = P_{rated}(EIR_{FPLR})(EIR_{FT})(CAP_{FT})$$

Where:

$\boldsymbol{PLR}$ — Part-load ratio based on available capacity (not rated capacity)

$\boldsymbol{EIR_{FPLR}}$ — A multiplier on the EIR of the heat pump as a function of part-load ratio

$\boldsymbol{EIR_{FT}}$ — A multiplier on the EIR of the heat pump as a function of the wet-bulb temperature entering the coil and the outdoor dry-bulb temperature

$\boldsymbol{Q_{operating}}$ — Present load on heat pump (Btu/h)

$\boldsymbol{Q_{available}}$ — Heat pump available capacity at present evaporator and condenser conditions (Btu/h)

$\boldsymbol{t_{db}}$ — The entering coil dry-bulb temperature (°F)

$\boldsymbol{t_{wt}}$ — The water supply temperature (°F)

$\boldsymbol{t_{odb}}$ — The outside air dry-bulb temperature (°F)

$\boldsymbol{P_{rated}}$ — Rated power draw at AHRI conditions (kW)

$\boldsymbol{P_{operating}}$ — Power draw at specified operating conditions (kW)

Units: None.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

Standard Design: Use prescribed curves as described above.

Air to Water Heat Pump Efficiency Adjustment Curves

Applicability: All AWHPs.

Definition: A curve or group of curves that varies the heating efficiency of an AWHP as a function of evaporator conditions and condenser conditions.

Multipass:

$$EIR_{FT} = a + b(t_{hwr}) + c(t_{hwr})^2 + d(t_{owb}) + e(t_{owb})^2 + f(t_{hwr})(t_{owb})$$

Packaged:

$$EIR_{FT} = a + b(t_{hwr}) + c(t_{hwr})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{hwr})(t_{odb})$$

Where:

t_{hwr} — The hot water return temperature (°C)

t_{wdb} — The outside air wet-bulb temperature (°C)

t_{odb} — The outside air dry-bulb temperature (°C)

Units: Data structure.

Input Restrictions: Curve coefficients are prescribed in Appendix 5.7 given the AWHP type.

Standard Design: Use Packaged curves specified in Appendix 5

Electric Heat Pump Supplemental Heating Capacity

Applicability: All heat pumps.

Definition: The design heating capacity of a heat pump supplemental heating coil.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all systems with heat pumps, auto-size, refer to Chapter 2.6.2 Sizing Equipment in the Standard Design.

Electric Supplemental Heating Control Temp

Applicability: All heat pumps.

Definition: The outside dry-bulb temperature below which the heat pump supplemental heating is allowed to operate.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed; default to 40°F.

Standard Design: For healthcare facilities, same as the Proposed Design. For buildings with heat pumps, no lockout, supplemental heat is allowed to operate whenever the heat pump cannot meet the load (supplemental gas heat), 40°F. For all other heat pumps 40°F.

Heat Pump Compressor Minimum Operating Temp

Applicability: All heat pumps.

Definition: The outside dry-bulb temperature below which the heat pump compressor is disabled.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For dual-fuel heat pumps, 45 °F. For all others heat pumps, 17 °F.

Coil Defrost

Applicability: Air-cooled electric heat pump.

Definition: The defrost control mechanism for an air-cooled heat pump.

The choices are:

Hot-gas defrost, on-demand
Hot-gas defrost, timed 3.5 minute cycle
Electric resistance defrost, on-demand
Electric resistance defrost, timed 3.5 minute cycle

Defrost shall be enabled whenever the outside air dry-bulb temperature drops below 40°F.

Units: List (see above).

Input Restrictions: Default to use hot-gas defrost, timed 3.5 minute cycle. User may select any of the above.

Standard Design: For healthcare facilities, same as the proposed design. For all other heat pumps, hot-gas defrost, timed 3.5 minute cycle.

Coil Defrost kW

Applicability: Heat pumps with electric resistance defrost.

Definition: The capacity of the electric resistance defrost heater.

Units: Kilowatts (kW).

Input Restrictions: As designed; defaults to 0 if nothing is entered.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Crank Case Heater kW

Applicability: All air source heat pumps.

Definition: The capacity of the electric resistance heater in the crank case of a direct expansion (DX) compressor. The crank case heater operates only when the compressor is off.

Units: Kilowatts (kW).

Input Restrictions: Where applicable, the value is prescribed to be 10 W per ton (rated net cooling capacity).

Standard Design: Where applicable, the value is prescribed to be 10 W per ton (rated net cooling capacity)

Crank Case Heater Shutoff Temperature

Applicability: All air source heat pumps.

Definition: The outdoor air dry-bulb temperature above which the crank case heater is not permitted to operate.

Units: Degrees Fahrenheit (°F).

Input Restrictions: Where applicable, the value is prescribed to be 50°F.

Standard Design: Where applicable, the value is prescribed to be 50°F.

5.7.7 Exhaust Air Heat Recovery

Recovery Type

Applicability: All systems with airside heat recovery.

Definition: The type of heat recovery system.

Units: List: sensible, latent, or total (sensible and latent).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design.

For all others, sensible if impacted based on requirements in 140.4(q) or 140.9(c)6. Not applicable for all systems.

Standard Design: *Existing Buildings:* For healthcare facilities, same as the proposed design.

For all others, sensible if impacted based on requirements in 140.4(q) or 140.9(c)6. Not applicable for all systems.

Recovery Airflow Rate

Applicability: All systems with airside heat recovery.

Definition: The design airflow rate through the heat recovery system.

Units: CFM.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design.

For all others, equal to the design outdoor airflow rate, and assume balanced flow if impacted based on requirements in 140.4(q) or 140.9(c)6. Not applicable for all systems.

Standard Design: Existing Buildings: Assume balanced flow if impacted based on requirements in 140.4(q) and 140.9(c)6. Not applicable for all systems.

Exhaust Air Sensible Heat Recovery Effectiveness

Applicability: Any system with outside air heat recovery.

Definition: The effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams. Effectiveness is defined as:

Where:

> $\boldsymbol{HREFF}$ — The air-to-air heat exchanger effectiveness
> $\boldsymbol{EEA_{db}}$ — The exhaust air dry-bulb temperature entering the heat exchanger
> $\boldsymbol{ELA_{db}}$ — The exhaust air dry-bulb temperature leaving the heat exchanger
> $\boldsymbol{OSA_{db}}$ — The outside air dry-bulb temperature

Units: Two unitless numbers (ratio between 0 and 1), separate for cooling and heating.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, the sensible effectiveness is 60% if the Proposed Design has heat recovery.

For all others, the sensible effectiveness is 60% if using for HVAC systems impacted based on requirements in 140.4(q) and 45% at heating design conditions and 25% at cooling design conditions if using HVAC systems impacted based on requirements in 140.9(c)6. Not applicable for all systems.

Standard Design: Existing Buildings: The sensible effectiveness is 60% if using for HVAC systems impacted based on requirements in 140.4(q) and 45% at heating design conditions and 25% at cooling design conditions if using for HVAC systems impacted based on requirements in 140.9(c)6. Not applicable for all systems.

Exhaust Air Sensible Part-Load Effectiveness

Applicability: Any system with outside air heat recovery.

Definition: The effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams at 75 percent of design airflow. Effectiveness is defined as:

$$HREFF = \frac{EEA_{db} - ELA_{db}}{EEA_{db} - OSA_{db}}$$

Where:

$HREFF$ — The air-to-air heat exchanger effectiveness

EEA_{db} — The exhaust air dry-bulb temperature entering the heat exchanger

ELA_{db} — The exhaust air dry-bulb temperature leaving the heat exchanger

OSA_{db} — The outside air dry-bulb temperature

Units: Two unitless numbers (ratio between 0 and 1), separate for cooling and heating.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, the sensible effectiveness is 60% if the Proposed Design has heat recovery.

For all others, the sensible effectiveness is 65% if using for HVAC systems impacted based on requirements in 140.4(q) and 45% at heating design conditions and 25% at cooling design conditions if using HVAC systems impacted based on requirements in 140.9(c)6. Not applicable for all systems.

Standard Design: Existing Buildings: The sensible effectiveness is 65% if using for HVAC systems impacted based on requirements in 140.4(q) and 45% at heating design conditions and 25% at cooling design conditions if using HVAC systems impacted based on requirements in 140.9(c)6. Not applicable for all systems.

Exhaust Air Latent Heat Recovery Effectiveness

Applicability: Any system with outside air enthalpy heat recovery.

Definition: The latent heat recovery effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams. Effectiveness is defined as:

$$HREFF = \frac{EEA_{w} - ELA_{w}}{EEA_{w} - OSA_{w}}$$

Where:

$\boldsymbol{HREFF}$ — The air-to-air heat exchanger effectiveness

$\boldsymbol{EEA_w}$ — The exhaust air humidity ratio (fraction of mass of moisture in air to mass of dry air) entering the heat exchanger

$\boldsymbol{ELA_w}$ — The exhaust air humidity ratio leaving the heat exchanger

$\boldsymbol{OSA_w}$ — The outside air humidity ratio

Note: For sensible heat exchangers, this term is not applicable

Units: Two unitless numbers (ratio between 0 and 1), separate for cooling and heating.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Not applicable.

Exhaust Air Latent Part-Load Effectiveness

Applicability: Any system with outside air enthalpy heat recovery.

Definition: The latent heat recovery effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams at 75 percent of design airflow. Effectiveness is defined as:

$$HREFF = \frac{EEA_w - ELA_w}{EEA_w - OSA_w}$$

Where:

$\boldsymbol{HREFF}$ — The air-to-air heat exchanger effectiveness

$\boldsymbol{EEA_w}$ — The exhaust air humidity ratio (fraction of mass of moisture in air to mass of dry air) entering the heat exchanger

$\boldsymbol{ELA_w}$ — The exhaust air humidity ratio leaving the heat exchanger

$\boldsymbol{OSA_w}$ — The outside air humidity ratio

Note: For sensible heat exchangers, this term is not applicable.

Units: Two unitless numbers (ratio between 0 and 1), separate for cooling and heating.

Input Restrictions: As designed.

Standard Design: Not applicable.

Heat Recovery Economizer Lockout

Applicability: All systems with airside heat recovery.

Definition: A flag to indicate whether or not the heat recovery is bypassed when economizer is enabled.

Units: Boolean.

Input Restrictions: As designed.

Standard Design: For healthcare facilities heat recovery, energy recovery bypass during economizer operation.

For all others, heat recovery bypass during economizer operation for HVAC systems impacted based on requirements in 140.4(q) and 140.9(c)6. Not applicable for all systems.

Standard Design: Existing Buildings: The economizer is disabled for HVAC systems impacted based on requirements in 140.4(q) and 140.9(c)6. Not applicable for all systems.

5.8 HVAC Primary Systems

5.8.1 Hydronic System Heating Equipment

Boiler Name

Applicability: All boilers.

Definition: A unique descriptor for each boiler, heat pump, central heating heat-exchanger, or heat recovery device.

Units: None.

Input Restrictions: User entry.

Where applicable, this should match the tags that are used on the plans for the proposed design.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, Boilers are only designated in the standard design if the baseline system type uses hot water for space heating.

Boiler Fuel Source

Applicability: All boilers. Not applicable to AWHP's.

Definition: The fuel source for the central heating equipment.

The choices are:

Gas

Electricity

Units: List (see above).

Input Restrictions: As designed.

This input is restricted, based on the choice of boiler type, according to the following rules:

- Steam Boiler
  - Electricity — n/a
  - Gas — n/a
  - Steam — Allowed
- Hot Water Boiler
  - Electricity — n/a
  - Gas — Allowed

- Steam — n/a

Standard Design: For healthcare facilities with electric boilers the standard design systems will match the proposed design except for the fuel type which is gas in the standard design. For all others, gas.

Standard Design: Existing Buildings: Same as proposed for existing, unaltered; same as newly constructed buildings if altered.

Boiler Type

Applicability: All boilers.

Definition: Type of fluid used for heat transfer.

The choices are:

Hot Water
Steam

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as Proposed Design. For all others, Hot Water boiler.

Standard Design: Existing Buildings: Same as proposed for existing, unaltered; same as newly constructed buildings if altered.

Boiler Draft Type

Applicability: All boilers.

Definition: How combustion airflow is drawn through the boiler.

The choices are Natural, Mechanical Noncondensing, or Condensing.

Natural draft boilers use natural convection to draw air for combustion through the boiler. Natural draft boilers are subject to outside air conditions and the temperature of the flue gases.

Condensing boilers reclaim heat of condensation from water in the flue gas to achieve efficiencies of 90 percent. However, if the water entering the boiler (return water temperature) is too hot, then condensing does not occur, and the boiler operates at efficiencies below 82 percent. Condensing boilers require a draft fan to ensure airflow through the complex flue gas passages.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design.

For gas-fired boilers in climate zones 1 through 6, 9 through 14 and 16 with rated capacity above 1 MMBtu/h and less than 10 MMBtu/h, condensing boilers.

For all others, non-condensing.

Number of Identical Boiler Units

Applicability: All boilers.

Definition: The number of identical units for staging.

Units: Numeric: integer.

Input Restrictions: As designed; default is 1.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others the Standard Design shall have one boiler when the standard design plant serves a conditioned floor area of 15,000 ft^2 or less and have two equally sized boilers for plants serving more than 15,000 ft^2.

Boiler Design Capacity

Applicability: All boilers.

Definition: The heating capacity at design conditions.

Units: Btu/h.

Input Restrictions: As designed.

If unmet load hours exceed 150, the user may need to manually adjust boiler design capacity.

Standard Design: For buildings with both healthcare and other occupancies, the proposed boiler capacity is scaled based on the ratio of the capacity of heating coils serving healthcare areas. For all others, the Standard Design boiler is sized to be 25 percent larger than the peak loads of the standard design. Standard design boilers shall be sized using weather files containing 99.6 percent heating design temperatures and 0.5 percent dry-bulb and 1 percent wet-bulb cooling design temperatures.

Boiler Efficiency Type

Applicability: All boilers.

Definition: The full load efficiency of a boiler is expressed as one of the following:

> Annual fuel utilization efficiency (AFUE) is a measure of the boiler’s efficiency over a predefined heating season.
>
> Thermal efficiency (Et) is the ratio of the heat transferred to the water divided by the heat input of the fuel.
>
> Combustion efficiency (Ec) is the measure of how much energy is extracted from the fuel and is the ratio of heat transferred to the combustion air divided by the heat input of the fuel.

Units: List (see above).

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design.

For all others, AFUE for all gas fired hot water boilers with less than 300,000 Btu/h capacity.

Thermal efficiency (Et) for all gas fired hot water boilers with capacities between 300,000 and 2,500,000 Btu/h and all gas-fired steam water boilers with capacities above 225,000 Btu/h.

Combustion efficiency (Ec), for all gas fired hot water boilers with capacities above 2,500,000 Btu/h.

Boiler Efficiency

Applicability: All boilers.

Definition: The full load efficiency of a boiler at rated conditions (see efficiency type above) expressed as a dimensionless ratio of output over input. The compliance software must accommodate input in either thermal efficiency (E_t), combustion efficiency (E_c), or AFUE. The compliance software shall make appropriate conversions to thermal efficiency if either AFUE or combustion efficiency is entered as the rated efficiency.

Where AFUE is provided, E_t shall be calculated as follows:

- $\mathbf{0.75 \leq AFUE < 0.80 — E_t = (0.1 \times AFUE) + 0.725}$
- $\mathbf{0.80 \leq AFUE \leq 1.00 — E_t = (0.875 \times AFUE) + 0.105}$

If combustion efficiency is entered, the compliance software shall convert the efficiency to thermal efficiency by the relation:

$$E_t = E_c - 0.015$$

All electric boilers will have an efficiency of 98 percent.

Units: Ratio.

Input Restrictions: The boiler efficiency should meet the minimum efficiency requirements as specified by Table 110.2-J.

Standard Design: Boilers with rated capacity below 1 MMBtu for the standard design have the minimum efficiency listed in Table E-4 of the *California Appliance Efficiency Regulations*.

Gas-fired boilers in climate zones 1 through 6, 9 through 14 and 16 with rated capacity 1 MMBtu/h to 10 MMBtu/h have a standard design efficiency of 90 percent.

Boiler Part-Load Performance Curve

Applicability: All boilers.

Definition: An adjustment factor that represents the percentage full load fuel consumption as a function of the percentage full load capacity. This curve shall take the form of a quadratic equation as follows:

$$Fuel_{partload} = Fuel_{design}\left[FHeatPLC(Q_{partload,}Q_{rated})\right]$$

$$FHeatPLC = \left(a + b\left(\frac{Q_{partload}}{Q_{rated}}\right) + c\left(\frac{Q_{partload}}{Q_{rated}}\right)^2\right)$$

Where:

$FHeatPLC$ — The fuel heating part-load efficiency curve
$Fuel_{partload}$ — The fuel consumption at part-load conditions (Btu/h)
$Fuel_{design}$ — The fuel consumption at design conditions (Btu/h)
$Q_{partload}$ — The boiler capacity at part-load conditions (Btu/h)
Q_{rated} — The boiler capacity at design conditions (Btu/h)
a — Constant
b — Constant
c — Constant

Units: Ratio.

Input Restrictions: Prescribed to the part-load performance curve in the ACM Appendix 5.7, based on the boiler draft type.

Standard Design: The standard design uses the mechanical draft fan curve in Appendix 5.7.

Boiler Forced Draft Fan Power

Applicability: All mechanical draft boilers.

Definition: The fan power of the mechanical draft fan at design conditions.

Units: Nameplate horsepower.

Input Restrictions: As designed.

The compliance software shall convert the user entry of motor horsepower to fan power in watts by the following equation:

Fan Power=Motor HP(746)(0.5)

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, Sized for an energy input ratio of 0.0000008 HP per Btu/h (0.2984 W per kBtu/h heat input).

Boiler Minimum Unloading Ratio

Applicability: All boilers.

Definition: The minimum unloading capacity of a boiler expressed as a percentage of the rated capacity. Below this level, the boiler must cycle to meet the load.

Units: Percent (%).

Input Restrictions: As designed.

If the user does not use the default values of 1 percent for electric boilers and 25 percent for gas boilers, the compliance software must indicate that supporting documentation is required on the output forms.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, 25 percent.

Boiler Minimum Flow Rate

Applicability: All boilers.

Definition: The minimum flow rate recommended by the boiler manufacturer for stable and reliable operation of the boiler.

Units: Gpm.

Input Restrictions: As designed.

If the boiler(s) is piped in a primary only configuration in a variable flow system then the compliance software shall assume there is a minimum flow bypass valve that allows the hot water pump to bypass water from the boiler outlet back to the boiler inlet to maintain the minimum flow rate when boiler is enabled.

Note: The boiler entering water temperature must accurately reflect the mixed temperature (colder water returning from the coil(s) and hotter bypass water) to accurately model boiler efficiency as a function of boiler entering water temperature.

Standard Design: For buildings with both healthcare and other occupancies, the proposed boiler minimum low rate is scaled based on the ratio to the capacity of heating coils serving healthcare areas. For all others, 0 gpm.

Air to Water Heat Pump Rated Heating Capacity

Applicability: All AWHPs.

Definition: The heating capacity of the AWHP at rated conditions.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Sized to 25% larger than 50% of the load at heating design conditions or 17°F whichever is greater [Design Load x 0.5 x 1.25].

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Air to Water Heat Pump Capacity Ratio Curves

Applicability: All AWHPs.

Definition: A curve or group of curves that varies the heating efficiency of an AWHP as a function of evaporator conditions and condenser conditions.

Multipass:

$$EIR_{FT} = a + b(t_{hwr}) + c(t_{hwr})^2 + d(t_{owb}) + e(t_{owb})^2 + f(t_{hwr})(t_{owb})$$

Non-modular:

$$EIR_{FT} = a + b(t_{hws}) + c(t_{hws})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{hws})(t_{odb})$$

Where:

t_{hwr} — The hot water return temperature (°C)

t_{hws} — The hot water supply temperature (°C)

t_{wdb} — The outside air wet-bulb temperature (°C)

t_{odb} — The outside air dry-bulb temperature (°C)

Units: Data structure.

Input Restrictions: Curve coefficients are prescribed in Appendix 5.7 given the AWHP type.

Standard Design: Use Packaged curves specified in Appendix 5.7.

Air to Water Heat Pump Supplemental Boiler Rated Heating Capacity

Applicability: All AWHPs.

Definition: The heating capacity of the AWHP's integral tank element at rated conditions.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: Sized to 25 percent larger than the full heating design load at design conditions.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed building rules if altered or replacement.

Air to Water Heat Pump Rated Heating COP

Applicability: All AWHPs.

Definition: The heating efficiency of the AWHP at rated full-load conditions.

Units: COP.

Input Restrictions: As designed. User entered COP is adjusted based on Appendix 5.7 performance curve.

Standard Design: Offices, 2.31 at 140 leaving water temperature. Schools in climate zone 2, 2.77 at 120 leaving water temperature. Schools in all other climate zones, 2.31 at 140 leaving water temperature. COP is adjusted based on Appendix 5.7 AWHP performance curve.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Air to Water Heat Pump COP Ratio Curves

Applicability: All AWHPs.

Definition: A curve or group of curves that varies the heating efficiency of an AWHP as a function of evaporator conditions and condenser conditions.

Multipass:

$$EIR_{FT} = a + b(t_{hwr}) + c(t_{hwr})^2 + d(t_{owb}) + e(t_{owb})^2 + f(t_{hwr})(t_{owb})$$

Non-modular:

$$EIR_{FT} = a + b(t_{hws}) + c(t_{hws})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{hws})(t_{odb})$$

Where:

t_{hwr} — The hot water return temperature (°C)

t_{hws} — The hot water supply temperature (°C)

t_{wdb} — The outside air wet-bulb temperature (°C)

t_{odb} — The outside air dry-bulb temperature (°C)

Units: Data structure.

Input Restrictions: Curve coefficients are prescribed in Appendix 5.7 given the AWHP type.

Standard Design: Use Packaged curves specified in Appendix 5.7.

Air to Water Heat Pump Rated Inlet Air Drybulb

Applicability: All AWHPs.

Definition: The dry-bulb temperature at rated full-load conditions.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: 47 °F.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Air to Water Heat Pump Rated Inlet Water Temperature

Applicability: All AWHPs.

Definition: The condenser inlet water temperature at rated full-load conditions.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For schools in climate zone 2, 120°F. All other climate zones, 140 °F.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Air to Water Heat Pump Minimum Outdoor Temperature for Compressor Operation

Applicability: All AWHPs.

Definition: The minimum outdoor air temperature where the compressor operates.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: 17 °F.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Hot Water Supply Temperature

Applicability: All boilers and AWHPs.

Definition: The temperature of the water produced by the boiler or AWHP and supplied to the hot water loop.

Units: Degrees Fahrenheit (°F).

Input Restrictions: Less than 130 °F

Standard Design: Use 130°F for standard design boiler. If the standard design is an AWHP, 120°F for schools in climate zone 2. All other AWHP standard designs, 130°F.

Hot Water Temperature Difference

Applicability: All boilers and AWHPs.

Definition: The difference between the temperature of the water returning to the boiler from the hot water loop and the temperature of the water supplied to the loop.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: Use 25°F when the standard design is a gas boiler. AWHP's serving offices, 10°F. AWHP's serving schools in climate zone 2, 15°F. AWHP's serving schools in all other climate zones, 10°F.

Hot Water Supply Temperature Reset

Applicability: All boilers and AWHPs.

Definition: Variation of the hot water supply temperature with outdoor air temperature.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: The hot water supply temperature is fixed to match the temperature reset of the proposed design.

5.8.2 Chillers

Chiller Name

Applicability: All chillers.

Definition: A unique descriptor for each chiller.

Units: Text, unique.

Input Restrictions: User entry: where applicable, this should match the tags that are used on the plans.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, Chillers are only designated when the standard design system uses chilled water. The chiller plan will include a heat recovery chiller sized as specified by 140.4(s)1 if the proposed design meets the 140.4(s)1A or 140.4(s)1B.

Chiller Type

Applicability: All chillers.

Definition: The type of chiller, either a vapor-compression chiller or an absorption chiller.

Vapor compression chillers operate on the reverse Rankine cycle, using mechanical energy to compress the refrigerant, and include:

- Reciprocating*
- Scroll*
- Screw*
- Centrifugal – uses rotating impeller blades to compress the air and impart velocity
- Single Effect Absorption
- Direct-Fired Single Effect Absorption – uses a single generator and condenser
- Direct-Fired Double Effect Absorption – uses two generators/ concentrators and condensers, one at a lower temperature and the other at a higher temperature. It is more efficient than the single effect, but it must use a higher temperature heat source.
- Indirect-Fired Double Effect Absorption
- Gas Engine-Driven*Positive displacement – includes reciprocating (piston-style), scroll and screw compressors.

Units: List (see above). The compliance software shall support all chiller types listed above.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, the standard design chiller is based on the design capacity of the standard design as follows:

Table 18: Type and Number of Chillers

Building Peak Cooling Load	Number and type of chiller(s)
< 300 tons	One water-cooled screw chiller
>300 tons < 600 tons	Two water-cooled screw chillers, sized equally

Building Peak Cooling Load	Number and type of chiller(s)
≥ 600 tons	A minimum of two water-cooled centrifugal chillers, sized to keep the unit size below 800 tons

Source: California Energy Commission

Number of Identical Chiller Units

Applicability: All chillers.

Definition: The number of identical units for staging.

Units: None.

Input Restrictions: As designed; default is 1.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, From the number indicated in Chiller Type.

Chiller Fuel Source

Applicability: All chillers.

Definition: The fuel source for the chiller.

The choices are:

Electricity (for all vapor-compression chillers)
Indirect (absorption units only)
Gas (absorption units only, designated as direct-fired units)
Hot water (absorption units only, designated as indirect-fired units)
Steam (absorption units only, designated as indirect-fired units)

Units: List (see above).

Input Restrictions: As designed.

This input is restricted, based on the choice of chiller type, according to the following rules:

Reciprocating

- Electricity — Allowed
- Indirect – n/a
- Gas — n/a
- Hot Water — n/a
- Steam — n/a

Scroll

- Electricity — Allowed
- Indirect – n/a
- Gas — n/a

- Hot Water — n/a
- Steam — n/a

Screw

- Electricity — Allowed
- Indirect – n/a
- Gas — n/a
- Hot Water — n/a
- Steam — n/a

Centrifugal

- Electricity — Allowed
- Indirect – n/a
- Gas — n/a
- Hot Water — n/a
- Steam — n/a

Single Effect Absorption

- Electricity — n/a
- Indirect - Allowed
- Gas — Allowed
- Hot Water — Allowed
- Steam — Allowed

Direct-Fired Double Effect Absorption

- Electricity — n/a
- Gas — Allowed
- Hot Water — Allowed
- Steam — Allowed

Indirect-Fired Absorption

- Electricity — n/a
- Gas — Allowed
- Hot Water — Allowed
- Steam — Allowed

Standard Design: For healthcare facilities, same as the proposed design. For all others, Electricity.

Chiller Rated Capacity

Applicability: All chillers.

Definition: The cooling capacity of a piece of heating equipment at rated conditions.

Units: Btu/h or tons.

Input Restrictions: As designed.

The user may need to manually adjust the capacity if the number of unmet load hours exceeds 150.

Standard Design: For buildings with both healthcare and other occupancies, the proposed chiller capacity is scaled based on the ratio to the capacity of cooling coils serving healthcare areas. For all others, the Standard Design chiller is sized to be 15 percent larger than the peak loads of the Standard Design.

Chiller Rated Efficiency

Applicability: All chillers.

Definition: The efficiency of the chiller (EER for air-cooled chillers, kW/ton for water-cooled electric chillers, and COP for fuel-fired and heat-driven chillers) at AHRI 550/590 rated full-load conditions.

Units: Ratio (kW/ton, COP, EER, depending on chiller type and condenser type).

Water-cooled electric chiller — kW/ton.

Air-cooled or evaporatively-cooled electric chiller — EER

All non-electric chillers – COP

Input Restrictions: As designed.

Must meet the minimum requirements of Table 110.2-D.

Standard Design: Use the minimum efficiency requirements from Tables 110.2-D Path B.

If chiller type is reciprocating, scroll, or screw, use the efficiency for positive displacement chillers from Table 110.2-D.

Standard Design: Existing Buildings: Same as proposed if unaltered; same as newly constructed buildings rules if altered or replacement.

Integrated Part-Load Value

Applicability: All chillers except single effect absorption chillers.

Definition: The part-load efficiency of a chiller developed from a weighted average of four rating conditions, as specified by AHRI 550/590.

Units: Ratio.

Input Restrictions: As designed; must meet the minimum requirements of Table 110.2-D.

Standard Design: For healthcare facilities, use the minimum efficiency requirements from Tables 110.2-D Path B. For all others, not used.

When the standard design system has a chiller, the standard design will always use Path B performance curves.

Chiller Minimum Unloading Ratio

Applicability: All chillers.

Definition: The minimum unloading capacity of a chiller expressed as a fraction of the rated capacity. Below this level the chiller must either cycle to meet the load or false-load the compressor (such as with hot gas bypass).

Table 19: Default Minimum Unloading Ratios

Chiller Type	Default Minimum Unloading Ratio
Reciprocating	25%
Screw	15%
Centrifugal	10%
Scroll	25%
Single Effect Absorption	10%
Double Effect Absorption	10%

Source: California Energy Commission

Units: Percent (%).

Input Restrictions: As designed but constrained to a minimum value of 10 percent and must be equal to or greater than the minimum part load ratio. If the user does not employ the default values, supporting documentation is required.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, use defaults listed above.

Chiller Minimum Part Load Ratio

Applicability: All chillers.

Definition: The minimum part load capacity of a chiller expressed as a fraction of the rated capacity. Below this level the chiller must cycle to meet the load.

If the chiller minimum part-load ratio (PLR) is less than the chiller minimum unloading ratio, then the compliance software shall assume hot gas bypass operation between the minimum PLR and the minimum unloading ratio.

Units: Percent (%).

Input Restrictions: As designed but constrained to a minimum value of 10 percent and must be equal to or greater than the minimum unloading ratio. If the user does not employ the default values, supporting documentation is required.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, When the standard design has a screw chiller, the minimum PLR is 15 percent. When the standard design has a centrifugal chiller, the minimum PLR is 10 percent.

Chiller Cooling Capacity Adjustment Curve

Applicability: All chillers.

Definition: A curve or group of curves or other functions that represent the available total cooling capacity as a function of evaporator and condenser conditions and perhaps other operating conditions. The default curves are given as:

$$Q_{available} = CAP_{FT}(Q_{rated})$$

For air-cooled chillers:

$$CAP_{FT} = a + b(t_{chws}) + c(t_{chws})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{chws})(t_{odb})$$

For water-cooled chillers:

$$CAP_{FT} = a + b(t_{chws}) + c(t_{chws})^2 + d(t_{cws}) + e(t_{cws})^2 + f(t_{chws})(t_{cws})$$

Where:

$\boldsymbol{Q_{available}}$ — Available cooling capacity at present evaporator and condenser conditions (MBH)
$\boldsymbol{t_{chws}}$ — The chilled water supply temperature (°F)
$\boldsymbol{t_{cws}}$ — The condenser water supply temperature (°F)
$\boldsymbol{t_{odb}}$ — The outside air dry-bulb temperature (°F)
$\boldsymbol{Q_{rated}}$ — Rated capacity at AHRI conditions (MBH)

Note: If an air-cooled unit employs an evaporative condenser, t_{odb} is the effective dry-bulb temperature of the air leaving the evaporative cooling unit.

Separate curves are provided for Path A and Path B chillers in Appendix 5.7.

Units: Data structure.

Input Restrictions: Prescribed curves are provided in Appendix 5.7 for the proposed design chiller type and the compliance path (A or B). If the default curves are overridden, supporting documentation is required.

Standard Design: Use prescribed curve for Path B chiller as applicable to the standard design chiller type.

Electric Chiller Cooling Efficiency Adjustment Curves

Applicability: All chillers.

Definition: A curve or group of curves that varies the cooling efficiency of an electric chiller as a function of evaporator conditions, condenser conditions and part-load ratio.

Note: For variable-speed chillers, the part-load cooling efficiency curve is a function of both part-load ratio and leaving condenser water temperature. The default curves are given as:

$$PLR = \frac{Q_{operating}}{Q_{available}(t_{chws}, t_{cws/odb})}$$

Variable Speed:

$$EIR_{FPLR} = a + b(PLR) + c(PLR)^2$$

Air-Cooled:

$$EIR_{FT} = a + b(t_{chws}) + c(t_{chws})^2 + d(t_{odb}) + e(t_{odb})^2 + f(t_{chws})(t_{odb})$$

Water-Cooled:

$$EIR_{FT} = a + b(t_{chws}) + c(t_{chws})^2 + d(t_{cws}) + e(t_{cws})^2 + f(t_{chws})(t_{cws})$$

$$P_{operating} = P_{rated}(EIR_{FPLR})(EIR_{FT})(CAP_{FT})$$

Where:

$\boldsymbol{PLR}$ — Part-load ratio based on available capacity (not rated capacity)
$\boldsymbol{Q_{operating}}$ — Present load on chiller (Btu/h)
$\boldsymbol{Q_{available}}$ — Chiller available capacity at present evaporator and condenser conditions (Btu/h)
$\boldsymbol{t_{chws}}$ — The chilled water supply temperature (°F)
$\boldsymbol{t_{cws}}$ — The condenser water supply temperature (°F)
$\boldsymbol{t_{odb}}$ — The outside air dry-bulb temperature (°F)
$\boldsymbol{P_{rated}}$ — Rated power draw at AHRI conditions (kW)
$\boldsymbol{P_{operating}}$ — Power draw at specified operating conditions (kW)

Note: If an air-cooled chiller employs an evaporative condenser, t_{odb} is the effective dry-bulb temperature of the air leaving the evaporative cooling unit.

Units: Data structure.

Input Restrictions: Curves are prescribed in Appendix 5.7 given the chiller capacity and type. A separate set of curves are provided for Path A chillers and Path B chillers. The path is determined by comparing compliance software inputs of full-load efficiency and integrated part-load value with the requirements of Table 110.2-D of the Energy Code.

Standard Design: Use Path B curves specified in Appendix 5.7.

Fuel and Steam Chiller Cooling Efficiency Adjustment Curves

Applicability: All chillers.

Definition: A curve or group of curves that varies the cooling efficiency of a fuel-fired or steam chiller as a function of evaporator conditions, condenser conditions, and part-load ratio. The default curves are given as follows:

Default curves for steam-driven single and double effect absorption chillers:

$$PLR = \frac{Q_{operating}}{Q_{available}(t_{chws}, t_{cws/odb})}$$

$$FIR_{FPLR} = a + b(PLR) + c(PLR)^2$$

$$FIR_{FT} = a + b(t_{chws}) + c(t_{chws})^2 + d(t_{cws}) + e(t_{cws})^2 + f(t_{chws})(t_{cws})$$

$$Fuel_{partload} = (Fuel_{rated})(FIR_{FPLR})(FIR_{FT})(CAP_{FT})$$

Default curves for direct-fired double effect absorption chillers:

$$PLR = \frac{Q_{operating}}{Q_{available}(t_{chws}, t_{cws/odb})}$$

$$FIR_{FPLR} = a + b(PLR) + c(PLR)^2$$

$$FIR_{FT1} = a + b(t_{chws}) + c(t_{chws})^2$$

$$FIR_{FT2} = d + e(t_{cws}) + f(t_{cws})^2$$

$$Fuel_{partload} = (Fuel_{rated})(FIR_{FPLR})(FIR_{FT1})(FIR_{FT2})(CAP_{FT})$$

The default curves for engine driven chillers are the same format as those for the steam-driven single and double effect absorption chillers but there are three sets of curves for different ranges of operation based on the engine speed.

Where:

$\boldsymbol{PLR}$ — Part-load ratio based on available capacity (not rated capacity)
$\boldsymbol{FIR_{FPLR}}$ — A multiplier on the fuel input ratio (FIR) to account for part-load conditions
$\boldsymbol{FIR_{FT}}$ — A multiplier on the fuel input ratio (FIR) to account for the chiller water supply temperature and the condenser water temperature
$\boldsymbol{FIR_{FT1}}$ — A multiplier on the fuel input ratio (FIR) to account for chilled water supply temperature
$\boldsymbol{FIR_{FT2}}$ — A multiplier on the fuel input ratio (FIR) to account for condenser water supply temperature
$\boldsymbol{CAP_{FT}}$ — A multiplier on the capacity of the chiller (Equation 45)
$\boldsymbol{Q_{operating}}$ — Present load on chiller (in Btu/h)
$\boldsymbol{Q_{available}}$ — Chiller available capacity at present evaporator and condenser conditions (in Btu/h)
$\boldsymbol{t_{chws}}$ — The chilled water supply temperature (in °F)
$\boldsymbol{t_{cws}}$ — The condenser water supply temperature (in °F)
$\boldsymbol{t_{odb}}$ — The outside air dry-bulb temperature (°F)
$\boldsymbol{Fuel_{rated}}$ — Rated fuel consumption at AHRI conditions (in Btu/h)

$Fuel_{partload}$ — Fuel consumption at specified operating conditions (in Btu/h)

Units: Data structure.

Input Restrictions: Restricted to curves specified in Appendix 5.7.

Standard Design: Use prescribed curves specified in Appendix 5.7.

Chilled Water Supply Temperature

Applicability: All chillers.

Definition: The chilled water supply temperature of the chiller at design conditions.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, the standard design chilled water supply temperature is set to 44°F.

Chilled Water Return Temperature

Applicability: All chillers.

Definition: The chilled water return temperature setpoint at design conditions.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, the standard design chilled water return temperature is set to 64°F.

Chilled Water Supply Temperature Control Type

Applicability: All chillers.

Definition: The method by which the chilled water setpoint temperature is reset.

The chilled water setpoint may be reset based on demand or outdoor air temperature.

Units: List fixed, scheduled, outsideairreset, wetbulbreset, fixeddualsetpoint.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, outside air-based reset.

Chilled Water Supply Temperature Reset

Applicability: All chillers.

Definition: The reset schedule for the chilled water supply temperature. The chilled water setpoint may be reset based on demand or outdoor air temperature.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, 10°F from design chilled water supply temperature.

The chilled water supply temperature reset follows an outside air reset scheme, where the setpoint is 44°F at outside air conditions of 80°F dry-bulb and above; the setpoint is 54°F at outside air conditions of 60°F dry-bulb and below; and ramps linearly from 44°F to 54°F as the outside air dry-bulb temperature varies between 80°F and 60°F.

CONDENSER TYPE

Applicability: All chillers.

Definition: The type of condenser for a chiller.

The choices are:

Air-cooled
Water-cooled

Air-cooled chillers use air to cool the condenser coils. Water-cooled chillers use cold water to cool the condenser and additionally need either a cooling tower or a local source of cold water. Evaporatively-cooled chillers are similar to air-cooled chillers, except a water mist is used to cool the condenser coil, making them more efficient.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, the standard design chiller is always assumed to have a water-cooled condenser, although the chiller type will change depending on the design capacity.

5.8.3 Cooling Towers

Standard Design Summary. Standard design system 6, 14b and 15has one or more cooling towers. One tower is assumed to be matched to each standard design chiller. Each standard design chiller has its own condenser water pump that operates when the chiller is brought into service.

COOLING TOWER NAME

Applicability: All cooling towers.

Definition: A unique descriptor for each cooling tower.

Units: Text, unique.

Input Restrictions: User entry: where applicable, this should match the tags that are used on the plans.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others descriptive name that keys the standard design building plant.

Cooling Tower Type

Applicability: All cooling towers.

Definition: Type of cooling tower employed.

The choices are:

- Open tower, centrifugal fan
- Open tower, axial fan
- Closed tower, centrifugal fan
- Closed tower, axial fan
- Closed tower evaporative, centrifugal fan
- Closed tower evaporative, axial fan

Open cooling towers collect the cooled water from the tower and pump it directly back to the cooling system. Closed towers circulate the evaporated water over a heat exchanger to indirectly cool the system fluid.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, if the open tower design condenser flow rate is greater than 900 gpm, the fan is axial, otherwise same as the proposed design. For all others, the standard design cooling tower is an open tower axial fan device.

Cooling Tower Capacity

Applicability: All cooling towers.

Definition: The tower thermal capacity per cell adjusted to Cooling Technology Institute (CTI) rated conditions of 95°F condenser water return, 85°F condenser water supply, and 78°F wet-bulb with a 3 gpm/nominal ton water flow. The default cooling tower curves below are at unity at these conditions.

Units: Btu/h.

Input Restrictions: As designed.

Standard Design: For buildings with both healthcare and other occupancies, the proposed cooling tower capacity is scaled based on the ratio to the capacity of chillers serving healthcare areas. For all others, the Standard Design tower is sized to supply 85°F condenser water at design conditions for the oversized chiller.

Cooling Tower Number of Cells

Applicability: All cooling towers.

Definition: The number of cells in the cooling tower.

Each cell will be modeled as equal size. Cells are subdivisions in cooling towers into individual cells, each with their own fan and water flow, that allow the cooling system to respond more efficiently to lower load conditions.

Units Numeric: integer.

Input Restrictions: As designed.

Standard Design: One cell per tower and one tower per chiller.

Cooling Tower Total Fan Horsepower

Applicability: All cooling towers.

Definition: The sum of the nameplate rated horsepower (hp) of all fan motors on the cooling tower. Pony motors should not be included.

Units: hp.

Input Restrictions: As designed, but the cooling towers shall meet minimum performance requirements in Table 110.2-E of the Energy Code.

Standard Design: Cooling towers with a design condenser water flow greater than 900 gpm shall have a fan horsepower calculated based on the water flow rate (3.0 gpm per nominal cooling ton) of between 42.1 and 80 gpm/hp in, as specified in Table 140.4-H-2 or 170.2-I of the Energy Code. Cooling towers with a design condenser water flow of 900 gpm or less shall have a fan horsepower of 42.1 gpm/hp.

Standard Design: Existing Buildings: 42.1 gpm/hp.

Cooling Tower Design Wet-Bulb

Applicability: All cooling towers.

Definition: The design wet-bulb temperature that was used for selection and sizing of the cooling tower.

Units: Degrees Fahrenheit (°F).

Input Restrictions: Specified from design wet-bulb conditions from Reference Appendix JA2 for the city where the building is located, or the city closest to where the building is located.

Standard Design: Specified from design wet-bulb conditions from Reference Appendix JA2 for the city where the building is located, or from the city closest to where the building is located.

Cooling Tower Design Leaving Water Temperature

Applicability: All cooling towers.

Definition: The design condenser water supply temperature (leaving tower) that was used for selection and sizing of the cooling tower.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed; default to 85°F.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, 85°F or 10°F above the design wet-bulb temperature, whichever is lower.

Cooling Tower Design Return Water Temperature

Applicability: All cooling towers.

Definition: The design condenser water return temperature (entering tower) that was used for selection and sizing of the cooling tower.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed; default to 95°F.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, set to a range of 10°F (10°F above the cooling tower design entering water temperature).

Cooling Tower Capacity Adjustment Curve

Applicability: All cooling towers.

Definition: A curve or group of curves that represent the available tower capacity (tower approach) as a function of tower air flow ratio, condenser water flow ratio, outdoor air wet-bulb temperature, and condenser water temperature range between supply and return temperature.

The default curves are given as follows:

$$\begin{aligned} Approach = {} & Coeff_1 + Coeff_2 \cdot Fr_{air} + Coeff_3 \cdot Fr_{air}^2 + Coeff_4 \cdot Fr_{air}^3 + Coeff_5 \cdot Fr_{water} + Coeff_6 \\ & \cdot Fr_{air} \cdot Fr_{water} + Coeff_7 \cdot Fr_{air}^2 \cdot Fr_{water} + Coeff_8 \cdot Fr_{water}^2 + Coeff_9 \cdot Fr_{air} \cdot Fr_{water}^2 \\ & + Coeff_{10} \cdot Fr_{water}^3 + Coeff_{11} \cdot T_{wb} + Coeff_{12} \cdot Fr_{air} \cdot T_{wb} + Coeff_{13} \cdot Fr_{air}^2 \cdot T_{wb} \\ & + Coeff_{14} \cdot Fr_{water} \cdot T_{wb} + Coeff_{15} \cdot Fr_{air} \cdot Fr_{water} \cdot T_{wb} + Coeff_{16} \cdot Fr_{water}^2 \cdot T_{wb} \\ & + Coeff_{17} \cdot T_{wb}^2 + Coeff_{18} \cdot Fr_{air} \cdot T_{wb}^2 + Coeff_{19} \cdot Fr_{water} \cdot T_{wb}^2 + Coeff_{20} \cdot T_{wb}^3 \\ & + Coeff_{21} \cdot Tr + Coeff_{22} \cdot Fr_{air} \cdot Tr + Coeff_{23} \cdot Fr_{air}^2 \cdot Tr + Coeff_{24} \cdot Fr_{water} \cdot Tr \\ & + Coeff_{25} \cdot Fr_{air} \cdot Fr_{water} \cdot Tr + Coeff_{26} \cdot Fr_{water}^2 \cdot Tr + Coeff_{27} \cdot T_{wb} \cdot Tr + Coeff_{28} \\ & \cdot Fr_{air} \cdot T_{wb} \cdot Tr + Coeff_{29} \cdot Fr_{water} \cdot T_{wb} \cdot Tr + Coeff_{30} \cdot T_{wb}^2 \cdot Tr + Coeff_{31} \cdot Tr^2 \\ & + Coeff_{32} \cdot Fr_{air} \cdot Tr^2 + Coeff_{33} \cdot Fr_{water} \cdot Tr^2 + Coeff_{34} \cdot T_{wb} \cdot Tr^2 + Coeff_{35} \cdot Tr^2 \end{aligned}$$

Where:

$\boldsymbol{Fr_{air}}$ – ratio of airflow to airflow at design conditions
$\boldsymbol{Fr_{water}}$ – ratio of water flow to water flow at design conditions
$\boldsymbol{Tr}$ – tower range (°F)
$\boldsymbol{T_{wb}}$ – wet-bulb temperature

Coefficients for this performance curve are provided in Appendix 5.7.

Units: Data structure.

Input Restrictions: User must use one of the prescribed curves defined in Appendix 5.7.

Standard Design: Use one of the prescribed curves defined in Appendix 5.7.

Cooling Tower Set Point Control

Applicability: All cooling towers.

Definition: The type of control for the condenser water supply.

The choices are Fixed

- Scheduled
- Outside air reset
- Wet bulb reset
- Fixed dual setpoint

A fixed control will modulate the tower fans to maintain the design condenser water supply temperature. A wet-bulb reset control will reset the condenser water supply temperature setpoint to a fixed approach to outside air wet-bulb temperature. The approach defaults to 10°F. A lower approach may be used with appropriate documentation.

Units: List (see above).

Input Restrictions: As designed; default to fixed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, fixed at the 0.4 percent design wet-bulb temperature, which is prescribed and specified for each of the 86 weather data files.

Cooling Tower Capacity Control

Applicability: All cooling towers.

Definition: Describes the modulation control employed in the cooling tower.

Choices include:

- Fluid Bypass provides a parallel path to divert some of the condenser water around the cooling tower at part-load conditions.
- Fan Cycling is a simple method of capacity control where the tower fan is cycled on and off. This is often used on multiple-cell installations.
- Two-Speed Fan/Pony Motor is another method of capacity control that saves fan energy. A lower horsepower pony motor is an alternative to a two-speed motor. The pony motor runs at part-load conditions (instead of the full-sized motor) and saves fan energy when the tower load is reduced. Additional building descriptors are triggered when this method of capacity control is selected.
- Variable-Speed Fan has a variable frequency drive installed on the tower fan for fan speed control and capacity modulation.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, if the fan motor hp is 7.5 or larger, variable-speed fan, otherwise, same as the proposed design. For all others, variable-speed fan.

Cooling Tower Low-Speed Airflow Ratio

Applicability: All cooling towers with two-speed, pony motors or variable-speed fan.

Definition: The percentage full-load airflow that the tower has at low speed or with the pony motor operating; equivalent to the percentage full-load capacity when operating at low speed.

Units: Ratio.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, 0.5.

Cooling Tower Low-Speed kW Ratio

Applicability: All cooling towers with two-speed/pony motors or variable-speed fan.

Definition: The percentage full-load power that the tower fans draw at low speed or with the pony motor operating.

Units: Ratio.

Input Restrictions: Calculated, using the as-designed flow ratio and the cooling tower power adjustment curve below.

Standard Design: For healthcare facilities, same as the proposed design. For all others, 0.25.

Cooling Tower Power Adjustment Curve

Applicability: All cooling towers with VSD control.

Definition: A curve that varies the cooling tower fan energy usage as a function of part-load ratio for cooling towers with variable speed fan control. The default curve is given as:

$$PLR = \frac{Q_{operating}}{Q_{available}(t_R, t_A, t_{OWB})}$$

$$TWR_{Fan-FPLR} = a + b(PLR) + c(PLR)^2 + d(PLR)^3$$

$$P_{operating} = P_{rated}(TWR_{Fan-FPLR})$$

Where:

- $\boldsymbol{PLR}$ — Part-load ratio based on available capacity (not rated capacity)
- $\boldsymbol{Q_{operating}}$ — Present load on tower (in Btu/h)
- $\boldsymbol{Q_{available}}$ — Tower available capacity at present range, approach, and outside wet-bulb conditions (in Btu/h)
- $\boldsymbol{t_{OWB}}$ — The outside air wet-bulb temperature (°F)
- $\boldsymbol{t_R}$ — The tower range (°F)
- $\boldsymbol{t_A}$ — The tower approach (°F)

- $\boldsymbol{P_{rated}}$ — Rated power draw at CTI conditions (kW)
- $\boldsymbol{P_{operating}}$ — Power draw at specified operating conditions (kW)

Refer to Appendix 5.7 for the fixed cooling tower curve coefficients.

Units: Data structure.

Input Restrictions: User shall use only default curves.

Standard Design: Use default curves given above.

COOLING TOWER MINIMUM SPEED

Applicability: All cooling towers with a VSD control.

Definition: The minimum fan speed setting of a VSD controlling a cooling tower fan expressed as a ratio of full load speed.

Units: Ratio.

Input Restrictions: As designed; default is 0.50.

Standard Design: For healthcare facilities, if the fan motor hp is 7.5 or larger, 0.5, otherwise, same as the proposed design. For all others, 0.5.

5.8.4 Water-side Economizers

None of the standard design building systems use a water-side economizer.

WATER-SIDE ECONOMIZER NAME

Applicability: All water-side economizers.

Definition: The name of a water-side economizer for a cooling system.

Units: Text, unique.

Input Restrictions: Descriptive reference to the construction documents.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

WATER ECONOMIZER TYPE

Applicability: All water-side economizers.

Definition: The type of water-side economizer. Choices include:

- None
- Heat exchanger in parallel with chillers. This would be used with an open cooling tower and is often referred to as a non-integrated economizer because the chillers are locked out when the plant is in economizer mode.

- Heat exchanger in series with chillers. This would be used with an open cooling tower and is often referred to as integrated because the chillers can operate simultaneously with water economizer operation.
- Direct water economizer. This would be used with a closed cooling tower. In this case, a heat exchanger is not needed. This type works only as a non-integrated economizer (also known as strainer-cycle).

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

WATER-SIDE ECONOMIZER HX EFFECTIVENESS

Applicability: Water-side economizers with an open cooling tower.

Definition: The effectiveness of a water-side heat exchanger at design conditions.

This is defined as:

$$Q_{econ} = (m_{CHW})(Cp_{CHW})(\varepsilon)\left(T_{CHW,R} - T_{CW,S}\right)$$

Where:

$\boldsymbol{Q_{econ}}$ — The maximum load that the economizer can handle (Btu/hr)
$\boldsymbol{m_{CHW}}$ — The chilled water flow rate (lb/hr)
$\boldsymbol{Cp_{CHW}}$ — The chilled water specific heat (BTU/lb-°F)
$\boldsymbol{T_{CHW,R}}$ — The chilled water return temperature (°F)
$\boldsymbol{T_{CW,S}}$ — The condenser water supply temperature (°F)
$\boldsymbol{\varepsilon}$ — The effectiveness of the water-side economizer heat exchanger

Units: Ratio

Input Restrictions: Not a user input.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

WATER-SIDE ECONOMIZER HEAT EXCHANGER HEAT TRANSFER COEFFICIENT

Applicability: Water-side economizers with an open cooling tower.

Definition: The heat transfer coefficient of the plate-and-frame heat exchanger with the waterside economizer.

Units: Btu/h-°F.

Input Restrictions: Not a user input. It is calculated based on other user inputs as follows:

$$UA = Cap_{Rtd}/LMTD$$

Where:

UA – The heat transfer coefficient (Btu/hr- °F)

Cap_{Rtd} – The design cooling capacity of the heat exchanger (Btu/hr)

$LMTD$ – The log mean temperature difference of the heat exchanger at the design conditions.

And $LMTD$ is calculated as:

$$LMTD = Tchw_{Lvg} - Tcw_{Ent}$$

When $Tchw_{Lvg} - Tcw_{Eng} = Tchw_{Ent} - Tcw_{Lvg}$. Otherwise

$$LMTD = \frac{\left((Tchw_{Lvg} - Tcw_{Ent}) - (Tchw_{Eng} - Tcw_{Lvg})\right)}{\ln\left((Tchw_{Lvg} - Tcw_{Ent})/(Tchw_{Eng} - Tcw_{Lvg})\right)}$$

Where:

$Tchw_{Ent}$ – The temperature of water entering the exchanger on the chilled water side of the system at design conditions (°F).

$Tchw_{Lvg}$ – The temperature of water leaving the exchanger on the chilled water side of the system at design conditions (°F).

Tcw_{Ent} – The temperature of water entering the exchanger on the condenser water side of the system at design conditions (°F).

Tcw_{Lvg} – The temperature of water leaving the exchanger on the condenser water side of the system at design conditions (°F).

Standard Design: For healthcare facilities, same as the proposed design. For all others, not applicable.

Water-Side Economizer Approach

Applicability: All water-side economizers (WSE).

Definition: The design temperature difference between the chilled water temperature leaving the WSE heat exchanger and the condenser water *entering* the WSE heat exchanger.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed; default is 4°F.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

Water-Side Economizer Maximum CWST

Applicability: All water-side economizers.

Definition: The control temperature (condenser water supply temperature, CWST) above which the water-side economizer is disabled.

Units: Degrees Fahrenheit (°F).

Input Restrictions: As designed; default is 50°F.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

Water-Side Economizer Availability Schedule

Applicability: All water-side economizers.

Definition: A schedule which represents the availability of the water-side economizer.

Units: Data structure: schedule, on/off.

Input Restrictions: Not a user input. Always available.

Standard Design: For healthcare facilities, same as the proposed design. For all others, no water economizer.

5.8.5 Pumps

Standard Design Summary — Hot water pumping in the standard design shall be modeled as a variable flow, primary only system. Two-way valves are assumed at the heating coils.

Chilled water pumping in the standard design is a primary only system. Each water-cooled chiller has its own variable speed chilled water pump and constant speed condenser water pump. Both water pumps operate when the chiller is activated.

General Notes — The building descriptors in this chapter are repeated for each pumping system. See the pump service building descriptor for a list of common pump services.

Pump Name

Applicability: All pumps.

Definition: A unique descriptor for each pump.

Units: Text, unique.

Input Restrictions: User entry: where applicable, should match the tags that are used on the plans.

Standard Design: For healthcare facilities, same as proposed design. For all others, Pumps are only designated in the standard design if the baseline system type includes primary systems. Assign a sequential tag to each piece of equipment. The sequential tags should indicate the pump service as part of the descriptor (e.g., CW for condenser water, CHW for chilled water, or HHW for heating hot water).

Pump Service

Applicability: All pumps.

Definition: The service for each pump.

Choices include:

Chilled water
Chilled water (primary)
Chilled water (secondary)

Heating water
Heating water (primary)
Heating water (secondary)
Service hot water
Condenser water (for heat rejection or water-source heat pump loops)
Loop water (for hydronic heat pumps)

Units: List (see above).

Input Restrictions: As designed.

Standard Design: As needed by the standard design system. See Chapter 5.1.3 HVAC System Map.

Number of Pumps

Applicability: All pumps.

Definition: The number of identical pumps in service in a particular loop, e.g., the heating hot water loop, chilled water loop, or condenser water loop.

Units: Numeric: integer.

Input Restrictions: As designed.

Standard Design: There will be one heating hot water pump for each boiler, one chilled water pump, and one condenser water pump for each chiller.

Water Loop Design

Applicability: All pumps.

Definition: The heating and cooling delivery systems can consist of a simple primary loop system, or more complicated primary/secondary loops or primary/secondary/tertiary loops.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, assume primary loops only for heating hot water and chilled water loops.

Pump Motor Modeling Method

Applicability: All pumps.

Definition: Compliance software commonly models pumps in one of two ways. The simple method is for the user to enter the electric power per unit of flow (W/gpm). This method is commonly used for smaller systems. A more detailed method requires a specification of the pump head, design flow, impeller, and motor efficiency.

Units: List power-per-unit-flow or detailed.

Input Restrictions: Detailed.

Standard Design: Detailed for chilled water and condenser water pumps; power-per-unit-flow for heating hot water and service hot water pumps.

Pump Motor Power-Per-Unit-Flow

Applicability: All pumps that use the power-per-unit-flow method.

Definition: The electric power of the pump divided by the flow at design conditions.

Units: W/gpm.

Input Restrictions: Not a user input for proposed model. Value is calculated based on other user input pump performance values.

Standard Design: For healthcare facilities, same as the proposed design. For all others, not applicable for chilled water and condenser water pumps; 19 W/gpm for heating hot water and service hot water pumps.

Pump Motor Horsepower

Applicability: All pumps.

Definition: The nameplate motor horsepower.

Units: Horsepower (hp).

Input Restrictions: Constrained to be a value from the following standard motor sizes:

1/12, 1/8, ¼, ½, ¾, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200

Alternatively, the nameplate horsepower can be entered as a numeric value.

Standard Design: For buildings with both healthcare and other occupancies, the proposed pump horsepower is scaled based on the ratio of plant equipment serving healthcare areas. Otherwise, set to the next larger nominal motor size, from Table 14: Minimum Nominal Efficiency for Electric Motors (Percent), for the calculated input brake horsepower.

Pump Design Head

Applicability: All standard and proposed design pumps that use the detailed method.

Definition: The head of the pump at design flow conditions.

Units: ft of water.

Input Restrictions: As designed but subject to an input restriction. The user inputs of pump design head, impeller efficiency, and pump design flow shall be used to calculate the proposed brake horsepower. This shall be compared to the pump motor.

Horsepower for the next smaller motor size (MHP_{i-1}) than the one specified by the user (MHP_i).

The proposed pump design head shall be constrained so that the resulting brake horsepower is no smaller than 95 percent of the next smaller motor size:

$$design\ bhp_{prop} = \max\left[design\ bhp_{prop-user-head}, 0.95(MHP_{i-1})\right]$$

Where:

- $\boldsymbol{design\ bhp_{prop}}$ — The brake horsepower used in the simulation
- $\boldsymbol{design\ bhp_{prop-user-head}}$ — The brake horsepower resulting from the user input of design head
- $\boldsymbol{MHP_i}$ — The pump motor horsepower specified by the user
- $\boldsymbol{i}$ — The index into the standard motor size table for the user motor horsepower
- $\boldsymbol{MHP_{i-1}}$ — The motor horsepower for the next smaller motor size. For example, if the user-specified pump motor horsepower is 25, the next smaller motor size in the table above is 20

Since all other user inputs that affect the proposed design brake horsepower are not modified, the proposed design pump design head is adjusted in the same proportion as the pump brake horsepower in the equation above. If the user-entered pump design head results in a brake horsepower that is at least 95 percent of the horsepower of the next smaller motor size, no modification of the user input is required.

Standard Design: For healthcare facilities, same as the proposed design. For all others, for chilled water pumps:

$$Head_{CHW} = (40ft) + 0.03\frac{ft}{ton} \times [chiller\ plant\ nominal\ capacity\ (tons)]$$

(not to exceed 100 ft)

For chilled water pumps serving four pipe fan coil systems:

For condenser water pumps: 45 ft

Impeller Efficiency

Applicability: All pumps in proposed design that use the detailed modeling method.

Definition: The full load efficiency of the impeller.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, 70%.

Motor Efficiency

Applicability: All pumps in proposed design that use the detailed modeling method.

Definition: The full load efficiency of the pump motor.

Units: Unitless.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. The motor efficiency is taken from Table 13: Minimum Nominal Efficiency for Electric Motors (Percent), using the calculated nameplate motor size.

Pump Minimum Flow

Applicability: All variable-speed pumps.

Definition: The minimum pump flow for a variable-speed pump.

For variable speed pumps, the minimum flow is set to be 10% of the design flow rate.

Units: gpm.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the proposed design. For all others, 0 gpm.

Pump Design Flow

Applicability: All pumps.

Definition: The flow rate of the pump at design conditions; derived from the load, and the design supply and return temperatures.

Units: gpm or gpm/ton for condenser and primary chilled water pumps.

Input Restrictions: As designed.

Standard Design: For buildings with both healthcare and other occupancies, the proposed pump flow is scaled based on the ratio to the capacity of plant equipment serving healthcare areas. For all others, the temperature change on the evaporator side of the chillers is 20°F (64°F less 44°F) and this equates to a flow of 1.2 gpm/ton. The temperature change on the condenser side of the chillers is 12°F, which equates to a flow of 2.0 gpm/cooling ton. For hot water pumps servicing boilers, the temperature change on the boilers is 30°F (135°F less 105°F), which equates to a flow of 0.067 gpm/kBtuh. For air-to-water heat pumps, the temperature change on the space heating side is 10°F (105°F less 95°F), which equates to 0.2 gpm/kBtuh.

Pump Control Type

Applicability: All pumps.

Definition: The type of control for the pump.

Choices are:

> Constant speed, fixed flow; Constant speed, variable flow (the default, with flow control through a valve)
> Two-speed
> Variable speed

Units: List, see above.

Input Restrictions: As designed; default is "constant speed, variable flow", which models the action of a constant speed pump riding the curve against two-way control valves.

Standard Design: For healthcare facilities, same as the proposed design. For all others, the chilled water and hot water pumps shall be modeled as variable-speed, condenser water pumps shall be modeled as constant speed.

Pump Operation

Applicability: All pumps.

Definition: The type of pump operation can be either on-demand, standby, or scheduled. On-demand operation means the pumps are only pumping when their associated equipment is cycling. Chiller and condenser pumps are on when the chiller is on and the heating hot water pump operates when its associated boiler is cycling. Standby operation allows hot or chilled water to circulate through the primary loop of a primary/secondary loop system or through a reduced portion of a primary-only system, assuming the system has appropriate three-way valves. Scheduled operation means that the pumps and their associated equipment are turned completely off according to occupancy schedules, time of year, or outside conditions. Under scheduled operation, when the systems are on, they are assumed to be in on-demand mode.

Units: List (see above).

Input Restrictions: As designed.

Standard Design: The standard design system pumps are assumed to operate in on-demand mode. The chilled water and condenser pumps are tied to the chiller operation, cycling on and off with the chiller, and the heating hot water pumps are tied to the boiler operation.

Pump Part-Load Curve

Applicability: All pumps.

Definition: A part-load power curve for the pump:

$$CIRC - PUMP - FPLR = a + b(PLR) + c(PLR)^2 + d(PLR)^3$$

$$P_{pump} = P_{design}(CIRC - PUMP - FPLR)$$

Where:

- $\boldsymbol{PLR}$ — Part-load ratio (the ratio of operating flow rate in gpm to design flow rate in gpm)
- $\boldsymbol{P_{pump}}$ — Pump power draw at part-load conditions (W)
- $\boldsymbol{P_{design}}$ — Pump power draw at design conditions (W)

Refer to Appendix 5.7 for a specification of the default pump part-load curve, and the pump part-load curve if there is differential pressure reset (if DDC controls are present).

Units: Data structure.

Input Restrictions: Where applicable, curves are prescribed based on system type, see Appendix 5.7.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, DP Reset curve for chilled water pumps; heating hot water pump power is assumed to be constant even though the pump is riding the curve.

5.8.6 Variable Refrigerant Flow (VRF) Systems

Variable refrigerant flow systems consist of an outdoor unit and one or more zonal systems as indoor units. The required system level inputs are shown below. Refer to the HVAC zone level systems chapter for zonal (indoor) units connected to a VRF system. Equipment performance curves are prescribed and defined in Appendix 5.4B for VRF systems.

VRF System Name

Applicability: VRF.

Definition: A unique name designating the VRF System.

Units: None.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Heat Recovery

Applicability: VRF.

Definition: Identification if heat recovery (refrigerant loop) is present.

Units: Boolean.

Input Restrictions: None (default : No).

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Control Priority

Applicability: VRF.

Definition: A control parameter used to determine when outdoor unit is in heating or cooling mode.

Choices include:

- Load Priority – The total zone load is used to choose the operating mode as either cooling or heating
- Master Thermostat Priority – The system operates according to the zone load where the master thermostat is located.

Units: List (see above).

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Control Zone

Applicability: Master Thermostat Control Zone.

Definition: The name of the control zone that controls the outdoor unit, when the Control Priority is Master Thermostat Priority.

Units: None.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Minimum Part-Load Ratio

Applicability: VRF.

Definition: The minimum part-load ratio for the heat pump. Below this ratio the unit will cycle to meet the load.

Units: Unitless.

Input Restrictions: 0.25 to 1.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Rated EER

Applicability: VRF.

Definition: Full load cooling efficiency (Btu/h of net cooling output divided by the electrical energy consumption in Watts) as specified by AHRI 1230 rated conditions.

Units: Btu/h-W.

Input Restrictions: As designed, the user-entered value must meet mandatory minimum requirements of the Appliance Standards for the applicable equipment type.

Standard Design: For healthcare facilities, the minimum heating efficiency from the Energy Code for the applicable equipment type. For all others, not applicable.

Rated COP

Applicability: VRF.

Definition: Full load heating efficiency (net heating output divided by the electrical energy consumption, both in the same units) at AHRI rating conditions.

Units: None.

Input Restrictions: As designed, the user-entered value must meet mandatory minimum requirements of the Appliance Standards for the applicable equipment type.

Standard Design: For healthcare facilities, the minimum heating efficiency from the Energy Code for the applicable equipment type. For all others, not applicable.

Rated Indoor Type

Applicability: VRF.

Definition: A flag to determine when the VRF system was rated with ducted or unducted indoor units.

Units: List: ducted, unducted.

Input Restrictions: Not a user input.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Equivalent Pipe Length

Applicability: VRF.

Definition: The equivalent pipe length between the farthest terminal unit and the condensing unit, including liquid refrigerant line length, fitting losses, and other losses.

Units: ft.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Max Vertical Height

Applicability: VRF.

Definition: The vertical height difference between the highest or lowest terminal unit and outdoor unit.

Units: ft.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Defrost Heat Source

Applicability: VRF.

Definition: The defrost heat source type.

Units: List – electric or gas.

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Defrost Control Strategy

Applicability: VRF.

Definition: The control method for enabling defrost.

Units: List – Timed Cycle or On Demand.

Input Restrictions: Not a user input.

Standard Design: Not applicable.

MAX DEFROST TEMP

Applicability: VRF.

Definition: The maximum outdoor dry-bulb temperature at which defrost will occur.

Units: Degree Fahrenheit (°F).

Input Restrictions: None.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

COMPRESSOR QUANTITY

Applicability: VRF.

Definition: The number of compressors represented by the unit.

Units: Unitless integer.

Input Restrictions: None.

Standard Design: Not applicable.

CRANKCASE HEATER CAPACITY

Applicability: VRF.

Definition: The capacity of the resistive heating element in or around the crank case of a compressor. The crank case heater operates only when the compressor is off.

Units: W.

Input Restrictions: The value is prescribed to be 10 W per ton (rated net cooling capacity).

Standard Design: Not applicable

CRANKCASE HEATER SHUTOFF TEMPERATURE

Applicability: VRF.

Definition: The outdoor air dry-bulb temperature above which the crankcase heater is not permitted to operate.

Units: Degree Fahrenheit (°F).

Input Restrictions: The value is prescribed to be 50°F.

Standard Design: Not applicable

5.8.7 Plant Management

Plant management is a method of sequencing equipment. Separate plant management schemes may be entered for chilled water systems, hot water systems, etc. The following building descriptors are specified for each load range, e.g., when the cooling load is below 300 tons, between 300 tons and 800 tons, and greater than 800 tons.

Equipment Type Managed

Applicability: All plant systems.

Definition: The type of equipment under a plant management control scheme.

Choices include:

- Chilled water cooling
- Hot water space heating
- Condenser water heat rejection
- Service water heating

Units: List (see above).

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Equipment Schedule

Applicability: All plant equipment.

Definition: A schedule that identifies when the equipment is in service.

Units: Data structure.

Input Restrictions: Prescribed to be on 24/7, the whole year.

Standard Design: Prescribed to be on 24/7, the whole year.

Equipment Operation

Applicability: All plant equipment.

Definition: Equipment operation can be either on-demand or always-on.

On-demand operation means the equipment cycles on when it is scheduled to be in service and when it is needed to meet building loads. Otherwise, it is off.

Always-on means that equipment runs continuously when it scheduled to be in service. For the purpose of the compliance model, always-on is used for equipment such as chillers that are base-loaded, and on-demand equipment is scheduled to be on only when the base-loaded equipment (one or more) cannot meet the load.

Units: None.

Input Restrictions: Not a user input.

Standard Design: Assume on-demand operation.

Equipment Staging Sequence

Applicability: All plant equipment.

Definition: The staging sequence for plant equipment (chillers and boilers) indicates how multiple pieces of equipment will be staged on and off when a single piece of equipment is unable to meet the load. In both the proposed and standard design, the compliance software uses the optimal sequence to determine plant staging based on part-load performance. This descriptor is used to identify sequencing when the plant contains unequal equipment, where the order in which the plant equipment is enabled affects plant energy use.

Units: Structure – an array, where each element includes a) the load range, in minimum tons and maximum tons; and b) a list of equipment that is enabled to operate. The equipment will run in the priority matching the order of the equipment listed.

Input Restrictions: As designed; user may specify load ranges for staging each plant equipment.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

The standard design chiller and boiler plant each consist of one or more equal chillers or boilers, so the loading order is not applicable.

5.8.8 Thermal Energy Storage

The compliance model inputs below document the requirements to model a chilled water thermal energy storage system with compliance software. Some systems (ice storage, eutectic salts) cannot be modeled with compliance software.

Thermal Energy Storage Systems Name

Applicability: All thermal energy storage systems.

Definition: A unique descriptor for thermal energy storage systems.

Units: Text, unique.

Input Restrictions: Where applicable, this should match the tags that are used on the plans such that a plan reviewer can make a connection.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Thermal Energy Storage Systems Type

Applicability: All thermal energy storage systems.

Definition: The type of thermal energy storage system being used.

Chilled water storage system is the only currently supported option.

Units: List, chilled water.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Discharge Priority

Applicability: All thermal energy storage systems.

Definition: A descriptor determines whether the storage system or a chiller will operate first to meet cooling loads during the discharge period. Storage priority will normally provide larger demand charge savings but requires a larger storage system. Chiller priority allows use of a significantly smaller storage system, but demand reduction will be smaller.

Units: List storage or chiller.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Operation Mode Schedule

Applicability: All thermal energy storage systems.

Definition: A schedule which controls operating mode of the thermal energy storage system.

A thermal energy storage system can be discharging (supplying chilled water to meet cooling loads), charging (receiving chilled water to be stored for later use), or off. The operation mode schedule specifies one of these modes for each of the 8,760 hours in a year.

Units: Data structure — thermal energy storage mode schedule, specifies charging, discharging, or off on an hourly basis.

Input Restrictions: Not a user input.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Rated Capacity

Applicability: All thermal energy storage systems.

Definition: The design cooling capacity of the thermal energy storage system.

The rated cooling capacity of the thermal energy storage system is determined by design flow rate of the thermal energy storage system and the temperature difference between the fluid system supply and return water temperature during discharging.

Units: Btu/hr.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Tank Location

Applicability: All thermal energy storage systems.

Definition: The location of the heat pump water heater for determining losses and heat energy interaction with the surroundings.

Units: List zone, outdoors, or underground.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Tank Shape

Applicability: All thermal energy storage systems.

Definition: The shape of the energy storage system tank used to calculate surface area of the tank for heat gain/loss calculations.

Units: List: Vertical cylinder, Horizontal cylinder, or rectangular.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Tank Volume

Applicability: All thermal energy storage systems.

Definition: The volume of water held in the thermal energy storage system tank.

The tank volume and the rated capacity will determine how long the storage system can meet the load.

Units: Gallons.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Tank Height

Applicability: All thermal energy storage systems.

Definition: For vertical cylinder or rectangular tank, the height will be the maximum internal height of water held in the upright storage tank. For horizontal cylinder tank, the height of the storage tank will be the inner diameter of the storage tank.

Units: Feet.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

Tank Length to Width Ratio

Applicability: All thermal energy storage systems.

Definition: The length to width ratio of a rectangular storage tank in plan view. It is required only if tank shape is rectangular.

If the tank is square, the length to width ratio is one. For a rectangular tank, the ratio will be greater than one since the length of the tank is always greater than the width of the tank. This is used to determine the surface area of the tank.

Units: Unitless ratio.

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

TANK R-VALUE

Applicability: All thermal energy storage systems.

Definition: The insulation applied to the tank used in calculating the tank U-factor.

Units: R-value (h-ft^2-F/Btu).

Input Restrictions: As designed.

Standard Design: For healthcare facilities, same as the Proposed Design. For all others, not applicable.

5.9 Miscellaneous Energy Uses

Miscellaneous energy uses are defined as those that may be treated separately since they have little or no interaction with the conditioned thermal zones or the HVAC systems that serve them.

5.9.1 Service Water Heating System Loads and Configuration

WATER HEATING SYSTEM NAME

Applicability: All water heating systems.

Definition: A unique descriptor for each water heating system.

A system consists of one or more water heaters, a distribution system, an estimate of hot water use, and a schedule for that use. Nonresidential buildings will typically have multiple systems, perhaps a separate electric water heater for each office break room, etc. Other building types such as hotels and hospitals may have a single system serving the entire building.

Units: Text, unique.

Input Restrictions: Where applicable, this should match the tags that are used on the plans such that a plan reviewer can make a connection.

Standard Design: The naming convention for the standard design system shall be similar to the proposed design.

Water Heating Peak Use

Applicability: All water heating systems, required.

Definition: An indication of the peak hot water usage (e.g., service to sinks, showers, kitchen appliances, etc.). When specified per occupant, this value is multiplied by design occupancy density values and modified by service water heating schedules to obtain hourly load values which are used in the simulation.

Peak consumption is commonly specified as gallons per hour (gph) per occupant, dwelling unit, hotel room, patient room, or floor area. If consumption is specified in gph, then additional inputs would be needed such as supply temperature, cold water inlet temperature, etc.

Compliance software that specifies peak use as a thermal load in Btu/h can apply ACM rules for the mains (cold water inlet) temperature and supply temperature to convert the prescribed peak use from gph/person to Btu/h-person. The thermal load does not include conversion efficiencies of water heating equipment.

Units: gph/person.

Input Restrictions: For nonresidential spaces and residential living spaces of hotels and motels (guestrooms), prescribed values from Appendix 5.4A if a service hot water heating system is installed; otherwise, all values are 0.

For multifamily spaces the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Prescribed values from Appendix 5.4A if a service hot water heating system is installed; otherwise, all values are 0.

For multifamily spaces the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Water Heating Schedule

Applicability: All water heating systems.

Definition: A fractional schedule reflecting the time pattern of water heating use.

This input modifies the water heating peak use described above.

Units: Data structure — schedule, fractional.

Input Restrictions: The schedules from Appendix 5.4A shall be used. For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: The schedules from Appendix 5.4A shall be used. For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Water Heating System Configuration

Applicability: All water heating systems.

Definition: The configuration and layout of the water heating system including the number of water heaters; the size, location, length, and insulation of distribution pipes; recirculation systems and pumps; and any other details about the system that would affect the energy model.

Units: Data structure.

Input Restrictions: None.

Standard Design: For healthcare facility spaces, the same as proposed. For multifamily spaces the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual shall be followed.

For all other spaces, the standard design shall have one gas storage water heater if any of the spaces have a Space Water Heating Fuel Type of Gas (from Appendix 5.4A), and the standard design building will have on electric water heater if the any of the spaces have a Space Water Heating Fuel Type of Electric.

Standard Design: Existing Buildings: Same as proposed if proposed system is existing.

WATER MAINS TEMPERATURE SCHEDULE

Applicability: All water heating systems.

Definition: A monthly temperature schedule indicating the water mains temperature.

This temperature and the setpoint temperature are used to convert the load into a water flow rate.

Units: Data structure — schedule, °F.

Input Restrictions: For nonresidential spaces and residential living spaces of hotels and motels (guestrooms), the schedules from Appendix 5.4A shall be used. The water mains temperature schedule shall be fixed for a given climate zone.

For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: For nonresidential spaces and residential living spaces of hotels and motels (guestrooms), the schedules from Appendix 5.4A shall be used. The water mains temperature schedule shall be fixed for a given climate zone.

For multifamily spaces the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

5.9.2 Water Heaters

This chapter describes the building descriptors for water heaters. Typically, a building will have multiple water heating systems and each system can have multiple water heaters, so these building descriptors may need to be specified more than once.

WATER HEATER NAME

Applicability: All water heaters.

Definition: A unique descriptor for each water heater in the system.

Some systems will have multiple pieces of equipment. For instance, a series of water heaters plumbed in parallel or a boiler with a separate storage tank.

Units: Text, unique.

Input Restrictions: Where applicable, this should match the tags that are used on the plans such that a plan reviewer can make a connection.

Standard Design: The naming convention for the standard design system shall be similar to the proposed design.

Water Heater Type and Size

Applicability: All water heaters.

Definition: This building descriptor includes information needed to determine the criteria from baseline standards. The choices and the associated rated capacity (heat input rate) are listed in the *2015 Appliance Efficiency Regulations*, except that oil-fired water heaters and boilers are not supported.

Units: List conventional, heat pump split, or heat pump packaged.

Input Restrictions: As designed.

Standard Design: For healthcare facility spaces, the same as proposed. For all other spaces, the standard design shall have one gas storage water heater if any of the spaces have a space water heating fuel type of gas (from Appendix 5.4A), and the standard design building will have on electric water heater if the any of the spaces have a space water heating fuel type of electric.

For school buildings less than 25,000 square feet and less than four floors in climate zones 2 through 15, the standard design shall have a heat pump water heating system.

For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Rated Capacity

Applicability: All water heaters.

Definition: For gas and electric resistance water heaters, the heating capacity of a water heater (input rate) at the rated conditions specified in DOE 10 CFR Part 430 or ANSI Z21.10. For heat pump water heaters, the rated heating capacity supplied to the water (output rate).

Units: Thousands of British thermal units per hour (MBH).

Input Restrictions: As designed.

Standard Design: The capacity of the standard design water heaters will be based on the larger of the total design hot water consumption rate (gallons/hr) of all the spaces in the building or 75 gallons per hour. The consumption rate is converted to Btu/hr (x (design supply temp – 55) x 8.2877 pounds/gallon x 1 Btu/pound-F). That value is multiplied by 0.60 to find the heat that must be supplied to the water.

All of the water heaters in the proposed design are similarly converted to a total Btu/hr heat output, summed across the water heaters, and multiplied by 0.60.

The standard design uses the smaller of these values and divides by thermal efficiency to find energy input.

If the standard design has both a gas water heater and an electric water heater, the total capacity will be pro-rated between the two based on the total hot water consumption rate of the spaces with water heating fuel type of electric or gas.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Storage Volume

Applicability: Storage water heaters.

Definition: The volume of a storage water heater used in the standby loss calculations and standard design calculations of energy factor and uniform energy factor.

Units: Gallons.

Input Restrictions: As designed.

Standard Design: The volume of the standard design water heaters will be based on the larger of the total design hot water consumption rate (gallons/hr) of all the spaces in the building or 75 gallons per hour. That value is multiplied by 1 hour and 0.40 to determine the storage volume.

All of the water heaters in the proposed design are similarly converted to a total Btu/hr heat output, summed across the water heaters. This value is multiplied by 0.40 and converted to gallons (design supply temp – 55) / 8.2877 pounds/gallon / 1 Btu/pound-F x 1 hr).

The standard design uses the smaller of these values.

For school buildings less than 25,000 square feet and less than 4 floors in climate zones 2 through 15, the standard design shall have at a minimum 1 heat pump water heater with a storage volume calculated based on the total design hot water consumption rate of all spaces in the building.

If the standard design has both a gas water heater and an electric water heater, the total volume will be pro-rated between the two based on the total hot water consumption rate of the spaces with water heating fuel type of electric or gas.

For multifamily spaces the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Input Power

Applicability: Heat pump water heaters.

Definition: The total design electrical input to a heat pump water heater at design conditions.

This power includes the input to the compressor, controls, evaporator fan, and pump (if present).

Units: Kilowatts (kW).

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Storage Tank Location

Applicability: Heat pump water heaters.

Definition: The location of a heat pump water heater.

Units: List:

Conditioned
Unconditioned

Input Restrictions: List see above.

Standard Design:

Energy Factor

Applicability: Equipment covered by the National Appliance Energy Conservation Act (NAECA), which includes small storage and instantaneous water heaters.

Definition: The energy factor (EF) is the ratio of the energy delivered by the water heater divided by the energy used, in the same units. EF is calculated according to the DOE 10 CFR Part 430 test procedure, which specifies a 24-hour pattern of draws, a storage temperature, inlet water temperature, and other test conditions. These conditions result in the energy delivered for the test period. Energy inputs are measured for the same test period and the EF ratio is calculated.

Units: Unitless ratio.

Input Restrictions: Building descriptors for the proposed design should be consistent with equipment specified on the construction documents or observed in the candidate building.

For storage water heaters manufactured after June 1, 2017, that contain a Uniform Energy Factor, the EF shall not be input by the user, but shall be calculated by:

$$F = \frac{(N^2PUa) - (NUb)}{d(U - N) + c(N^2P - NPU) - Ub + NPUa}$$

Where:

$\boldsymbol{F}$ — Energy Factor
$\boldsymbol{N}$ — Recovery Efficiency
$\boldsymbol{P}$ — Power Input (W)

$\boldsymbol{U}$ — UEF

Draw Pattern (see the following descriptors)

- Very Small
  - a — 0.250266
  - b — 57.5
  - c — 0.039864
  - d — 67.5
- Low
  - a — 0.065860
  - b — 57.5
  - c — 0.039864
  - d — 67.5
- Medium
  - a — 0.045503
  - b — 57.5
  - c — 0.039864
  - d — 67.5
- High
  - a — 0.029794
  - b — 57.5
  - c — 0.039864
  - d — 67.5

For instantaneous electric water heaters manufactured after June 1, 2017, with a Uniform Energy Factor, the EF shall not be input by the user, but shall be equal to the calculated recovery efficiency.

For instantaneous gas-fired water heaters manufactured after June 1, 2017, with a Uniform Energy Factor, the EF shall not be input by the user, but shall be calculated by:

$$F = N \times 0.9734 + 0.01835$$

Where:

$\boldsymbol{F}$ — Energy Factor
$\boldsymbol{N}$ — Recovery Efficiency

Standard Design: For nonresidential buildings and nonresidential spaces, the energy factor for the standard design system shall be determined from the *Appliance Efficiency Regulations*.

For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Uniform Energy Factor

Applicability: Equipment covered by NAECA that is rated after June 1, 2017, with a Uniform Energy Factor (UEF) that includes small storage and instantaneous water heaters.

Definition: The UEF defines an efficiency level for a specific targeted use pattern.

Units: Unitless ratio.

Input Restrictions: Must meet mandatory minimum requirements defined by federal or state appliance efficiency standards.

Standard Design: For school buildings less than 25,000 square feet and less than 4 floors in climate zones 2 through 15, the standard design shall a heat pump water heater with a UEF of 2.15.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

First Hour Rating

Applicability: Water heating storage tanks with a UEF rating.

Definition: The first hour rating is a measure of the overall capacity of the water heater that incorporates both the heat input rate and the tank storage capacity and is used to determine the draw pattern.

Units: gal/hr.

Input Restrictions: As designed.

Standard Design: For school buildings less than 25,000 square feet and less than 4 floors in climate zones 2 through 15, the standard design shall be based on a heat pump water heater with a First Hour Rating of 75

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Design Flow Rate

*Applicability: Instantaneous w*ater heater.

Definition: Water flow rate of an instantaneous water heater and is used to determine the draw pattern.

Units: gal/hr.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Draw Pattern

Applicability: Storage water heating tanks with a UEF rating.

Definition: The draw pattern is determined as: very small, low, medium, or high from the user entry of first hour rating (FHR) or flow rate depending on the type of the water heater.

Table 20: Draw Pattern

Draw Pattern	Storage	Instantaneous
Very small	< 18 gal/hr	< 1.7 gpm
Low	≥ 18 gal/hr and < 51 gal/hr	≥ 1.7 gpm and < 2.8 gpm
Medium	≥ 51gal/hr and < 75 gal/hr	≥ 2.8 gpm and < 4 gpm
High	≥ 75 gal/hr	≥ 4 gpm

Units: List:

Very small
Low
Medium
High

Input Restrictions: Not user editable. Draw pattern is determined from FHR or flow rate user input.

Standard Design: For school buildings less than 25,000 square feet and less than 4 floors in climate zones 2 through 15, the standard design shall be based on a heat pump water heater with a draw pattern of “High”.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Thermal Efficiency

Applicability: Oil and gas-fired water heaters or gas-service water heater systems not covered by NAECA.

Definition: The full load efficiency of a water heater at rated conditions expressed as a dimensionless ratio of output over input. It is also referred to as recovery efficiency.

Units: Unitless ratio.

Input Restrictions: Building descriptors for the proposed design should be consistent with equipment specified on the construction documents or observed in the candidate building.

Standard Design: For nonresidential buildings and nonresidential spaces, the thermal efficiency is determined from Table F-2 in the *Appliance Efficiency Regulations*.

For multifamily spaces, the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings:

Baseline efficiency is set from the Appliance Efficiency Regulations

Tank Standby Loss

Applicability: Water heaters not covered by NAECA.

Definition: The tank standby loss for storage tanks, which includes the effect of recovery efficiency.

Units: Btu/h for the entire tank.

Input Restrictions: Standby loss is calculated as:

$$STBY = 577.5 \times S \times VOL$$

Where:

- $\boldsymbol{S}$ — The standby loss fraction listed in the CEC's Appliance Database of Certified Water Heaters
- $\boldsymbol{VO}$ — The actual storage capacity of the water heater as listed in the CEC's Appliance Database of Certified Water Heaters (gallons)

Standard Design: Table F-2 of the Appliance Efficiency Standards.

Tank Off-Cycle Loss Coefficient

Applicability: Water heaters.

Definition: The tank standby loss coefficient (UA) for the water heater.

For small water heaters covered by NAECA, the loss coefficient is a derived parameter, a function of the EF and recovery efficiency.

Units: Btu/h - °F.

Input Restrictions: For NAECA covered water heaters, the loss coefficient is calculated by:

$$UA = \frac{\frac{1}{EF} - \frac{1}{RE}}{67.5\left(\frac{24}{41094} - \frac{1}{RE(P_{on})}\right)}$$

Where:

- $\boldsymbol{EF}$ — The energy factor of the rated water heater (unitless)
- $\boldsymbol{RE}$ — The recovery efficiency of the rated water heater. If this data is not available, the default shall be 0.78 for gas water heaters and 0.93 for electric water heaters.
- $\boldsymbol{P_{on}}$ — The input power to the water heater, in Btu/h

Standard Design: For nonresidential spaces, 10 Btu/h-F. For multifamily spaces and residential living spaces of hotels and motels (guestrooms), the rules in Chapter 6 Multifamily Building Descriptors Reference of the Nonresidential ACM Reference Manual are followed.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

The baseline loss coefficient for NAECA water heaters shall be10 Btu/h-F for gas-fired water heaters

Off Cycle Parasitic Losses

Applicability: Water heaters.

Definition: The rate of parasitic losses, such as a pilot light or controls, when the water heater is not heating.

Units: Watts.

Input Restrictions: As designed.

Standard Design: 0.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Off Cycle Fuel Type

Applicability: Water heaters.

Definition: The type of fuel that serves energy using parasitic equipment, such as a pilot light or controls, when the water heater is not heating.

Units: List electricity, gas, oil, or propane.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

On-Cycle Parasitic Losses

Applicability: Water heaters.

Definition: The rate of parasitic losses, such as a pilot light or controls, when the water heater is not heating. It may be different than off-cycle losses if the flue energy is considered.

Units: Watts.

Input Restrictions: As designed.

Standard Design: Not applicable.

Existing Buildings: Same as proposed if water heater is existing.

On-Cycle Fuel Type

Applicability: Water heaters

Definition: The type of fuel that serves energy using parasitic equipment, such as a pilot light or controls, when the water heater is not heating

Units: List electricity, gas, oil, or propane

Input Restrictions: As designed

Standard Design: Not applicable

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Water Heater Ambient Location

Applicability: Water heaters.

Definition: The location of the water heater for determining losses and energy interaction with the surroundings.

Units: List schedule, zone, outdoors.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Water Heater Compressor Location

Applicability: Heat pump water heaters.

Definition: The location of the heat pump compressor for determining losses and energy interaction with the surroundings.

The air temperature at the compressor location also controls the compressor's crankcase heater operation.

Units: List zone, outdoors.

Input Restrictions: As designed

Standard Design: Not applicable

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Tank Standby Loss Fraction

Applicability: Storage tank water heaters.

Definition: The tank standby loss fraction for storage tanks.

Units: Unitless.

Input Restrictions: Prescribed to the value listed in the Appliance Database of Certified Water Heaters.

Standard Design: Not applicable.

The part-load curve procedure in Title 24 can be an alternate method of specifying the effects of standby and parasitic losses on performance. The primary method is to specify a loss coefficient for the storage tank.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Fuel Water Heater Part-Load Efficiency Curve

Applicability: Water heating equipment for which a loss coefficient is not specified (alternate method).

Definition: A set of factors that adjust the full-load thermal efficiency for part load conditions; set as a curve.

Units: Percent (%).

Input Restrictions: The following prescribed curve shall be used based on user inputs. The curve shall take the form of a quadratic equation as follows:

$$Fuel_{partload} = Fuel_{design} \times FHeatPLC$$

$$FHeatPLC = \left(a + b\left(\frac{Q_{partload}}{Q_{rated}}\right)\right)$$

For Title 24, the coefficients shall be determined by:

$$a = \frac{STBY}{INPUT}$$

$$b = \frac{(INPUT \times RE) - STBY}{SRL}$$

$$PLR_n = \frac{SRL \times F_{whpl(n)}}{INPUT \times RE}$$

Recovery efficiency substituted with thermal efficiency when applicable.

For boilers, instantaneous gas, or other storage type water heaters, not in the scope of covered consumer products as defined in the Title 10 or the Code of Federal Regulations, Part 430:

$$STBY = 577.5 \times S \times VOL$$

Required inputs and standard and proposed design assumptions depend on the type of water heater and whether or not it is a DOE covered consumer product.

Where:

$\boldsymbol{FHeatPLC}$ — The fuel heating part load efficiency curve
$\boldsymbol{Fuel_{partload}}$ — The fuel consumption at part-load conditions (Btu/h)
$\boldsymbol{Fuel_{design}}$ — The fuel consumption at design conditions (Btu/h)
$\boldsymbol{Q_{partload}}$ — The water heater capacity at part-load conditions (Btu/h)
$\boldsymbol{Q_{rated}}$ — The water heater capacity at design conditions (Btu/h)
$\boldsymbol{PLR_n}$ — Part-load ratio for the n^{th} hour and shall always be less than 1
$\boldsymbol{INPUT}$ — The input capacity of the water heater expressed in Btu/hr
$\boldsymbol{STBY}$ — Hourly standby loss expressed in Btu/hr. For large storage gas water heaters, STBY is listed in the CEC's appliance database. The value includes pilot energy and standby losses. For all systems, refer to equation N2-62.

SRL — The standard recovery load, taken from Appendix 5.4A, in Btu/hr, adjusted for the number of occupants according to the occupancy schedules.
S — The standby loss fraction listed in the CEC's Appliance Database of Certified Water Heaters
VOL — The actual storage capacity of the water heater as listed in the Appliance Database of Certified Water Heaters

Standard Design: Not applicable.

Standard Design: *Existing Buildings:* Same as proposed if water heater is existing.

Service Water Heating Heat Recovery

Applicability: Water heating systems with heat recovery from the mechanical cooling system.

Definition: Service hot water heat recovery is the process by which recovered waste heat from the cooling system is used to pre-heat or heat the service hot water system.

Units: None

Input Restrictions: As designed.

Standard Design: The standard design will include service hot water heat recovery if the conditions of 140.4(r)2 are met.

Standard Design: Existing Buildings: Not applicable.

5.9.3 Recirculation Systems

This chapter describes the building descriptors for hot water recirculation systems. For nonresidential application, recirculation systems are not modeled. For multifamily, the standard design has a recirculation system when the proposed design does.

Recirculating systems shall follow the rules set forth in Appendix B: Water Heating Calculation Method.

5.9.4 Water Heating Auxiliaries

External Storage Tank Insulation

Applicability: All water heating systems that have an external storage tank.

Definition: Some water heating systems have a storage tank that is separate from the water heater(s) that provides additional storage capacity. This building descriptor addresses the heat loss related to the external tank, which is an additional load that must be satisfied by the water heater(s).

Units: R-value (h-ft^2-F/Btu).

Input Restrictions: As specified in manufacturer data and documented on the construction documents.

Standard Design: Heat loss associated with the storage tank in the standard design shall meet the requirements for an unfired storage tank in the baseline standards which is an insulation R-value of 12.5. The surface area and location of the storage tank shall be the same as the proposed design.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

External Storage Tank Area

Applicability: All water heating systems that have an external storage tank.

Definition: Some water heating systems have a storage tank that is separate from the water heater(s) that provides additional storage capacity. This documents the entire exterior surface area of the tank.

Units: ft^2.

Input Restrictions: As specified in manufacturer specifications.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

External Storage Tank Location

Applicability: All water heating systems that have an external storage tank.

Definition: Location of the storage tank, used to determine the heat loss rate and energy exchange with the surroundings.

Units: List schedule, zone, outdoors.

Input Restrictions: As designed.

Standard Design: Not applicable.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

Solar Thermal

Applicability: Water heating systems with a solar thermal system.

Definition: A solar thermal water heating system consists of one or more collectors. Water is passed through these collectors and is heated under the right conditions. There are two general types of solar water heaters: integrated collector storage (ICS) systems and active systems. Active systems include pumps to circulate the water, storage tanks, piping, and controls. ICS systems generally have no pumps and piping is minimal.

Solar systems may be tested and rated as a complete system or the collectors may be separately tested and rated. Solar Rating & Certification Corporation (SRCC) OG-300 is the test procedure for whole systems and SRCC OG-100 is the test procedure for collectors. The building descriptors used to define the solar thermal system may vary with each compliance software application and with the details of system design.

The solar fraction shall be estimated by the f-chart procedure for solar water heating systems.

Units: Unitless fraction.

Input Restrictions: For multifamily buildings, the solar fraction provided by the solar DHW system shall be between 0 and 1. For all other buildings, the value is 0 (solar thermal may not be modeled for compliance.).

Standard Design: The standard design has no solar auxiliary system.

Combined Space Heating and Water Heating

Applicability: Projects that use a domestic hot water water heater to provide both space heat and water heating.

Definition: A system that provides both space heating and water heating from the same equipment, generally a domestic hot water heater. Such systems are restricted by the baseline standards but may be modeled in the candidate building. The restrictions are due to the misalignment of the space heating load and the water heating load. The first is highly intermittent and weather dependent, and the latter is more constant and not generally weather-related.

Units: Data structure.

Input Restrictions: The proposed design may have a combined space and water heating system.

Standard Design: The standard design shall be modeled with separate space heating and water heating systems.

Standard Design: Existing Buildings: Same as proposed if water heater is existing.

5.9.5 Exterior Lighting

Outdoor lighting requirements are specified in Section 140.7 of the Energy Code. Outdoor lighting shall not be modeled in the proposed design or standard design, and no tradeoffs are available with other building end uses or systems. Outdoor lighting shall meet all prescriptive requirements in the Energy Code.

5.9.6 Other Electricity Use

This set of building descriptors should be used to include any miscellaneous electricity use that would add to the electric load of the building and would be on the building meter. These energy uses are assumed to be outside the building envelope and do not contribute heat gain to any thermal zone.

Miscellaneous Electric Power

Applicability: All buildings with miscellaneous electric equipment located on the building site.

Definition: The power for miscellaneous equipment.

Units: Watts (W).

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Miscellaneous Electric Schedule

Applicability: All buildings with miscellaneous electric equipment located on the building site.

Definition: The schedule of operation for miscellaneous electric equipment that is used to convert electric power to energy use.

Units: Data structure — schedule, fractional.

Input Restrictions: The schedule specified for the building should match the operation patterns of the system.

Standard Design: Same as the proposed design.

5.9.7 Other Gas Use

This set of building descriptors should be used to include any miscellaneous gas use that would add to the load of the building and would be on the building meter. These energy uses are assumed to be outside the building envelope and do not contribute heat gain to any thermal zone.

Other Gas Power

Applicability: All buildings that have commercial gas equipment.

Definition: Gas power is the peak power which is modified by the schedule (see below).

Units: Btu/h-ft^2.

Input Restrictions: As designed.

Standard Design: Same as the proposed design.

Other Gas Schedule

Applicability: All buildings that have commercial gas equipment.

Definition: The schedule of operation for commercial gas equipment that is used to convert gas power to energy use.

Units: Data structure — schedule, fractional.

Input Restrictions: Continuous operation is prescribed.

Standard Design: Same as the proposed design.

5.10Onsite Energy Generation and Storage

5.10.1 Onsite Photovoltaic Energy Generation

Photovoltaic (PV) Rated Capacity

Applicability: All buildings with onsite photovoltaic generation.

Definition: The rated capacity of the PV system in kilowatts$_{dc}$.

Units: kW$_{dc}$.

Input Restrictions: Non-negative value.

Standard Design: The standard design PV system is based on requirements in 2025 Title 24 Part 6, Section 140.10(a). The PV capacity of the building is based on the PV capacity for each space where mapping of the space function to PV capacity building type is documented in Appendix C. When the PV system meets one of the prescriptive exceptions, the standard design is modeled with a PV system consistent with that prescriptive exception. The minimum capacity is the smaller of the minimum rated PV system capacity system size determined by Equation 140.10-A shown below, or the total of all available Solar Access Roof Areas (SARA)

(Solar Access Roof Area) multiplied by 18 for steep-sloped roofs or SARA multiplied by 14 for low-sloped roofs.

$$kW_{PVdc} = \frac{\sum_{1}^{n} CFA_i \times A_i}{1000}$$

Where:

kW_{PVdc} = Capacity of the building's PV system in kW_{dc}

CFA_i = Conditioned floor area in square feet of the i^{th} space

A_i = PV capacity factor for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the PV requirement by building type from Table 140.10-A in the Energy Code as described in Appendix C

PV Module Type

Applicability: All buildings with onsite photovoltaic generation.

Definition: The type of photovoltaic module that makes up the system.

Compliance software offers two module options:
Standard is a typical poly- or mono-crystalline silicon module, with efficiencies of 14-17 percent.
Premium is appropriate for modeling high efficiency (approximately 18-20 percent) monocrystalline silicon modules that have anti-reflective coatings and lower temperature coefficients.

Units: List: Standard, Premium.

Standard Design: Standard module type.

Annual Solar Access

Applicability: All buildings with onsite photovoltaic generation.

Definition: The annual solar insolation (accounting for shading obstructions) divided by the total annual solar insolation if the same areas were unshaded by those obstructions.

Units: Percent.

Input Restrictions: 0-100 percent.

Standard Design: 98 percent.

Module Level Power Electronics

Applicability: All buildings with onsite photovoltaic generation.

Definition: The type of power electronics present in each photovoltaic module.

Units: List: None, Microinverters, DC Power Optimizers.

Standard Design: None.

PV Tracking (Array Type)

Applicability: All buildings with onsite photovoltaic generation.

Definition: The tracking mechanism used to improve efficiency of electricity generation. Options are fixed, one-axis or two-axis.

Units: None.

Input Restrictions: List: None, 1-axis, 2-axis.

Standard Design: Fixed

California Flexible Installation (CFI)

Applicability: All buildings with onsite photovoltaic generations that choose to not model actual installation.

Definition: Whether or not PV system installation adheres to CFI limits, in which case azimuth and tilt specification is not required. All panels must have no shading except for horizon shading of no more than 2% of annual solar access.

CFI1 allows the PV installation at any orientation with an azimuth from 150 to 270 degrees on a roof with a pitch from 0:12 to 7:12.

CFI2 allows the PV installation at any orientation with an azimuth from 105 to 300 degrees on a roof with a pitch from 0:12 to 7:12. CF2 reduces PV production by 10% compared to CF1. To meet the Total LSC, the difference can be made up by increasing PV size by 10% or increasing energy efficiency features or through battery storage.

Units: None.

Input Restrictions: List: n/a, CFI1, CFI2.

Standard Design: CFI1.

Standard Design: Existing Buildings: Same as the proposed.

PV Azimuth

Applicability: All buildings with onsite photovoltaic generations and that no do not choose to use CFI1 or CFI2 selection limits.

Definition: The azimuth in degrees from true North (180F for South, for example). Not applicable for building-integrated panels or panels installed with no tilt.

Units: Degrees.

Input Restrictions: 0 to 360 degrees.

Standard Design: 170 degrees (face South).

PV Tilt

Applicability: All buildings with onsite photovoltaic generation and that choose to use CFI1 or CFI2 selection limits.

Definition: The tilt of the PV panels from horizontal, in degrees.

Units: Degrees.

Input Restrictions: 0 to 90 degrees.

Standard Design: 22.61 degrees (equivalent to 5:12 roof pitch).

PV Inverter Efficiency

Applicability: All buildings that have onsite photovoltaic generation and detailed inputs is selected.

Definition: The rated efficiency of the inverter in converting DC to AC power.

Units: Percent.

Input Restrictions: 0-100 percent.

Standard Design: 96 percent.

5.10.2 Battery Energy Storage System (BESS)

Battery Energy Storage System Minimum Rated Usable Energy Capacity

Applicability: All buildings with an onsite battery energy storage system.

Definition: The minimum rated usable energy storage capacity of all onsite battery energy storage systems, in kWh_{batt}.

Units: kWh_{batt}.

Input Restrictions: Positive number.

Standard Design: The mapping of space function to battery storage capacity factor by building type is documented in Appendix C.

If SARA is not used to determine then the PV system capacity, the minimum rated useable energy capacity is based on the battery energy storage system capacity, Equation 140.10-B:

$$kWh_{batt,min} = \frac{\sum_1^n CFA_i \times B_i}{1000 \times \sqrt{C}}$$

Where:

$kWh_{batt,\,min}$ = Minimum rated useable energy capacity of the battery energy storage system in kWh

CFA_i = Conditioned floor area in square feet of the i^{th} space that is subject to the PV system requirements

B_i = Battery energy storage system capacity factor for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the battery requirement by building type from Table 140.10-B in the Energy Code as described in Appendix C Appendix 5.4A battery energy storage system capacity factor in kWh per square feet for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the building type battery requirement from Table 140.10-B in the Building Energy Efficiency Standards Energy Code

C = Rated single charge-discharge cycle AC to AC (round-trip) efficiency of the battery energy storage system

If SARA is used to determine the PV system capacity, then the minimum rated useable energy capacity is based on Equation 140.10-C:

$$kWh_{batt,min} = \frac{\sum_1^n CFA_i \times B_i}{1000 \times \sqrt{C}} \times \frac{kW_{PVdc,SARA}}{kW_{PVdc}}$$

Where:

$kWh_{batt,\ min}$ = Minimum rated useable energy capacity of the battery energy storage system in kWh

CFA_i = Conditioned floor area in square feet of the i^{th} space that is subject to the PV system requirements

B_i = Battery energy storage system capacity factor for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the battery requirement by building type from Table 140.10-B in the Energy Code

C = Rated single charge-discharge cycle AC to AC (round-trip) efficiency of the battery energy storage system

kW_{PVdc} = Minimum rated PV system capacity of the building's PV system in kW as calculated in Section 140.10(a) per Equation 140.10-A

$kW_{PVdc,\ SARA}$ = Minimum rated PV system capacity in kW from the SARA calculation, as described in Section 140.10(a)

BESS Charging/Discharging Rate or Roundtrip Efficiencies

Applicability: All buildings with an onsite battery energy storage system.

Definition: The efficiency of charging and discharging electricity to and from the battery.

Units: Fraction.

Input Restrictions: Positive number.

Standard Design: The standard design charge and discharge efficiencies are 95%.

Standard Design: Existing Buildings: Same as the proposed.

BESS Minimum Rated Power Capacity

Applicability: All buildings with an onsite battery energy storage system.

Definition: The rated minimum power capacity a battery can store. This capacity is determined based on the battery energy storage system minimum rated usable energy capacity.

Units: kW.

Input Restrictions: Positive number.

Standard Design: The rated power capacity of a battery energy storage system is based on the minimum rated useable energy capacity of the battery energy storage system determined by Equation 140.10-B or if SARA is limited, by Equation 140.10-C. The mapping of space function to battery storage capacity factor by building type is documented in Appendix C.

If SARA is not used to determine the PV system capacity, then the minimum rated useable energy capacity is based on the battery energy storage system capacity, Equation 140.10-B:

$$kWh_{batt,min} = \frac{\sum_{1}^{n} CFA_i \times B_i}{1000 \times \sqrt{C}}$$

Where:

$kWh_{batt,\,min}$ = Minimum rated useable energy capacity of the battery energy storage system in kWh

CFA_i = Conditioned floor area in square feet of the i^{th} space that is subject to the PV system requirements

B_i = Battery energy storage system capacity factor for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the battery requirement by building type from Table 140.10-B in the Energy Code

C = Rated single charge-discharge cycle AC to AC (round-trip) efficiency of the battery energy storage system

If SARA is used to determine the PV system capacity, then the minimum rated useable energy capacity, SARA-adjusted, is based on the SARA-adjusted battery energy storage system minimum rated usable energy capacity, SARA-adjusted, Equation 140.10-C:

$$kWh_{batt,min} = \frac{\sum_{1}^{n} CFA_i \times B_i}{1000 \times \sqrt{C}} \times \frac{kW_{PVdc,SARA}}{kW_{PVdc}}$$

Where:

$kWh_{batt,\,min}$ = Minimum rated useable energy capacity of the battery energy storage system in kWh

CFA_i = Conditioned floor area in square feet of the i^{th} space that is subject to the PV system requirements

B_i = Battery energy storage system capacity factor for the i^{th} space's space function given the mapping of space function to building type from Appendix 5.4A and the battery requirement by building type from Table 140.10-B in the Energy Code

C = Rated single charge-discharge cycle AC to AC (round-trip) efficiency of the battery energy storage system

kW_{PVdc} = Minimum rated PV system capacity of the building's PV system in kW as calculated in Section 140.10(a)per Equation 140.10-A

$kW_{PVdc,\ SARA}$ = Minimum rated PV system capacity in kW from the SARA calculation, as described in Section 140.10(a)

The battery storage rated power capacity is calculated as:

$$kW_{batt} = \frac{kWh_{batt,min}}{4}$$

Where:

kW_{batt} = Minimum rated power capacity of the battery energy storage system in kW_{dc}

kWh_{batt} = Minimum rated useable energy capacity of the battery energy storage system in kWh

BESS Discharge Control

Applicability: All buildings with an onsite battery energy storage system.

Definition: Battery energy storage systems can be controlled using the basic control strategy or the Time of Use strategy (TOU) described in JA12.

Units: None.

Input Restrictions: List: The basic control strategy or TOU control strategy described in JA12.

Standard Design: TOU Control.

TOU Start/End Months

Applicability: All buildings with an onsite battery energy storage system with Time of Use control.

Definition: The start and end months where the Time of Use control scheme is active.

Units: None.

Input Restrictions: Not a user input.

Standard Design: TOU battery control operates all year, months 1-12.

Simulate Standalone Battery

Applicability: All buildings with an onsite battery energy storage system with no photovoltaic system or lowrise multifamily buildings served by community solar.

Definition: Standalone batteries are charged from the grid during low system load or LSC hours and discharged to support the building load and/or grid during peak time or high LSC hours.

Units: None.

Standard Design: Standalone batteries are not modeled in the standard design.

5.11Common Data Structures

This chapter describes common data structures. The data structures presented here define objects and example parameters needed to define them. The parameters described are the most common for energy simulation engines. However, other parameters or data constructs are acceptable. The fields used by the simulation program must be mapped to the fields used by the building descriptor.

5.11.1 Schedule

This data structure provides information on how equipment, people, lights, or other items are operated on an hourly basis. The ultimate construct of a schedule is an hourly time series for the simulation period, typically 8,760 hours (365 days, 24 hours per day). Compliance software has often built up the hourly schedule from 24-hour schedules for different day types such as weekdays, Saturdays, Sundays, holidays, etc.

There are several types of schedules:

Temperature schedules specify a temperature to be maintained in a space, a temperature to be delivered from an air handler, or the leaving temperature from a chiller or other equipment.
Fraction schedules specify the fraction of lights that are on, the fraction of people that are in the space, the fraction of maximum infiltration, or other factors.
On/off schedules specify when equipment is operating or when infiltration is occurring.
Time period schedules define periods of time for equipment sequencing, utility tariffs, etc. A time period schedule typically breaks the year in to two or more seasons. For each season, day types are identified such as weekday, Saturday, Sunday, and holidays. Each day type in each season is then divided into time periods.

5.11.2 Holidays

A series of dates defining holidays for the simulation period. Dates identified are operated for the schedule specified for holidays.

5.11.3 Surface Geometry

This data structure represents the location, size, and position of a surface. Surfaces include roofs, walls, floors, and partitions. Surfaces are typically planar and can be represented in various manners, including:

- Rectangular surfaces, which may be represented by a height and width along with the X, Y, and Z of surface origin, and the tilt and azimuth.
- By a series of vertices (X, Y, and Z coordinates defining the perimeter of a surface). More complex polygons may be represented in this manner.

5.11.4 Opening Geometry

This data structure represents the location and size of an opening within a surface. The most common method of specifying the geometry of an opening is to identify the parent surface, the height and width of the opening, and the horizontal and vertical offset (X and Y coordinates relative to the origin of the parent surface). An opening can also include a recess into the parent surface, which provides shading. However, other geometric constructs are acceptable.

5.11.5 Opening Shade

This data structure describes the dimensions and position of external shading devices such as overhangs, side fins, or louvers that shade the opening. Overhangs are specified in terms of the projection distance, height above the opening, and extension distance on each side of the opening.

5.11.6 Construction Assembly

This data structure describes the layers that make up the construction of a wall, roof, floor, or partition. Typically, a construction consists of a sequence of materials, described from the outside surface to the inside surface.

5.11.7 Fenestration Construction

This data structure describes the frame, glass, and other features of a window or skylight. Information may be defined in multiple ways, but the criterion is published as a combination of U-factor, solar heat gain coefficient (SHGC), and visible light transmission (VT). Some simulation programs use more detailed methods of describing the performance of fenestration that consider the angle of incidence of sun striking the fenestration and other factors, such as the properties of each pane and the fill. The compliance software only uses whole window performance properties (U-factor, SHGC, VT).

5.11.8 Material

This data structure describes a material that is used to build up a construction assembly. Typical material properties include specific heat, density, conductivity, and thickness. Materials can also be described in terms of their thermal resistance. The latter approach is sometimes used to approximate construction layers that are not homogeneous, such as framing members in combination with cavity insulation.

5.11.9 Slab Construction

This data structure describes the composition of a slab-on-grade. The compliance model has building descriptors for the perimeter length and the F-factor, which represents the heat loss per lineal foot.

5.12Exterior Surface Properties

This data structure describes the characteristics of exterior surfaces. Exterior surface properties may include emissivity, reflectivity, and roughness. The first two govern radiation exchange from the surface, while the latter governs the magnitude of the exterior air film resistance.

5.12.1 Occupant Heat Rate

This data structure represents the rate of heat and moisture generated by building occupants. This is typically specified in terms of a sensible heat rate and a latent heat rate. Both are specified in Btu/h.

5.12.2 Furniture and Contents

This data structure represents the thermal mass effect of furniture and other building contents. This is expressed in terms of lb/ft² for the space in question.

5.12.3 Reference Position in a Space

This data structure locates a reference point in a space, typically for the purposes of daylighting control. The typical construct for the reference point is a set of coordinates (X, Y, and Z) relative to the space coordinate system.

5.13Two-Dimensional Curve

This data structure explains one parameter in terms of another. An example is a curve that modifies the efficiency of an air conditioner relative to the fraction of time that the equipment operates within the period of an hour. The relationship can be expressed in terms of the X and Y coordinates of points on the curve, or it can be expressed as an equation.

5.13.1 Three-Dimensional Curve

This data structure explains one parameter in terms of two others. An example is a curve that modifies the efficiency of an air conditioner relative to the outside air dry-bulb temperature and the wet-bulb temperature of air returning to the coil. The relationship is a three-dimensional surface and can be expressed in terms of the X, Y, and Z coordinates of points on the curve, or it can be expressed as an equation.

5.13.2 Temperature Reset Schedule

This data structure describes the relationship between one temperature and another. For example, the independent variable might be outside air temperature and the dependent variable is supply air temperature. In this case, a common schedule would be to set the supply air temperature at 55°F when the outside air temperature is 80°F or warmer and at 62°F when the outside air temperature is 58°F or cooler with the supply air temperature scaling between 55°F and 62°F when the outside air temperature is between 80°F and 58°F.

6. Multifamily Building Descriptors Reference

6.1 Standard Design

For multifamily buildings, the standard design building, from which the energy budget is established, is in the same location and has the same floor area, volume, configuration, wall areas and orientations as the proposed design. The details are described below.

The *energy budget* for the multifamily standard design is the energy that would be used by a building similar to the proposed design if the proposed building met the requirements of the prescriptive standards. The compliance software generates the standard design automatically, based on fixed and restricted inputs and assumptions. Custom energy budget generation shall not be accessible to program users for modification when the program is used for compliance or when the program generates compliance forms.

The basis of the standard design is prescriptive requirements from Section 170.2 of the Energy Code. Prescriptive requirements vary by climate zone. Reference Appendices, Joint Appendix JA2, Table 2-1, contains the 16 California climate zones and representative cities. The climate zone is based on the zip code for the proposed building, as documented in Reference Appendices, Joint Appendix JA2.1.1.

The following chapters present the details of how the proposed design and standard design are determined. For many modeling assumptions, the standard design is the same as the proposed design. When a building has special features, for which the CEC has established alternate modeling assumptions, the standard design features will differ from the proposed design so the building receives appropriate credit for its efficiency. When measures require verification by a Energy Code Compliance (ECC) rater, installer test and report, or are designated as a *special feature,* the specific requirement is listed on the Certificate of Compliance

6.2 Proposed Design

The multifamily building configuration is defined by the user through entries that include floor areas, wall areas, roof and ceiling areas, fenestration (which includes skylights), and door areas, the performance characteristics such as U-factors, R-values, solar heat gain coefficient (SHGC), visible transmittance (VT), solar reflectance, and information about the orientation and tilt is required for roofs, and other elements, and end use energy use such as HVAC, lighting, and DHW. Details about any solar generation systems and battery storage are also defined. The user entries for all these building elements are consistent with the actual building design and configuration. If the compliance software models the specific geometry of the building by using a coordinate system or graphic entry technique, the data generated are consistent with the actual building design and configuration.

6.2.1 6.3 Heat Pump Water Heater Load Shifting

Any HPWH installed in multifamily buildings three habitable stores or less, which is compliant with Reference Appendices, Joint Appendix JA13 will receive LSC credit in each climate zone according as shown in Table 21: JA13 HPWH Basic Control Credit. The LSC percentage reduction is applied upon the completion of the compliant simulation run. Note that this percentage reduction only applies to the LSC values for water heating.

Table 21: JA13 HPWH Basic Control Credit

Climate Zone	Credit
1	6.7
2	3.7
3	7.6
4	4.0
5	8.5
6	6.8
7	8.8
8	4.4
9	4.4
10	4.4
11	4.2
12	4.7
13	8.0
14	3.1

15	8.2
16	22.7

6.3 Self-Utilization Credit

When a PV system is coupled with a battery storage system, the compliance software allows a portion of the Photovoltaic and BESS LSC to be traded against the efficiency LSC. This modest credit can be used for tradeoffs against building envelope and efficiencies of the equipment installed in the building. More detail is provided in Chapter 6.4.1 Photovoltaics Requirements Three Habitable Floors or Less. The self-utilization credit is only applicable to multifamily buildings three habitable stories or less.

6.4 Photovoltaic and Battery Energy Storage System Requirements

Requirements for PV systems and battery energy storage systems are dependent on the number of floors of the building. Multifamily buildings with three or fewer habitable floors have different requirements than multifamily buildings with four or more habitable floors. Modeling software will calculate PV system and battery energy storage system requirements to account for the number of habitable floors of the buildings.

6.4.1 Photovoltaic and Battery Energy Storage System Requirements for Three Habitable Floors or Less

The PV requirements are applicable to newly constructed multifamily buildings three habitable floors or less. PV system details are based on the publicly available System Advisor Model algorithms developed by the National Renewable Energy Laboratory, or similar calculation methods approved by the Energy Commission. See Appendix F. for more information.

Photovoltaic Standard Design Three Habitable Floors or Less

The standard design PV system is based on requirements in Section 170.2(f) for multifamily buildings – three habitable floors or fewer. The PV capacity of the building is based on the PV capacity for each space where mapping of the space function to PV capacity building type is documented in Appendix C. When the PV system meets one of the prescriptive exceptions, the standard design is modeled with a PV system consistent with that prescriptive exception.

Photovoltaic Proposed Design Three Habitable Floors or Less

For PV sizing calculations, the compliance software includes user-defined values for:

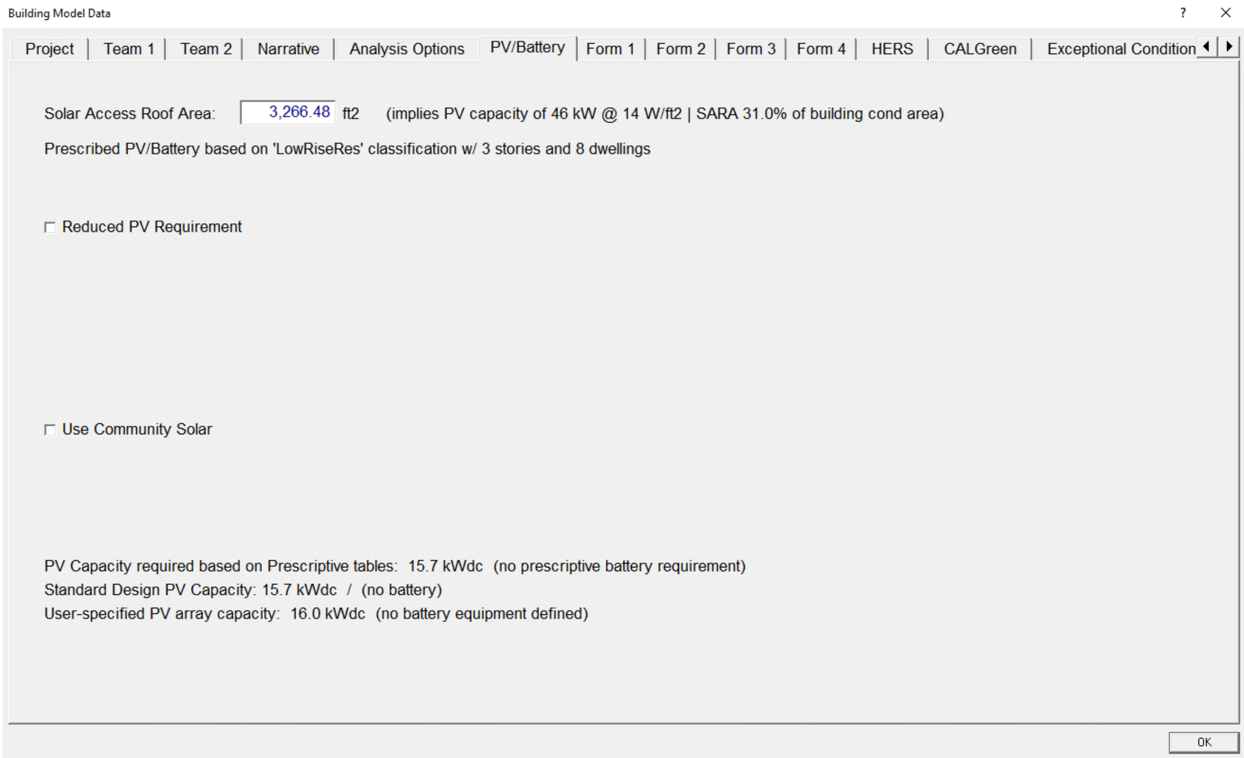
- Array azimuth, either the actual orientation or a range of azimuths included under CFI1 (installation of 150–270 degrees) or CFI2 (installation of 105-300 degrees).
- Module type, including standard (for example, poly- or mono-crystalline silicon modules with efficiencies of 14 – 17 percent), and premium (for example, high-efficiency monocrystalline silicon modules with anti-reflective coatings with efficiencies of 18 – 20 percent).
- Inverter efficiency.
- Array tilt in degrees or roof pitch, or CFI1 or CFI2 (installation up to 7:12).
- CF2 reduces PV production by 10% compared to CF1. To meet the Total LSC, the difference can be made up by increasing PV size by 10% or increasing energy efficiency features or through battery storage.
- Array tracking type including fixed, single-axis tracking, and two-axis tracking.
- Annual solar access percentage, excluding horizon shading, of the modules.
- SARA

When the PV standard design system size is determined by one of the prescriptive exceptions, the proposed design system size shall not exceed the PV standard design size specified by the exception limits. When the PV standard design system is determined based on a limited SARA, the proposed design system size shall not exceed the SARA-determined size. The PV size is reported in kW_{dc} on the Certificate of Compliance.

Community Solar Three Habitable Floors or Less

For projects that use an approved community solar program to provide the required PV, approved compliance software must determine and report the amount (PV kW_{dc}) needed to offset the standard design PV system LSC.

Figure 9: Community Solar



Source: California Energy Commission

Battery Energy Storage System Three Habitable Floors or Less

Detailed calculations for PV and battery energy storage systems are included in Appendices C and D.

The compliance software provides credit for a battery energy storage system coupled with a PV array or simulated as standalone. If specified, the battery storage size must be 5 kWh or larger. For Energy Code compliance, PV has no impact on energy efficiency requirements or the efficiency LSC unless a battery storage system is included, and the self-utilization credit is modeled.

Battery Energy Storage System Controls Three Habitable Floors or Less

The time-of-use control strategy, as described in Reference Appendices, Joint Appendix JA12, is used to simulate the BESS for the standard design. The proposed design control strategy can use either the basic control strategy or TOU control strategy.

The controls for separate battery energy storage systems uses the basic control strategy, described in Reference Appendices, Joint Appendix JA12, for the standard design of energy storage systems that are installed separate from an on-site solar photovoltaic system.

Verification and Reporting Three Habitable Floors or Less

The following PV capacity and battery energy storage system requirements are reported as special features on the Certificate of Compliance:

- PV system
  - Minimum rated PV system capacity, kW_{dc}
- Battery energy storage system
  - Minimum rated usable energy capacity, kWh
  - Compliance cycling capacity, kWh
  - Roundtrip efficiency, %
  - Field-assembled or integrated

Self-Utilization Credit Three Habitable Floors or Less

The 2025 Energy Code does not allow a tradeoff between the Efficiency LSC and Source Energy and the effect of PV on the Total LSC/Source Energy unless battery storage is provided. When the PV system is coupled with at least a 5 kWh battery storage system, the compliance software allows a portion of the photovoltaic and BESSLSC and Source Energy to be traded against the Efficiency LSC. A modest self-utilization credit can be used for tradeoffs against building envelope and efficiencies of the equipment installed in the building. A checkbox is provided in the compliance software to enable this credit.

Table 22: Self-Utilization Credits

Climate Zone	Multifamily
01	10%
02	7%
03	10%
04	9%
05	11%
06	4%
07	4%
08	10%
09	10%
10	10%
11	10%
12	10%
13	10%
14	10%
15	9%
16	12%

Source: California Energy Commission

6.4.2 Photovoltaic and Battery Energy Storage System Requirements Four or More Habitable Floors

Requirements for PV systems and battery energy storage systems in this chapter are applicable to newly constructed multifamily buildings with four or more habitable floors. PV system details are based on the publicly available system calculation from PVWatts®, which is a web application developed by the National Renewable Energy Laboratory, or similar calculation method approved by the Energy Commission. See Appendix F. for more information.

Photovoltaic Standard Design More than Three Habitable Floors

For multifamily buildings with more than three habitable floors and mixed occupancy buildings with more than three habitable floors with at least 80 percent of the floor area used for residential occupancy, a newly installed PV system meeting the minimum qualification requirements of Reference Appendices, Joint Appendix JA11 is required. The PV size in kWdc is the smaller of the PV system size determined by Equation 170.2-D, or the total of all available SARA multiplied by 14 W/ft^2 for low sloped roofs and 18W/ft^2 for steep sloped roofs, where the PV capacity factor of Equation 170.2-D is determined by building type.

When the solar electric generation system meets one of the prescriptive exceptions, the standard design is modeled with a PV system consistent with that prescriptive exception.

Photovoltaic Proposed Design More than Three Habitable Floors

For PV calculations, the compliance software includes user-defined values for:

- Array orientation, including CFI1 (installation of 150–270 degrees, CFI2 (installation of 105-300), or the actual orientation. Module type, including standard (for example, poly- or monocrystalline silicon modules), premium (for example, high-efficiency monocrystalline silicon modules with anti-reflective coatings)
- Inverter efficiency.
- Array tilt in degrees or roof pitch, or CFI1 or CFI2 (installation up to 7:12).
- Array tracking type including fixed, single-axis tracking, and two-axis tracking.
- CF2 reduces PV production by 10% compared to CF1. To meet the Total LSC, the difference can be made up by increasing PV size by 10% or increasing energy efficiency features or through battery
- Annual solar access percentage, excluding horizon shading, of the modules.
- Solar Access Roof Area (SARA)

When the PV standard design system size is determined by one of the prescriptive exceptions, the proposed system size shall not exceed the PV standard design size specified by the exception limits.

The PV size is reported in kW_{dc} on the Certificate of Compliance.

Battery Energy Storage System Standard Design More Than Three Habitable Floors

For multifamily buildings more than three habitable floors that are required to have a PV System to meet Section 170.2(g), a battery energy storage system meeting qualification requirements of Reference

Appendices, Joint Appendix JA12 is also required. The battery energy storage system minimum rated usable energy capacity and minimum rated power capacity is determined by Equation 170.2-E and Equation 170.2-G respectively, where the storage capacity and power factors of these equations is determined by individual space function. The mapping of space function to PV or battery used to determine capacity factors by building type is documented in Appendix C.

When the battery energy storage system meets one of the prescriptive exceptions in Section 170.2(h), the standard design is modeled with a battery energy storage system consistent with that prescriptive exception.

Battery Energy Storage System Proposed Design More Than Three Habitable Floors

Detailed calculations for PV and battery storage are included in Appendices C and D.

When the PV standard design system size is determined by one of the prescriptive exceptions, the proposed design is modeled with a system size that does not exceed the battery system capacity and rated power required by the standard design.

Battery Energy Storage System Controls More Than Three Habitable Floors

The control strategy used to simulate the BESS is the time-of-use control strategy as described in Reference Appendices, Joint Appendix JA12, for the standard design. The proposed design control strategy can use either the basic control strategy or TOU control strategy.

The controls for separate battery energy storage systems strategy uses the TOU control strategy as described in Reference Appendices, Joint Appendix JA12 for energy storage systems installed separate from an on-site solar photovoltaic system.

6.5 The Building

Proposed Design

The building is defined through entries for zones, surfaces, and equipment. Zone types are first defined as either dwelling unit spaces or common use spaces, then further defined by conditioning status and space function. Dwelling unit zones are always conditioned whereas the user defines type of conditioning and space function for common use spaces within the project. The compliance software models surfaces separating conditioned space from exterior or unconditioned spaces (such as a garage or storage), which have no solar gains, as interior surfaces with insulation meeting standards requirements. Exterior surfaces of an attached garage or storage space are modeled as part of the unconditioned zone.

The input file will include entries for floor areas, wall, door, roof and ceiling areas, and fenestration and skylight areas, as well as the water-heating, space-conditioning, ventilation, and distribution systems.

Each surface area is entered along with performance characteristics, including building materials, U-factor, SHGC , and VT. The orientation and tilt (Figure 10: Surface Definitions) are required for envelope elements.

Building elements are to be consistent with the actual building design and configuration.

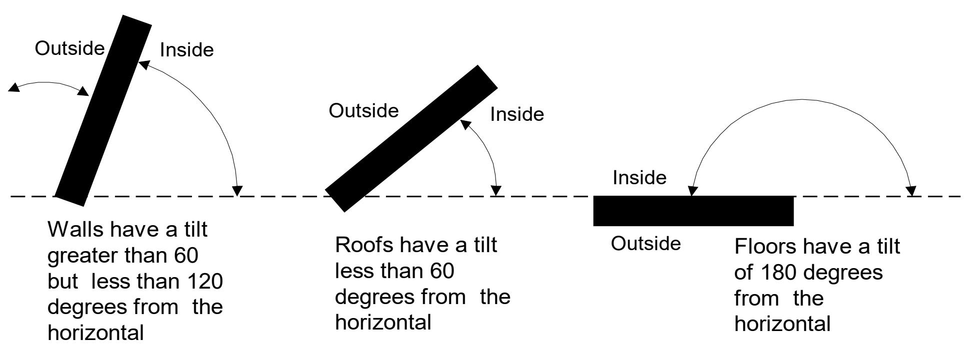
Standard Design

To determine the standard design, the compliance software creates a building with the same general characteristics (number of floors, orientation, climate zone). Energy features are set to be equal to Section 170.2, Table 170.2-A and Table 170.2-K for multifamily buildings. See Section 6.13 for details regarding additions and alterations. The details are below.

Verification and Reporting

All inputs that are used to establish compliance requirements are reported on the Certificate of Compliance.

Figure 10: Surface Definitions



Source: California Energy Commission

6.5.1 Dwelling Unit Types

Internal gains and IAQ ventilation calculations depend on the conditioned floor area and number of bedrooms. For multifamily buildings with individual IAQ ventilation systems, each combination of bedrooms and conditioned floor area has a different minimum ventilation CFM that must be verified. In buildings with multiple dwelling units, a dwelling unit type has the same floor area, number of bedrooms, IAQ ventilation system, space conditioning systems, and appliances (washer/dryer in the dwelling unit).

Proposed Design

For each dwelling unit type the user inputs the following information:

Unit type name
Conditioned floor area (CFA) in square feet per dwelling unit
Number of bedrooms
Appliance data
Space conditioning systems
DHW system
IAQ ventilation system

Standard Design

The standard design shall have the same conditioned floor area and number of bedrooms and type of dwelling units as the proposed design.

Verification and Reporting

The number of units of each type and minimum IAQ ventilation for each unit type is reported on the Certificate of Compliance for field verification.

6.5.2 Dwelling Units per Space

Multifamily projects have multiple dwelling units within the project. The dwelling units per space represents the number of residential living units within a single compliance model space and is shown as a positive integer.

Proposed Design

The proposed design represents the building as designed.

Standard Design

The standard design assumes the same number of dwelling units as identified in the proposed design. This applies for both newly constructed buildings projects and existing building projects.

6.5.3 Number of Bedrooms

Multifamily projects can have multiple bedrooms within a dwelling unit. The user will provide the number of bedrooms per dwelling unit as an integer with a minimum of 0 and a maximum of 5.

Proposed Design

The proposed design represents the number of bedrooms per dwelling unit as designed.

Standard Design

The standard design assumes the same number of bedrooms per dwelling unit as identified in the proposed design. This applies for both newly constructed buildings projects and existing building projects.

6.5.4 Number of Occupants

Applicability: Multifamily projects will need to specify the number of people in a space. The number of people is modified by an hourly schedule, which approaches but does not exceed 1.0. Therefore, the number of people specified by the building descriptor is similar to design conditions as opposed to average occupancy.

The number of people may be specified in ft^2/person, or people/1000 ft^2.

Proposed Design

For nonresidential occupancies within a mixed-use building, the number of occupants is prescribed, and the values are given by Space Type in Appendix 5.4A. For multifamily common use areas, the rules established in [Chapter 6 Multifamily Building Descriptors Reference]() of the Nonresidential ACM

Reference Manual apply. For multifamily dwelling units, the number of occupants is defined as: Max (number of bedrooms +1, 2).

Standard Design:

The number of occupants must be identical for both the proposed and standard design cases. This applies for both newly constructed buildings and existing building projects.

6.5.5 Lighting Classification Method

For multifamily common areas in the building, the indoor lighting power is specified using the area category method.

Proposed Design

Area category method can be used for all areas of the building with space types listed in Appendix 5.4A, and can be used to specify both general lighting power and additional lighting power for these multifamily common use spaces.

Standard Design

The standard design lighting power shall be modeled as described for nonresidential spaces except as noted below.

- Area category method lighting power allowances, as well as additional lighting power qualified systems and allowances are defined by Table 170.2-M

6.5.6 Multifamily General Lighting Power

All common area spaces in multifamily buildings may have multifamily general lighting power. General lighting power is the power used by installed electric lighting that provides a uniform level of illumination throughout an area, exclusive of any provision for special visual tasks or decorative effect, and also known as ambient lighting.

Proposed Design

For spaces without additional lighting power allowances or similar requirements, this input will be the same as the regulated lighting power.

Trade-offs in general lighting power are allowed between spaces all using the area category method.

Standard Design

General lighting power is the product of the lighting power densities for the space type from Appendix 5.4A and the floor areas for the corresponding conditioned spaces.

When the lighting status is “existing” (and unaltered) for the space, the standard design is the same as the existing, proposed design.

When the lighting status is “altered” for the space, and at least 10 percent of existing luminaires have been altered:

If the lighting status is “existing”, then the standard design LPD is the same as the proposed design.

If the lighting status is “new”, then the standard design LPD is same as newly constructed buildings.

If the lighting status is “altered”, then the standard design LPD is the same as newly constructed buildings.

6.5.7 Multifamily Additional Lighting Power Task Area

Common areas spaces in multifamily buildings that use area category method can identify multifamily additional lighting power task area.

Proposed Design

The area associated with each of the additional lighting allowances in the ALP building descriptor. This area is based on the proposed designed but cannot exceed the floor area of the space.

Standard Design

The standard design multifamily additional lighting power task area is the same as the proposed. This applies for both newly constructed buildings and existing building projects.

6.6 Air Leakage and Infiltration

The compliance software distributes the leakage over the envelope surfaces in accordance with the building configuration and constructs a pressure flow network to simulate the airflows between the conditioned zones, unconditioned zones, and outside.

6.6.1 Building Air Leakage and Infiltration

The airflow through a blower door at 50 pascals (Pa) of pressure measured in cubic feet per minute is called CFM50. CFM50 multiplied by 60 minutes, divided by the volume of conditioned space, is the air changes per hour at 50 Pa, called ACH50.

Proposed Design

The proposed design for primarily dwelling unit zones in multifamily buildings shall be 2.3 ACH50. The proposed design for zones in multifamily buildings that are primarily common use and nonresidential areas shall be modeled as 7 ACH50.

Standard Design

The standard design multifamily dwelling and common area air leakage and infiltration is the same as the proposed.

Verification and Reporting

For dwelling units in multifamily buildings, diagnostic testing to confirm the mandatory maximum compartmentalization value of 0.3 CFM50/ft^2 of dwelling surface area in the proposed design is required and must be reported in the ECC required verification listing on the Certificate of Compliance.

6.6.2 Dwelling Unit Zones and Surfaces

Multifamily buildings that have floors between dwelling units must define dwelling zones by floor and exterior exposure (orientation), or each dwelling unit as a separate zone. Users should define a sufficient number of exterior and interior surfaces so that the compliance software can simulate the airflows between the conditioned zones, unconditioned zones, and outside.

6.7 Residential Building Materials and Construction

6.7.1 Materials

Only materials approved by the CEC may be used in defining constructions. Additional materials may be added to the compliance software at the CEC's discretion.

Table 23: Materials List shows a partial list of the materials available for construction assemblies. Additional material information can be found in Reference Appendices Joint Appendix JA4.

Material Name

The material name is used to select the material for a construction.

Thickness

Some materials, such as three-coat stucco, are defined with a specific thickness (not editable by the compliance user). The thickness of other materials, such as softwood used for framing, is selected by the compliance user based on the construction of the building.

Conductivity

The conductivity of the material is the steady-state heat flow per square foot, per foot of thickness, or per degree Fahrenheit temperature difference. It is used in simulating the heat flow in the construction.

Table 23: Materials List

Material Name	Thickness (in.)	Conductivity (Btu/h-°F-ft)	Coefficient for Temperature Adjustment of Conductivity (°F(-1))	Specific Heat (Btu/lb-°F)	Density (lb/ft^3)	R-Value per Inch (°F-ft^2-h/ Btu-in)
Gypsum Board	0.5	0.09167	0.00122	0.27	40	0.9091
Wood Layer	Varies	0.06127	0.0012	0.45	41	1.36
Synthetic Stucco	0.375	0.2		0.2	58	0.2
3 Coat Stucco	0.875	0.4167		0.2	116	0.2
All other siding						0.21
Carpet	0.5	0.02		0.34	12.3	4.1667
Light Roof	0.2	1		0.2	120	0.0833

Material Name	Thickness (in.)	Conductivity (Btu/h-°F-ft)	Coefficient for Temperature Adjustment of Conductivity (°F(-1))	Specific Heat (Btu/lb-°F)	Density (lb/ft³)	R-Value per Inch (°F-ft²-h/ Btu-in)
5 PSF Roof	0.5	1		0.2	120	0.0833
10 PSF Roof	1	1		0.2	120	0.0833
15 PSF Roof	1.5	1		0.2	120	0.0833
25 PSF Roof	2.5	1		0.2	120	0.0833
TileGap	0.75	0.07353		0.24	0.075	1.1333
SlabOnGrade	3.5	1		0.2	144	0.0833
Earth		1		0.2	115	0.0833
SoftWood		0.08167	0.0012	0.39	35	1.0204
Concrete		1		0.2	144	0.0833
Foam Sheathing	Varies	varies	0.00175	0.35	1.5	Varies
Ceiling Insulation	Varies	varies	0.00418	0.2	1.5	Varies
Cavity Insulation	varies	varies	0.00325	0.2	1.5	Varies
Vertical Wall Cavity	3.5	0.314	0.00397	0.24	0.075	
GHR Tile	1.21	0.026	0.00175	0.2	38	
ENSOPRO	0.66	0.03	0.00175	0.35	2	
ENSOPRO Plus	1.36	0.025	0.00175	0.35	2	
Door						5

Source: California Energy Commission

Coefficient for Temperature Adjustment of Conductivity

The conductivity of insulation materials varies with temperature according to the coefficient listed. Other materials have a coefficient of zero (0), and the conductivity does not vary with temperature.

Specific Heat

The specific heat is the amount of heat in British thermal units (Btu) it takes to raise the temperature of 1 pound of the material 1 degree Fahrenheit (Btu/lb-°F).

Density

The density of the material is the weight of the material in pounds per cubic foot (lb/ft³).

R-value per inch

The R-value is the resistance to heat flow for a 1-inch-thick layer.

6.7.2 Residential Construction Assemblies

"Constructions" are defined by the compliance user for use in defining the building. The user assembles a construction from one or more layers of materials. For framed constructions, there is a framing layer that has parallel paths for the framing and the cavity between the framing members. The layers that are allowed depend on the surface type. The compliance software calculates a winter design U-factor that is compared to construction that meets the prescriptive standard. The U-factor is displayed as an aid to the user. The calculations used in the energy simulation are based on each layer and framing rather than the U-factor.

Assembly Types

The types of surfaces that the construction assemblies can be assigned to are:

Exterior wall
Interior wall
Underground wall
Attic roof
Cathedral roof
Ceiling below attic
Interior ceiling
Interior floor
Exterior floor (over unconditioned space or exterior)Floor over crawl space

Note: Exterior walls and floors, and Cathedral Ceilings can be described by either Residential Construction Assemblies (described in this section) or Nonresidential Construction Assemblies described in Chapters 5.5.3, 5.5.4, and 5.5.5 above.

Construction Type

For residential construction assemblies, a Construction Type must be defined. The available construction types depend on the Assembly Type described above.

For ceiling below attic the available construction is:

- Wood framed ceiling: In a residence with a truss roof, the ceiling is where the insulation is located, while the structure above the ceiling is encompassed by the term "attic" or "roof." The attic or roof consists of (moving from inside to outside) the radiant barrier, below-deck insulation, framing, above-deck insulation, and the roofing product, such as asphalt or tile roofing. See more in Chapter 6.10.2 Ceiling Below Attic.

For cathedral ceiling (with the roof defined as part of the assembly), the available construction types are:

- Wood framed ceiling: Since there is no attic, the roof structure is connected to the insulated assembly at this point
- Built up roof
- Structurally insulated panels (SIPs) ceiling

For attic roof, the available construction types are:

Wood-framed ceiling

- Built-up roof
- SIPs ceiling.

For interior ceiling, the available construction type is:

- Wood-framed ceiling

For interior and exterior walls, the only available construction types are:

- Wood- framed wall
- Metal-framed wall
- Concrete / ICF / brick
- Hollow unit masonry
- Adobe / strawbale / log
- Sips wall
- Dual panel hollow (DPH) wall

For underground walls, the only available construction type is:

- Concrete / ICF / brick

For floors (over exterior, over crawl space, or interior), the construction types are:

- Wood-framed floor
- SIPs floor
- Concrete / ICF / brick

For slab floors and underground floors, the construction type is:

- No frame (concrete/CMU)

Party surfaces separate conditioned space included in the analysis from conditioned space that may or may not be included in the analysis. Party surfaces for spaces that are modeled include surfaces between multifamily dwelling units. Party surfaces for spaces not included in the analysis include spaces joining an addition alone to the existing dwelling. Interior walls, ceilings, or floors can be party surfaces.

Construction Layers

All assemblies have a cavity path and a frame path.

As assemblies are completed, the screen displays whether the construction meets the prescriptive requirement for that component.

Proposed Design

The user defines a construction for each surface type included in the proposed design. Any variation in insulation R-value, framing size or spacing, interior or exterior sheathing, or interior or exterior finish requires the user to define a different construction. Insulation R-values are based on manufacturer-rated properties rounded to the nearest whole R-value. Layers such as sheetrock, wood sheathing, stucco, and carpet whose properties are not compliance variables are included as generic layers with standard thickness and properties.

Walls separating conditioned spaces from unconditioned spaces are modeled as interior walls with unconditioned space as the adjacent zone, which the compliance software recognizes as a “demising wall. Floors over an unconditioned space are modeled as an interior or demising floor. The exterior surfaces of unconditioned spaces are modeled, though not subject to energy code requirements.

Standard Design

The compliance software assembles a construction that meets the prescriptive standards for each user-defined construction or assembly. For ceiling/roof assembly, the standard design is based on Table 170.2-A Option B. For cathedral ceiling assemblies, the standard design is based on Table 170.2-A Option D. Exterior surface requirements are based on Table 170.2-A and vary based on the type of exterior surface and climate zone.

Verification and Reporting

All proposed constructions, including insulation, frame type, frame size, and exterior finish or exterior condition, are listed on the Certificate of Compliance. Nonstandard framing (e.g., 24” on center wall framing, advanced wall framing) is reported as a special feature.

6.7.3 Spray-Foam Insulation

The R-values for spray-applied polyurethane foam (SPF) insulation differ depending on whether the product is open cell or closed cell. Spray-foam insulation R-values are calculated based on the nominal thickness of the insulation multiplied by the default thermal resistivity per inch, or the total R-value may be calculated based on the thickness of the insulation multiplied by the tested R-value per inch as certified by the Department of Consumer Affairs, Bureau of Household Goods and Services (see details Chapter 6.7.3 Spray-Foam Insulation and Reference Appendices, Residential Appendix RA3.5).

Table 24: Required Thickness Spray Foam Insulation (in inches)

Required R-values for SPF insulation	R-11	R-13	R-15	R-19	R-21	R-22	R-25	R-30	R-38
Required thickness closed cell @ R5.8/inch	2.00	2.25	2.75	3.50	3.75	4.00	4.50	5.25	6.75
Required thickness open cell @ R3.6/inch	3.0	3.5	4.2	5.3	5.8	6.1	6.9	8.3	10.6

Source: California Energy Commission

Additional documentation and verification requirements for a value other than the default values shown in Table 24: Required Thickness Spray Foam Insulation (in inches) are required. (See Reference Appendices, Residential Appendix RA3.5.6.) For continuous insulation refer to Section 5.5.4 Exterior Walls.

6.7.3.1 Medium Density Closed-Cell SPF Insulation

The default R-value for spray-foam insulation with a closed cellular structure is R-5.8 per inch, based on the installed nominal thickness of insulation. Closed-cell insulation has an installed nominal density of 1.5 to 2.5 pounds per cubic foot (pcf).

6.7.3.2 Low-Density Open-Cell SPF Insulation

The default R-value for spray-foam insulation with an open cellular structure is calculated as R-3.6 per inch, based on the nominal required thickness of insulation. Open-cell insulation has an installed nominal density of 0.4 to 1.5 pcf.

Proposed Design

The user will select either typical values for open-cell or closed-cell spray-foam insulation or higher-than-typical values and enter the total R-value (rounded to the nearest whole value).

Standard Design

The compliance software assembles a construction that meets the prescriptive standards for each assembly type (ceiling/roof, wall, and floor).

Verification and Reporting for Buildings with up to Three Habitable Floors

When the user elects to use higher-than-typical R-values for open-cell or closed-cell spray-foam insulation, a special features note is included on the Certificate of Compliance requiring documentation requirements specified in Reference Appendices, Joint Appendix JA4.1.7. Furthermore, a ECC verification requirement for the installation of spray-foam insulation using higher-than-default values is included on the Certificate of Compliance.

6.7.4 Quality Insulation Installation For Building Up To Three Habitable Floors

The compliance software user may specify quality insulation installation (QII) for the proposed design as “yes” or “no.” The effective R-value of cavity insulation is reduced, as shown in Table 25: Modeling Rules for Unverified Insulation Installation Quality in buildings with no QII. When set to “no,” framed walls, ceilings, and floors are modeled with added winter heat flow between the conditioned zone and attic to represent construction cavities open to the attic. QII does not affect the performance of continuous sheathing in any construction.

Proposed Design

The compliance software user may specify compliance with QII. The default is “no” for QII. This results in a 30% derating applied to the cavity insulation.

Standard Design

The standard design is modeled with “yes” for verified QII for newly constructed multifamily buildings and additions greater than 700 square feet in Climate Zones 1-6 and 8-16 (Climate Zone 7 has no QII for multifamily buildings). This results in the removal of the 30% derating to the cavity insulation.

VERIFICATION AND REPORTING

The presence of QII is reported in the ECC required verification listings on the Certificate of Compliance. Verified QII is certified by the installer and field verified to comply with Reference Appendices, Residential Appendix RA3.5. Credit for verified QII applies to ceilings/attics, knee walls, exterior walls, and exterior floors.

For alterations to existing pre-1978 construction, if the existing wall construction is assumed to have no insulation, no wall degradation is assumed for the existing wall.

Table 25: Modeling Rules for Unverified Insulation Installation Quality

Component	Modification
Walls, Floors, Attic Roofs, Cathedral Ceilings	Multiply the cavity insulation R-value/inch by 0.7.
Ceilings Below Attic	Multiply the blown and batt insulation R-value/inch by 0.96-0.00347*R.
Ceilings Below Attic	Add a heat flow from the conditioned zone to the attic of 0.015 times the area of the ceiling below attic times (the conditioned zone temperature — attic temperature) whenever the attic is colder than the conditioned space.

Source: California Energy Commission

6.8 Building Mechanical Systems

A space-conditioning system (also referred to as an HVAC system) is made up of the heating subsystem (also referred to as “heating unit,” “heating equipment,” or “heating system”); cooling subsystem (also referred to as “cooling unit,” “cooling equipment,” or “cooling system”); the distribution subsystem details (if any); and fan subsystem (if any). Ventilation cooling systems and indoor air-quality-ventilation systems are defined as part of the dwelling unit information for multifamily buildings.

Mechanical Systems serving Multifamily buildings

The standard design HVAC systems for dwelling units and common areas in multifamily buildings is described in Table 26: Residential Standard Design HVAC System below:

Table 26: Residential Standard Design HVAC System

Space Type	Above-Grade Floors	Climate Zone	Standard Design
Dwelling Unit	Habitable floors ≤ 3	1-15	Single zone system with constant volume fan, no economizer, DX heat pump with electric resistance supplemental heat
Dwelling Unit	Habitable floors ≤ 3	16	Single zone system with constant volume fan, no economizer, DX cooling and furnace
Dwelling Unit	Habitable floors > 3	2-15	Single zone system with constant volume fan, no economizer, DX heat pump with electric resistance supplemental heat
Dwelling Unit	Habitable floors > 3	1, 16	Single zone system with constant volume fan, no economizer, DX heat pump with gas furnace supplemental heat
Directly Conditioned Common Area	Habitable floors ≤ 3	1-15	Single zone system with constant volume fan, DX heat pump with electric resistance supplemental heat
Directly Conditioned Common Area	Habitable floors ≤ 3	16	Single zone system with constant volume fan, DX cooling and furnace
Directly Conditioned Common Area	Four or more habitable floors	2-15	Single zone system with constant volume fan, DX heat pump with electric resistance supplemental heat
Directly Conditioned Common Area	Four or more habitable floors	1, 16	Single zone system with constant volume fan, DX heat pump with gas furnace supplemental heat
Indirectly Conditioned Common Area	No limit	All	Same as proposed design with code minimum ventilation

Source: California Energy Commission

Requirements for the standard design mechanical systems in dwelling units are described in Sections 6..1 Heating Subsystems through 6.8.6 Indoor Air Quality (IAQ) Ventilation. These requirements are not applicable to common areas.

Multifamily common areas may be directly or indirectly conditioned. When the proposed design is indirectly conditioned, the standard design HVAC system matches the proposed design with code minimum ventilation. In cases where a central balanced ventilation system serves both dwelling units and an indirectly conditioned space, the requirements for heat recovery performance are based on the requirements for the dwelling units.

The standard design common area system fan shall run continuously to provide ventilation when the space is occupied. The heating and cooling efficiencies, fan power and economizer requirements, heat recovery performance and other requirements shall match those described in Chapter 5 Nonresidential Building Descriptors Reference for non-residential systems with the following exceptions:

- All heating and cooling system efficiencies shall follow the requirements for equipment using single-phase power.
- Relief fans, if included, shall not be modeled or be modeled the same in the proposed and standard designs
- Only fan power credits from Section 170.2(c)4Ai for higher levels of filtration shall be accounted for in the standard design.
- Distribution systems shall not be modeled

Multifamily Parking Garages

Parking garages shall be modeled with exhaust systems. Follow rules in Chapter 5 Nonresidential Building Descriptors Reference.

6.8.1 Heating Subsystems

The heating subsystem section describes the equipment that supplies heat to a space-conditioning system. Heating subsystems are categorized according to the types shown in Table 28: HVAC Heating Equipment Types and Table 29: Heat Pump Equipment Types.

Furnace capacity is determined by the compliance software as 200 percent of the heating load at the heating design temperature. Heat pump compressor size is determined by the compliance software as the larger of the compressor size calculated to meet 110 percent of the cooling load at the cooling design temperature, or the compressor size calculated to meet 110 percent of the heating load at the heating design temperature.

If the heat pump heating capacity is insufficient to meet load during any hour, and supplemental heating is provided by electric resistance, the unmet portion of the load is met by supplemental heating.

If the heat pump heating capacity is insufficient to meet load during any hour, and supplemental heating is provided by gas, the entire heating load for the hour would be met by supplemental heating. In applications where heating load is greater than or equal to cooling load, the heat pump is disabled whenever the outdoor air temperature is below the heat pump lockout temperature. The heat pump lockout temperature is 40 °F. In applications where cooling load is greater than heating load, the heat pump is disabled whenever the heating load is greater than the heating capacity.

Proposed Design

The user selects the heating subsystem equipment type, and supplies required inputs from those listed in Table 19 for the heating subsystem, including the rated heating efficiency. The rated heating capacity is not used as a compliance variable by the compliance software.

Standard Design

For dwelling unit space conditioning systems, the standard design heating subsystem is dependent on climate zone and number of habitable stories. For multifamily buildings with three habitable stories or less in Climate Zones 1-15 the space conditioning system is a heat pump. For multifamily buildings with three habitable stories or less in Climate Zone 16 the space conditioning system is an air conditioner with furnace. For multifamily buildings with four or more habitable stories in Climate Zones 2-15 the space conditioning system is a heat pump. For multifamily buildings with four or more habitable stories in Climate Zones 1 and 16 the space conditioning system is a dual-fuel heat pump.

When the standard design is a heat pump, the equipment used in the standard design building is an electric split-system heat pump with a heating seasonal performance factor (HSPF/HSPF2) meeting the current *Appliance Efficiency Regulations* minimum efficiency for heat pumps.

When the standard design is a gas heating system, the equipment used in the standard design building is a gas furnace (or propane if natural gas is not available), and an annual fuel utilization efficiency (AFUE) meeting the *Appliance Efficiency Regulations* minimum efficiency for central systems.

See Table 28: HVAC Heating Equipment Types and Table 29: Heat Pump Equipment Types for complete details on heating subsystems noted above.

Table 27: Standard Design Dwelling Unit Heating System

Proposed Design	Standard Design
Three or less habitable stories; Climate Zones 1-15	Single zone system with constant volume fan, no economizer, DX heat pump with electric resistance supplemental heat
Three or less habitable stories; Climate Zones 16	Single zone system with constant volume fan, no economizer, DX cooling and furnace
Four or more habitable stories; Climate Zones 2-15	Single zone system with constant volume fan, no economizer, DX heat pump with electric resistance supplemental heat
Four or more habitable stories; Climate Zones 1 and 16	Single zone system with constant volume fan, no economizer, DX heat pump with gas furnace supplemental heat

Source: California Energy Commission

Verification and Reporting

The proposed heating system type and rated efficiency are reported on the Certificate of Compliance. For heat pumps, with electric resistance supplemental heat, the ECC-verified rated heating capacity of each proposed heat pump is reported on the Certificate of Compliance. Installed capacities must be equal to or larger than the capacities modeled at 47 ° F and 17 ° F (Reference Appendix 3.4.4.2).

Table 28: HVAC Heating Equipment Types

Name	Heating Equipment Description
CntrlFurnace	Gas- or oil-fired central furnaces, propane furnaces, or heating equipment considered equivalent to a gas-fired central furnace, such as wood stoves that qualify for the wood heat exceptional method. Gas fan-type central furnaces have a minimum AFUE=80% before December 18, 2028 and 95% on or after December 18, 2028. Distribution can be gravity flow or use any of the ducted systems.
PkgGasFurnace	The furnace side of a packaged air-conditioning system. Packaged gas or propane furnaces have a minimum AFUE=81%. Distribution can be any of the ducted systems.
WallFurnace Gravity	Noncentral gas- or oil-fired wall furnace, gravity flow. Equipment has varying efficiency requirements by capacity. Distribution is ductless.
WallFurnace Fan	Noncentral gas- or oil-fired wall furnace, fan-forced. Equipment has varying efficiency requirements by capacity. Distribution is ductless.
FloorFurnace	Noncentral gas- or oil-fired floor furnace. Equipment has varying efficiency requirements by capacity. Distribution is ductless.
RoomHeater	Noncentral gas- or oil-fired room heaters. Noncentral gas- or oil-fired wall furnace, gravity flow. Equipment has varying efficiency requirements by capacity. Distribution is ductless.
WoodHeat	Wood-fired stove. In areas with no natural gas available, a wood-heating system with any supplemental heating system is allowed to be installed if exceptional method criteria described in the *Residential Compliance Manual* are met.
Boiler	Gas or oil boilers. Distribution systems can be radiant, baseboard, or any of the ducted systems. Boiler may be specified for dedicated hydronic systems. Systems in which the boiler provides space heating and fires an indirect gas water heater (IndGas) may be listed as Boiler/CombHydro Boiler and is listed under “Equipment Type” in the HVAC Systems listing.

Name	Heating Equipment Description
Electric	All electric heating systems other than space-conditioning heat pumps. Included are electric resistance heaters, electric boilers, and storage water heat pumps (air-water) (StoHP). Distribution system can be radiant, baseboard, or any of the ducted systems.
CombHydro	Water-heating system can be any gas water heater. Distribution systems can be radiant, baseboard, or any of the ducted systems and can be used with any of the terminal units (FanCoil, RadiantFlr, Baseboard, and FanConv).
FPFC	Four-pipe fan coil (FPFC)

Source: California Energy Commission

Table 29: Heat Pump Equipment Types

Name	Heat Pump Equipment Description
SplitHeatPump	Central split heat pump system. Distribution system is one of the ducted systems.
SDHVSplitHeatPump	Small duct, high velocity, central split-system that produces at least 1.2 inches of external static pressure when operated at the certified air volume rate of 220–350 CFM per rated ton of cooling capacity and uses high-velocity room outlets generally greater than 1,000 feet per minute that have less than 6.0 square inches of free area.
Ductless MiniSplit HeatPump	A heat pump system that has an outdoor section and one or more ductless indoor sections. The indoor section(s) cycle on and off in unison in response to an indoor thermostat.
DuctlessMultiSplitHeatPump	A heat pump system that has an outdoor section and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
DuctlessVRFHeatPump	A variable-refrigerant-flow (VRF) heat pump system that has one or more outdoor sections and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
PkgHeatPump	Central packaged heat pump systems. Central packaged heat pumps are heat pumps in which the blower, coils, and compressor are contained in a single package, powered by single-phase electric current, air-cooled, and rated below 65,000 Btu/h. The distribution system is one of the ducted systems.

Name	Heat Pump Equipment Description
LrgPkgHeatPump	Large central packaged heat pump systems, rated above 65,000 Btu/h.
RoomHeatPump	Noncentral room air-conditioning systems. These include packaged terminal (commonly called “through-the-wall”) units and any other ductless heat pump systems.
SglPkgVertHeatPump	Single-package vertical heat pump. This is a package air conditioner that uses reverse cycle refrigeration as the prime heat source and may include secondary supplemental heating by means of electrical resistance.
PkgTermHeatPump	Packaged terminal heat pump. This is a package terminal air conditioner that uses reverse cycle refrigeration as the prime heat source; has a supplementary heating source available, with the choice of electric resistant heat; and is industrial equipment.
DuctedMiniSplitHeatPump	Ducted mini-split heat pump is a system that has an outdoor section and one or more ducted indoor sections. The indoor section(s) cycle on and off in unison in response to an indoor thermostat.
DuctedMultiSplitHeatPump	Ducted multi-split heat pump is a system that has a single outdoor section, and two or more ducted indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
Ducted+DuctlessMultiSplitHeatPump	Multi-split heat pump system with a combination of ducted and ductless indoor units.
AirToWaterHeatPump	An indoor conditioning coil, a compressor, and a refrigerant-to-water heat exchanger that provides heating and cooling functions. Also, able to heat domestic hot water.
GroundSourceHeatPump	An indoor conditioning coil with air-moving means, a compressor, and a refrigerant-to-ground heat exchanger that provides heating, cooling, or heating and cooling functions. May also have the ability to heat domestic hot water.
VariableCapacityHeatPump	A variable capacity heat pump with the ability to change the speed of compressor and ancillary components to vary capacity from the nominal rate capacity.
SZDFHP	Single-zone dual fuel heat pump system with constant volume fan, direct expansion heat pump cooling and heating, and gas supplemental heating.
CHPWH	Central heat pump water heater systems including primary heating equipment, primary heating storage volume, location,

Name	Heat Pump Equipment Description
	secondary heating equipment, secondary heating storage volume, set point controls, and the way in which the components are plumbed.

Source: California Energy Commission

6.8.1.1 Heating Seasonal Performance Factor (HSPF/HSPF2)

Proposed Design

The compliance software allows the user to specify the HSPF/HSPF2 value for heat pump equipment. A conversion factor is used to convert HSPF2 to HSPF ratings for modeling. For split-system, small-duct high-velocity, and space-constrained equipment, the conversion factor is 1/0.85. For single-package equipment, the conversion factor is 1/0.84.

Standard Design

The standard design is the minimum allowable HSPF for the type of heat pump equipment modeled in the proposed design, based on the applicable *Appliance Efficiency Regulations*.

Verification and Reporting

If an HSPF/HSPF2 for the proposed design is higher than the default minimum efficiency modeled in compliance software, the HSPF/HSPF2 requires field verification. The HSPF/HSPF2 rating is verified using rating data from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance website or another directory of certified product performance ratings approved by the CEC for determining compliance. Verified HSPF/HSPF2 is reported in the ECC-required verification listings on the Certificate of Compliance.

6.8.1.2 Combined Hydronic Space/Water Heating

Combined hydronic space/water heating is a system whereby a water heater is used to provide space heating and water heating. Space-heating terminals may include fan coils, baseboards, and radiant floors.

For combined hydronic systems, the water-heating portion is modeled as a domestic hot water system as described in 6.11 Domestic Hot Water (DHW). For space heating, an effective AFUE is calculated for gas water heaters. For electric water heaters, an effective HSPF/HSPF2 is calculated. The procedures for calculating the effective AFUE or HSPF/HSPF2 are described below.

Combined hydronic space-conditioning cannot be combined with heat pump water heating or with zonal control credit.

Proposed Design

When a fan coil is used to distribute heat, the fan energy and the heat contribution of the fan motor must be considered. The algorithms for fans used in combined hydronic systems are the same as those used for gas furnaces and are described in Appendix G.

If a large fan coil is used and air-distribution ducts are in the attic, crawl space, or other unconditioned space, the efficiency of the air-distribution system must be determined using methods consistent with those described in Chapter 6.8.3 Distribution Systems. Duct efficiency is accounted for when the distribution type is ducted.

6.8.1.3 Commercial or Consumer Storage Gas Water Heater

When storage gas water heaters are used in combined hydronic applications, the effective AFUE is given by the following equation:

$$AFUE_{eff} = RE - \left[\frac{PL}{RI}\right] \qquad \textbf{Equation 7}$$

Where:

$AFUE_{eff}$ – The effective AFUE of the gas water heater in satisfying the space heating load.

RE – The recovery efficiency (or thermal efficiency) of the gas storage water heater. A default value of 0.70 may be assumed if the recovery efficiency is unknown. This value is generally available from the CEC's Modernized Appliance Efficiency Database System (MAEDbS).

PL – Pipe losses (kBtu/h). This can be assumed to be zero when there is less than 10 feet of piping between the water heater storage tank and the fan coil, or when other heating elements are in unconditioned space.

RI – The rated input of the gas water heater (kBtu/h) available from the CEC's appliance directory, MAEDbS.

6.8.1.4 Instantaneous Gas Water Heater

When instantaneous gas water heaters are used in combined hydronic applications, the effective AFUE is given by the following equation:

$$AFUE_{eff} = UEF \qquad \textbf{Equation 8}$$

Where:

$AFUE_{eff}$ – The effective AFUE of the gas water heater in satisfying the space heating load.

UEF – The rated uniform energy factor of the instantaneous gas water heater.

6.8.1.5 Storage Electric Water Heater

The HSPF of storage water heaters used for space heating in a combined hydronic system is given by the following equations.

$$HSPF_{eff} = 3.413\left[1 - \frac{PL}{3.413kWi}\right] \qquad \textbf{Equation 9}$$

Where:

$HSPF_{eff}$ – The effective HSPF of the electric water heater in satisfying the space-heating load.

PL – Pipe losses (kBtu/h). Assumed zero when less than 10 feet of piping between the water heater storage tank and the fan coil or other heating elements are in unconditioned space.

kW_i – The kilowatts of input to the water heater available from the CEC's appliance directory.

Standard Design

When a hydronic system is proposed to use electricity for heating, the heating equipment for the standard design is an electric split-system heat pump with an HSPF/HSPF2 meeting the *Appliance Efficiency Regulations* requirements for split-systems. The standard design heat pump compressor size is determined by the compliance software based on the compressor size calculated for the air-conditioning system.

When electricity is not used for heating, the equipment used in the standard design building is a gas furnace (or propane if natural gas is not available) with default ducts in the attic and an AFUE meeting the *Appliance Efficiency Regulations* minimum efficiency for central systems. When a proposed design uses electric and non-electric heat, the standard design is a gas furnace.

6.8.1.6 Special Systems — Hydronic Distribution Systems and Terminals

Hydronic distribution systems in unconditioned spaces are included in the building model to account for heat loss to these unconditioned spaces. Heat loss is affected by the length of piping in unconditioned spaces, pipe size, pipe insulation thickness, and pipe insulation R-value.

Proposed Design

This listing is completed for hydronic systems that have more than 10 feet of piping (plan view) in unconditioned space. As many rows as necessary may be used to describe the piping system.

Standard Design

The standard design is established for a hydronic system in the same way as for a central system, as described in Chapter 6.8.1 Heating Subsystems.

Verification and Reporting

A hydronic or combined hydronic system is reported on the Certificate of Compliance.

Other information reported includes:

Piping Run Length (ft). The length (plan view) of distribution pipe in unconditioned space, in feet, between the primary heating/cooling source and the point of distribution.
Nominal Pipe Size (in.). The nominal (as opposed to true) pipe diameter in inches.
Insulation Thickness (in.). The thickness of the insulation in inches. Enter "none" if the pipe is uninsulated.

Insulation R-value (hr-ft^2-° F/Btu). The installed R-value of the pipe insulation. Minimum pipe insulation for hydronic systems is as specified in Section 160.4(f).

6.8.1.7 Ground-Source Heat Pump

A ground-source heat pump system, which uses the earth as a source of energy for heating and as a sink for energy when cooling, is simulated as a minimum efficiency split-system equivalent to the standard design with default duct conditions in place of the proposed system. The mandatory efficiencies for ground-source heat pumps are a minimum coefficient of performance (COP) for heating and EER/EER2 for cooling.

6.8.1.8 Air-to-Water Heat Pumps

Air-to-water heat pumps (AWHPs) must be listed in the CEC's appliance directory, MAEDbS. For the proposed design, fixed compressor speed AWHPs would be modeled equivalent to the prescriptive air source heat pump in heating and cooling operation. Variable compressor speed AWHPs are modeled with a 2% reduction in hourly heating energy use and an 8% reduction in hourly cooling energy use, relative to the prescriptive air source heat pump.

6.8.1.9 Air Source Heat Pumps

The compliance software shall represent air source heat pump performance at different outdoor dry bulb temperatures, compressor speeds, and entering air conditions, such that the modeled performance is consistent with the rated capacities and efficiencies input by the user. For performance at outdoor dry bulb temperatures and compressor speeds where user input is not provided, the compliance software shall use statistically representative normalized relationships of capacity and efficiency based on performance data of relevant products. For variable capacity heat pumps, these relationships shall enable the calculation of performance at both minimum and maximum capacity compressor operation. Air source heat pump equipment is simulated based on the Resnet Guidelines for Simulating Unitary Air-conditioning and Air-source Heat Pump Equipment, March 28, 2025. This document can be found at https://www.resnet.us/about/standards/publications/.

If VCHP maximum heating capacity is insufficient to meet the load, it is assumed that the unmet portion of the load will be met by electric resistance heat. Defrost occurs between 35 °F and 17 °F outdoor temperature with electric resistance auxiliary heat assumed to compensate for heat lost during the defrost cycle.

6.8.2 Cooling Subsystems

The cooling subsystem describes the equipment that supplies cooling to a space-conditioning system.

Air conditioner compressor size is determined by the compliance software as 110 percent of the cooling load at the cooling design temperature. For heat pumps the compressor size is the larger of 110 percent of the heating load or 110 percent of the cooling load.

The compliance software shall represent unitary air conditioner performance at different outdoor dry bulb temperatures, compressor speeds, and entering air conditions, such that the modeled performance is consistent with the rated capacities and efficiencies input by the user. For performance at outdoor dry bulb temperatures and compressor speeds where user input is not provided, the compliance software shall use statistically representative normalized relationships of capacity and efficiency based on performance data of relevant products. Unitary air conditioning equipment is simulated based on the Resnet Guidelines for Simulating Unitary Air-conditioning and Air-source Heat Pump Equipment, March 28, 2025.

Proposed Design

Cooling subsystems are categorized according to the types shown in Table 30: HVAC Cooling Equipment Types (Air Conditioners) or Table 29: Heat Pump Equipment Types The user selects the type of cooling equipment and enters basic information to model the energy use of the equipment, such as equipment efficiency ratings. For some types of equipment, the user may also specify through checkboxes if the equipment has a multispeed compressor and if the system is zoned or not. For ducted cooling systems, the cooling airflow from the conditioned zone through the cooling coil is input as CFM per ton. The rated cooling capacity is not a compliance variable by the compliance software.

See below for more details on specific inputs.

Standard Design

The cooling system for the standard design building is a single-zone, ducted air-conditioning system or split heat pump system that meets the default minimum requirements of the applicable *Appliance Efficiency Regulations*. Fan efficacy meeting the 2025 Energy Code's mandatory is assumed in all climate zones.

For heat pumps less than 45,000 BTU the EER2 in the standard design is based on the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is below 11.7, then the EER2 in the standard design is equal to the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is 11.7 or greater, then the EER2 of the standard design is 11.7. Consequently, the maximum EER2 of heat pump equipment for cooling in the standard design is 11.7.

For heat pumps 45,000 BTU or larger, the EER2 in the standard design is based on the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is below 11.2, then the EER2 in the standard design is equal to the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is 11.2 or greater, then the EER2 of the standard design is 11.2. Consequently, the maximum EER2 of heat pump equipment for cooling in the standard design is 11.2.

Table 30: HVAC Cooling Equipment Types (Air Conditioners)

Name	Cooling Equipment Description
NoCooling	Entered when the proposed building is not cooled or when cooling is optional (to be installed at some future date). Both the standard design and the proposed design use the same default system (refer to Chapter 6.8.5 No Cooling).
SplitAirCond	Split air-conditioning systems. Distribution system is one of the ducted systems. (Efficiency metric: SEER/SEER2 and EER/EER2)
PkgAirCond	Central packaged air-conditioning systems less than 65,000 Btu/h cooling capacity. Distribution system is one of the ducted systems. (Efficiency metric: SEER/SEER2 and EER/EER2)
LrgPkgAirCond	Large packaged air-conditioning systems rated at or above 65,000 Btu/h cooling capacity. Distribution system is one of the ducted systems.
SDHVSplitAirCond	Small-duct, high-velocity, split air-conditioning system.
DuctlessMiniSplitAirCond	Ductless mini-split air-conditioning system having an outdoor section and one or more indoor sections. The indoor sections cycle on and off in unison in response to an indoor thermostat.

Name	**Cooling Equipment Description**
DuctlessMultiSplitAirCond	Ductless multi-split air-conditioning system having an outdoor section and two or more indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
DuctlessVRFAirCond	Ductless variable refrigerant flow (VRF) air-conditioning system.
SglPkgVertAirCond	Single-packaged vertical air-conditioning is a self-contained cooling system that is factory-assembled, is arranged vertically, can be mounted on the exterior or interior of a space and, can be installed through the wall. These units can be ducted or ductless.
PkgTermAirCond	Packaged terminal air-conditioning (PTAC) is a self-contained cooling system that is installed through the wall. These systems do not use ducts.
DuctedMiniSplitAirCond	Ducted mini-split air-conditioning system having an outdoor section and one or more indoor sections. The indoor sections cycle on and off in unison in response to an indoor thermostat.
DuctedMultiSplitAirCond	Ducted multi-split air-conditioning system having an outdoor section and two or more indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
Ducted+DuctlessMulti SplitAirCond	Combination of ducted and ductless multi-split air-conditioning system have an outdoor section and two or more indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats.
RoomAirCond	Room air conditioner is a self-contained cooling system that is installed through the wall. These systems do not use ducts. Same as DuctlessSplitAirCond except that cooling is not supplied to each habitable space in the dwelling unit.
EvapCondenser	Evaporatively cooled condensers. A split mechanical system, with a water-cooled condenser coil.
FPFC	Four-pipe fan coil (FPFC)

Source: California Energy Commission

VERIFICATION AND REPORTING

Information shown on the Certificate of Compliance includes cooling equipment type and cooling efficiency (SEER/SEER2 or EER/EER2 or IEER. Measures requiring verification (Table 33: Summary of Space Conditioning Measures Requiring Verification) are listed in the ECC verification section of the Certificate of Compliance.

6.8.2.1 Verified Refrigerant Charge

Proper refrigerant charge is necessary for electrically driven compressor air-conditioning and heating systems to operate at full capacity and efficiency. For cooling, software calculations set the cooling compressor efficiency multiplier to 0.90 to account for the effect of improper refrigerant charge or 0.96 for proper charge. For heating, software calculations set the heating compressor efficiency multiplier to 0.92 to account for the effect of improper refrigerant charge or 0.96 for proper charge.

Proposed Design

The compliance software allows the user to indicate if systems will have diagnostically tested refrigerant charge. This allowance applies only to ducted split-systems and packaged air-conditioners and heat pumps.

Standard Design

The standard design building is modeled with either diagnostically tested refrigerant charge or a field-verified FID if the building is in Climate Zone 2 or 8–15, and refrigerant charge verification is required by Section 170.2(c)3B and Table 170.2-K for the proposed cooling system type.

Verification and Reporting

Refrigerant charge requires field verification or diagnostic testing and is reported in the ECC required verification listings on the Certificate of Compliance. Details on refrigerant charge measurement are discussed in *Reference Appendices, Residential Appendix RA3.2*.

Table 31: Summary of Space Conditioning Measures Requiring Verification

Measure	Description	Procedures
Verified Refrigerant Charge	Air-cooled air-conditioners and air-source heat pumps must be tested diagnostically to verify that the system has the correct refrigerant charge. The system must also meet the system airflow requirement.	RA1.2, RA3.2
Verified System Airflow	When compliance requires verified system airflow greater than or equal to a specified criterion.	RA3.3
Verified Air-Handling Unit Fan Efficacy	To verify that fan efficacy (watt/CFM) is less than or equal to a specified criterion.	RA3.3
Verified HSPF/HSPF2, SEER/SEER2 or EER/EER2	Credit for increased efficiency by installation of specific air-conditioner or heat pump models.	RA3.4.4.1
Verified Heat Pump Capacity	Optional verification of heat-pump system capacity.	RA3.4.4.2

Source: California Energy Commission

6.8.2.2 Verified System Airflow

Adequate airflow to the conditioned space is required to allow ducted air-conditioning systems to operate at full efficiency and capacity. Efficiency is achieved by the air-distribution system design by improving the efficiency of motors or by designing and installing air distribution systems that have less resistance to airflow. Compliance software calculations account for the effect of airflow on sensible heat ratio and compressor efficiency.

For systems other than small-duct, high-velocity types, a value less than 350 CFM/ton (minimum 150 CFM/ton) is a valid input only if zonally controlled equipment is selected and multispeed compressor is not selected. Inputs less than 350 CFM/ton for zonally controlled systems require verification using procedures in *Reference Appendices, Residential Appendix* RA3.3.

Section 160.3(b)5L requires verification that the central air-handling unit airflow rate is greater than or equal to 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems. Values greater than the required CFM/ton may be input for compliance credit, which requires diagnostic testing using procedures in *Reference Appendices, Residential Appendix RA3.3*.

For single-zone systems:

- As an alternative to verification of 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems, ECC verification of a return duct design that conforms to the specification given in Table 160.3-A or B may be used to demonstrate compliance.
- The return duct design alternative is not an input to the compliance software but must be documented on the certificate of installation.
- If a value greater than 350 CFM/ton for systems other than small-duct, high-velocity types or greater than 250 CFM/ton for small-duct, high-velocity systems is modeled for compliance credit, the alternative return duct design method using Table 160.3-A or B is not allowed for demonstrating compliance.
- Variable capacity systems including multispeed and variable-speed compressor systems must verify airflow rate (CFM/ton) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For zonally controlled systems:

- The Table 160.3-A or B return duct design alternative is not allowed for zonally controlled systems.
- Variable capacity systems including multispeed, variable-speed, and single-speed compressor systems must all verify airflow rate (CFM/ton) by operating the system at maximum compressor capacity and maximum system fan speed in every zonal control mode with all zones calling for conditioning.
- Single-speed compressor systems must also verify airflow rate (CFM/ton) in every zonal control mode.
- For systems that input less than 350 CFM/ton, ECC verification compliance cannot use group sampling.

PROPOSED DESIGN

The default cooling airflow is 150 CFM/ton for a system with “zonally controlled” selected and “multispeed compressor” not selected (single-speed). Users may model airflow for these systems greater than or equal to 150 CFM/ton, which must be verified using the procedures in *Reference Appendices, Residential Appendix RA3.3.* Inputs less than the rates required by Section 160.3(b)5L will be penalized in the compliance calculation.

The default cooling airflow is 350 CFM/ton for systems other than small-duct, high-velocity types or 250 CFM/ton for small-duct, high-velocity systems. Users may model a higher-than-default airflow for these systems and receive credit in the compliance calculation if greater-than-default system airflow is diagnostically tested using the procedures of *Reference Appendices, Residential Appendix RA3.3*.

Standard Design

The standard design shall assume a system that complies with mandatory (Section 160.3) and prescriptive (Section 170.2) requirements for the applicable climate zone.

Verification and Reporting

The airflow rate verification compliance target (CFM or CFM/ton) is reported in the ECC required verification listings of the Certificate of Compliance. When there is no cooling system, it is reported on the Certificate of Compliance as a special feature.

6.8.2.3 Verified Air-Handling Unit Fan Efficacy

The mandatory requirement in Section 160.3(b)5L is for an air-handling unit fan efficacy equal to or less than 0.45 watts/CFM for gas furnace air-handling units, 0.58 watts/CFM for air-handling units that are not gas furnaces, and 0.62 W/CFM for small-duct, high-velocity systems as verified by a ECC rater. Users may model a lower fan efficacy (W/CFM) and receive credit in the compliance calculation if the proposed fan efficacy value is diagnostically tested using the procedures in *Reference Appendices, Residential Appendix RA3.3*.

For single-zone systems:

- Installers may elect to use an alternative to ECC verification of the watts/CFM required by Section 160.3(b)5L: ECC verification of a return duct design that conforms to the specification given in Table 160.3-A or B.
- The return duct design alternative is not an input to the compliance software but must be documented on the certificate of installation.
- If a value less than the watts/CFM required by Section 160.3(b)5L is modeled by the compliance software user for compliance credit, the alternative return duct design method using Table 160.3-A or B is not allowed for use in demonstrating compliance.
- Multispeed or variable-speed compressor systems must verify fan efficacy (watt/CFM) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For zonally controlled systems:

- The Table 160.3-A or B return duct design alternative is not allowed for zonally controlled systems.

- Variable capacity systems including multispeed, variable-speed, and single-speed compressor systems must all verify fan efficacy (watt/CFM) by operating the system at maximum compressor capacity and maximum system fan speed with all zones calling for conditioning.
- Single-speed compressor systems must verify fan efficacy in every zonal control mode.

Proposed Design

The compliance software shall allow the user to enter the fan efficacy. The default mandatory value is 0.45, 0.58, or 0.62 W/CFM, depending on the applicable system type. However, users may specify a lower value and receive credit in the compliance calculation if verified and diagnostically tested using the procedures of *Reference Appendices, Residential Appendix RA3.3*.

If no cooling system is installed, a default value of 0.45 W/CFM is assumed.

Standard Design

The standard design shall assume a verified fan efficacy complying with the mandatory requirement of equal to or less than the following:

0.45 W/CFM for gas furnace air-handling units, as well as air-handling unit that are not gas furnaces and have a capacity less than 54,000 BTU/h
0.58 W/CFM for air-handling units that are not gas furnaces and have a capacity greater than or equal to 54,000 BTU/h
0.62 W/CFM for small duct high velocity forced air systems.

Verification and Reporting

For user inputs lower than the default mandatory requirement, fan efficacy is reported in the ECC-required verification listings of the Certificate of Compliance.

For default mandatory 0.45 or 0.58 watts/cfm, the choice of either fan efficacy or alternative return duct design according to Table 160.3-A or B is reported in the ECC-required verification listings of the Certificate of Compliance.

No cooling system is reported as a special feature on the Certificate of Compliance.

6.8.2.4 Verified Energy Efficiency Ratio (EER/EER2) For Buildings Up To Three Habitable Floors

Proposed Design

Compliance software shall allow the user the option to enter an EER/EER2 rating for central cooling equipment. For equipment that is rated only with an EER/EER2, the user will enter the EER/EER2. The *Appliance Efficiency Regulations* require a minimum SEER/SEER2 and EER/EER2 for central cooling equipment. Only if a value higher than a default minimum EER/EER2 is used is it reported as a ECC-verified measure. A conversion factor is used to convert EER2 to EER ratings for modeling. For all air conditioners the conversion factor is 1/0.96.

Standard Design

The standard design is based on the default minimum efficiency EER/EER2 for the type of cooling equipment modeled in the proposed design, based on the applicable *Appliance Efficiency Regulations*. For heat pumps less than 45,000 BTU the EER2 in the standard design is based on the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is below 11.7, then the EER2 in the standard design is equal to the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is 11.7 or greater, then the EER2 of the standard design is 11.7. Consequently, the maximum EER2 of heat pump equipment for cooling in the standard design is 11.7.

For heat pumps 45,000 BTU or larger, the EER2 in the standard design is based on the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is below 11.2, then the EER2 in the standard design is equal to the EER2 of the equipment in the proposed design. When the EER2 of the equipment in the proposed design is 11.2 or greater, then the EER2 of the standard design is 11.2. Consequently, the maximum EER2 of heat pump equipment for cooling in the standard design is 11.2.Verification and Reporting

If an EER/EER2 is modeled in compliance software for credit, the EER/EER2 requires field verification. The EER/EER2 rating is verified using rating data from website or another directory of certified product performance ratings approved by the CEC for determining compliance. Verified EER is reported in the Certificate of Compliance ECC-required verification listings on the LMCC.

6.8.2.5 Verified Seasonal Energy Efficiency Ratio (SEER/SEER2) For Buildings Up To Three Habitable Floors

Proposed Design

The compliance software allows the user to specify the SEER/SEER2 value. A conversion factor is used to convert SEER2 to SEER ratings for modeling. For split-system equipment the conversion factor is 1/0.95; for single-package equipment the conversion factor is 1/0.96; for small-duct high-velocity the conversion factor is 1.00; and for space-constrained equipment the conversion factor is 1/0.99.

Standard Design

The standard design is based on the default minimum efficiency SEER/SEER2 for the type of cooling equipment modeled in the proposed design, based on the applicable *Appliance Efficiency Regulations*. For central-cooling equipment, the minimum efficiency is 14 SEER/13.8 SEER2 for split systems.

Verification and Reporting

If a SEER/SEER2 higher than the default minimum efficiency is modeled in compliance software, the SEER/SEER2 requires field verification. The higher-than-minimum SEER/SEER2 rating is verified using rating data from AHRI Directory of Certified Product Performance website or another directory of certified product performance ratings approved by the CEC for determining compliance. Verified SEER/SEER2 is reported in the ECC-required verification listings on the Certificate of Compliance.

6.8.2.6 Verified Evaporatively Cooled Condensers For Buildings Up To Three Habitable Floors

Proposed Design

Compliance software shall allow users to specify an evaporatively cooled condensing unit. The installation must comply with the requirements of Reference Appendices, Residential Appendix RA4.3.2

to ensure the predicted energy savings are achieved. This credit must be combined with verified refrigerant charge testing, EER/EER2, and duct leakage testing.

Standard Design

The standard design is based on a split-system air-conditioner meeting the requirements of Section 170.2(c) and Table 170.2-K.

Verification and Reporting

An evaporatively-cooled condensing unit, verified EER/EER2, and duct leakage testing are reported in the ECC required verification listings on the Certificate of Compliance.

6.8.2.7 Evaporative Cooling

Evaporative cooling technology is best suited for dry climates where indirect, or indirect-direct cooling of the supply air stream can occur without compromising indoor comfort.

Proposed Design

Compliance software shall allow users to specify one of three types of evaporative cooling: (1) indirect; or (2) indirect-direct. Product specifications and other modeling details for evaporative cooling are found in the CEC's appliance directory, MAEDbS. For indirect or indirect-direct, select the appropriate type from the CEC's appliance directory MAEDbS and input a 13 EER as well as the airflow and media saturation effectiveness or cooling effectiveness from the CEC's appliance directory, MAEDbS.

Standard Design

The standard design is based on a split-system air-conditioner meeting the requirements of Section 170.2(c) and Table 170.2-K.

Verification and Reporting

When indirect or indirect-direct evaporative cooling is modeled, the EER/EER2 verification is shown in the ECC verification section of the Certificate of Compliance along with the system type, airflow, and system effectiveness.

6.8.3 Distribution Subsystems

If multiple HVAC distribution systems serve a building, each system, and the conditioned space it serves may be modeled in detail separately or the systems may be aggregated and modeled as one large system. If the systems are aggregated, they must be the same type, and all meet the same minimum specifications.

For duct efficiency calculations, the supply duct begins at the exit from the furnace or air-handler cabinet.

6.8.3.1 Distribution Type

Fan-powered, ducted distribution systems can be used with most heating or cooling systems. When ducted systems are used with furnaces, boilers, or combined hydronic/water heating systems, the electricity used by the fan is calculated. R-value and duct location are specified when a ducted system is specified.

Proposed Design

The compliance software shall allow the user to select from the basic types of HVAC distribution systems and locations listed in Table 32: HVAC Distribution Type and Location Descriptors. For ducted systems, the default location of the HVAC ducts and the air handler are in conditioned space for multifamily buildings and in the attic for all other buildings.

Table 32: HVAC Distribution Type and Location Descriptors

Name	HVAC Distribution Type and Location Description
Ducts located in attic (ventilated and unventilated)	Ducts located overhead in the attic space.
Ducts located in a crawl space	Ducts located under floor in the crawl space.
Ducts located in a garage	Ducts located in an unconditioned garage space.
Ducts located within the conditioned space (except < 12 linear ft)	Ducts located within the conditioned floor space except for less than 12 linear feet of duct, furnace cabinet, and plenums — typically an HVAC unit in the garage mounted on return box with all other ducts in conditioned space.
Ducts located entirely in conditioned space	HVAC unit or systems with all HVAC ducts (supply and return) within the conditioned floor space. Location of ducts in conditioned space eliminates conduction losses but does not change losses due to leakage. Leakage either from ducts that are not tested for leakage or from sealed ducts is modeled as leakage to outside the conditioned space.
Distribution system without ducts (none)	Air-distribution systems without ducts such as ductless split-system air-conditioners and heat pumps, window air-conditioners, through-the-wall heat pumps, wall furnaces, floor furnaces, radiant electric panels, combined hydronic heating equipment, electric baseboards, or hydronic baseboard finned-tube natural convection systems, etc.
Ducts located in outdoor locations	Ducts in exposed locations outdoors.
Verified low-leakage ducts located entirely in conditioned space	Duct systems for which air leakage to outside is equal to or less than 25 CFM when measured in accordance with Reference Residential Appendix RA3.1.4.3.8.
Ducts located in multiple places	Ducts with different supply and return duct locations.

Source: California Energy Commission

Table 33: Summary of Verified Distribution Systems

Measure	Description	Procedures
Multifamily Buildings Verified Duct Sealing	Mandatory measures require that space-conditioning ducts be sealed. Field verification and diagnostic testing are required to verify that approved duct system materials are used and that duct leakage meets the specified criteria.	RA3.1.4.3
Multifamily Buildings Verified Duct Location, Reduced Surface Area and R-value	Compliance credit can be taken for improved supply duct location, reduced surface area, and R-value. Field verification is required to verify that the duct system was installed according to the duct design, including location, size and length of ducts, duct insulation R-value, and installation of buried ducts.[1] For buried duct measures, verified QII is required, as well as duct sealing.	RA3.1.4.1, 3.1.4.1.1
Multifamily Buildings Low-Leakage Ducts in Conditioned Space	When the Energy Code specify use of the procedures in Reference Appendices, Residential Appendix RA3.1.4.3.8 to determine if the space-conditioning system ducts are entirely in directly conditioned space, the duct system location is verified by diagnostic testing. Compliance credit can be taken for verified duct systems with low air leakage to the outside when measured in accordance with Reference Appendices, Residential Appendix RA3.1.4.3.8. Field verification for ducts in conditioned space is required. Duct sealing is required.	RA3.1.4.3.8
Multifamily Buildings Hydronic Delivery in Conditioned Space	Compliance credit can be taken for hydronic delivery systems with no ducting or piping in unconditioned space. For radiant ceiling panels, the verifications in Reference Appendices, Residential Appendix RA3.4.5 must be completed to qualify.	RA3.4.5
Multifamily Buildings Low-Leakage Air-Handling Units	Compliance credit can be taken for installing a factory-sealed air-handling unit tested by the manufacturer and certified to the CEC to have met the requirements for a low-leakage air-handling unit. Field verification of the air handler model number is required. Duct sealing is required.	RA3.1.4.3.9

Measure	Description	Procedures
Multifamily Buildings Verified Return Duct Design	Verification to confirm that the return duct design conforms to the criteria given in Table 160.3-A or Table 160.3-B. as an alternative to meeting 0.45 or 0.58 W/CFM fan efficacy of Section 160.3(b)5L.	RA3.1.4.4
Multifamily Buildings Verified Bypass Duct Condition	Verification to determine if system is zonally controlled and confirm that bypass ducts condition modeled matches installation.	RA3.1.4.6

1. Compliance credit for increased duct insulation R-value (not buried ducts) may be taken without field verification if the R-value is the same throughout the building, and for supply ducts located in crawl spaces and garages where all supply registers are either in the floor or within 2 feet of the floor. If these conditions are met, ECC rater verification is not required.

Source: California Energy Commission

The compliance software will allow users to select default assumptions or specify any of the verified or diagnostically tested HVAC distribution system conditions in the proposed design (Table 33: Summary of Verified Distribution Systems), including duct leakage target, R-value, supply and return duct area, diameter, and location.

Standard Design

The standard heating and cooling system for central systems is modeled with air distribution ducts located as described in Table 34: Summary of Standard Design Duct Location for Buildings Up to Three Habitable , with duct leakage as specified in Table 42: Duct/Air Handler Leakage. The standard design duct insulation is determined by Table 170.2-K as R-6 in Climate Zones 3 and 5–7, and R-8 in Climate Zones 1, 2, 4, and 8–16. The standard design building is assumed to have the same number of floors as the proposed design for determining the duct efficiency.

Table 34: Summary of Standard Design Duct Location for Buildings Up to Three Habitable Floors

Configuration of the Proposed Design	Standard Design Duct Location	Detailed Specifications
Attic over the dwelling unit	Ducts and air handler located in the attic	Ducts sealed (mandatory requirement) No credit for verified R-value, location, or duct design
No attic but crawl space or basement	Ducts and air handler located in the crawl space or basement	Ducts sealed (mandatory requirement) No credit for verified R-value, location, or duct design
Multifamily buildings with no attic, crawl space or basement	Ducts and air handler located indoors	Ducts sealed (mandatory requirement) No credit for verified R-value, location, or duct design

This table is applicable only when the standard design system has air-distribution ducts

Source: California Energy Commission

Verification and Reporting

Distribution type, location, R-value, and the determination of whether tested and sealed will be shown on the Certificate of Compliance. If there are no ducts, the absence of ducts is shown as a special feature on the Certificate of Compliance. Any duct location other than attic (for example, crawl space) is shown as a special feature on the Certificate of Compliance. Ducts in crawl space or the basement shall include a special feature note if supply registers are within 2 feet of the floor. Measures that require ECC verification will be shown in the ECC required verification section of the Certificate of Compliance.

6.8.3.2 Duct Location For Buildings Up to Three Habitable Floors

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses.

Proposed Design

If any part of the supply or return duct system is in an unconditioned attic, that entire duct system is modeled with an attic location. If no part of the supply or return duct system is located in the attic, but the duct system is not entirely in conditioned space, it is modeled in the unconditioned zone, which contains the largest fraction of the surface area. If the supply or return duct system is entirely in conditioned space, the duct system is modeled in conditioned space.

For ducted HVAC systems with some or all ducts in unconditioned space, the user specifies the R-value and surface area of supply and return ducts and the duct location.

Duct location and areas other than the defaults shown in Table 34: Summary of Standard Design Duct Location for Buildings Up to Three Habitable may be used following the verification procedures in *Reference Appendices, Residential Appendix RA3.1.4.1*.

Standard Design

The standard design duct location is determined from the building conditions.

Verification and Reporting

Duct location is reported on the Certificate of Compliance. Ducts entirely in conditioned space and verified low-leakage ducts entirely in conditioned space are reported in the ECC-required verification listing on the Certificate of Compliance.

Default duct locations are shown in Table 35: Location of Default Duct Surface Area. The duct surface area for crawl space and basement applies only to buildings or zones with all ducts installed in the crawl space or basement. If the duct is installed in locations other than crawl space or basement, the default duct location is “Other.” For dwelling units with two or more floors, 35 percent of the default duct area may be assumed to be in conditioned space, as shown in Table 35: Location of Default Duct Surface Area.

The surface area of ducts in conditioned space is ignored in calculating conduction losses.

Table 35: Location of Default Duct Surface Area

Supply Duct Location	One floor	Two or more floors
All in crawl space	100% crawl space	65% crawl space, 35% conditioned space
All in basement	100% basement	65% basement, 35% conditioned space
Other	100% attic	65% attic, 35% conditioned space

Source: California Energy Commission

6.8.3.3 Duct Surface Area

The supply-side and return-side duct surface areas are treated separately in distribution efficiency calculations. The duct surface area is determined using the following methods.

6.8.3.4 Default Return Duct Surface Area

Default return duct surface area is calculated using:

$$A_{r,out} = K_r \times A_{floor}$$

Equation 10

Where K_r (return duct surface area coefficient) is 0.05 for one-floor dwelling units and 0.1 for dwelling units with two or more floors and A_{floor} is the floor area. $A_{r,out}$ is the surface area of the return duct.

6.8.3.5 Default Supply Duct Surface Area

STANDARD DESIGN

The standard design and default proposed design supply duct surface area is calculated using Equation 5.

$$A_{s,\,out} = 0.27 \times A_{floor} \times K_S$$ **Equation 11**

Where K_s (supply duct surface area coefficient) is 1 for one-floor buildings and 0.65 for two or more floors and A_{floor} is the floor area. $A_{s,out}$ is the surface area of the return duct.

6.8.3.6 Supply Duct Surface Area for Less Than 12 feet of Duct in Unconditioned Space

PROPOSED DESIGN

For proposed design HVAC systems with air handlers outside the conditioned space but with less than 12 linear feet of duct outside the conditioned space, including air handler and plenum, the supply duct surface area outside the conditioned space is calculated using Equation 6. The return duct area remains the default for this case.

$$A_{s,out} = 0.027 \times A_{floor}$$ **Equation 12**

6.8.3.7 Diagnostic Duct Surface Area for Buildings Up to Three Habitable Floors

Proposed designs may claim credit for reduced surface area using the procedures in *Reference Appendices, Residential Appendix RA3.1.4.1*.

The surface area of each duct system segment shall be calculated based on the associated inside dimensions and length. The total supply surface area in each unconditioned location (attic, attic with radiant barrier, crawl space, basement, other) is the sum of the area of all duct segments in that location. The surface area of ducts completely inside conditioned space need not be input in the compliance software and is not included in the calculation of duct system efficiency. The area of ducts in floor cavities or vertical chases that are surrounded by conditioned space and separated from unconditioned space with draft stops are also not included. The compliance software assumes the user input duct system area is 85 percent of the total duct system area. The other 15 percent is assumed to be air handler, plenum, and connectors. Because of this, the total duct system area used in the building simulation is:

Simulated Duct System Area = 1.1765 multiplied by the total user entered duct system area

6.8.3.8 Bypass Duct

Section 170.2(c)3C prohibits use of bypass ducts unless a bypass duct is otherwise specified on the certificate of compliance. A bypass duct may be needed for some single-speed outdoor condensing unit systems. The compliance software allows users to specify a bypass duct for the system. Selection of a bypass duct does not trigger changes in the ACM modeling defaults, but verification by a ECC rater is required to use the procedure in Reference Appendices, Residential Appendix RA3.1.4.6.

Specification of a zonally controlled system with a single-speed condensing unit will trigger a default airflow rate value of 150 CFM/ton for the calculations. User input less than 350 CFM/ton reduces the compliance margin as compared to systems that model 350 CFM/ton as described in Chapter 6.8.2.2 Verified System Airflow.

Proposed Design

Compliance software shall allow users to specify whether a bypass duct is used for a zonally controlled forced air system.

Standard Design

The standard design is based on a split-system air-conditioner meeting the requirements of Section 170.2 and Table 170.2-K. The system is not a zonally controlled system.

Verification and Reporting

An HVAC system with zonal control, and the determination of whether the system is assumed to have a bypass duct or have no bypass duct, is reported in the ECC-required verification listings on the Certificate of Compliance.

6.8.3.9 Duct System Insulation

For conduction calculations in the standard and proposed designs, 85 percent of the supply and return duct surface is assumed duct material at the related specified R-value, and 15 percent is assumed air handler, plenum, connectors, and other components at the mandatory minimum R-value.

The area weighted effective R-value is calculated by the compliance software using Equation 7, including each segment of the duct system that has a different R-value.

$$R_{eff} = \frac{(A_1 + A_2 .... + A_N)}{\left[\frac{A_1}{R_1} + \frac{A_2}{R_2} .... + \frac{A_N}{R_N}\right]} \qquad \textbf{Equation 13}$$

Where:

R_{eff} - Area weighted effective R-value of duct system for use in calculating duct efficiency, (h-ft²-°F/Btu)
A_N - Area of duct segment n, square feet
R_N - R-value of duct segment n including film resistance (duct insulation rated R + 0.7) (h-ft²-°F/Btu)

Proposed Design

The compliance software user inputs the R-value of the proposed duct insulation and details. The default duct thermal resistance is based on Table 170.2-K, which is R-6 in Climate Zones 3 and 5–7, R-8 in Zones 1, 2, 4, and 8–16.

Duct location and duct R-value are reported on the Certificate of Compliance. Credit for systems with mixed insulation levels, nonstandard supply and return duct surface areas, or ducts buried in the attic require the compliance and diagnostic procedures in *Reference Appendices, Residential Appendix RA3.1.4.1*.

If verified duct design is selected, the user must enter the duct design into the compliance software. For each duct segment entered, the user must specify Type (supply/return), Buried (yes/no, as specified by Chapter 6.8.3.10 Buried Attic Ducts), Diameter (inside/nominal), Length, and Duct Insulation R-value. User-entered duct design must be verified by a ECC rater according to the procedures in *Reference Appendices, Residential Appendix RA3.1.4.1.1*. User-entered duct design and duct location are reported on the Certificate of Compliance when nonstandard values are specified.

Standard Design

The required duct insulation R-value is from Table 170.2-K for the applicable climate zone used in the standard design.

Verification and Reporting

Duct type (supply/return), nominal diameter, length, R-value, and location, and supply and return areas are reported on the Certificate of Compliance. Verified duct design is reported in the ECC-required verification listing on the Certificate of Compliance.

6.8.3.10 Buried Attic Ducts

Ducts partly, fully, or deeply buried in blown attic insulation in dwelling units meeting the requirements for verified QII may take credit for increased effective duct insulation. To qualify for buried duct credit, ducts must meet mandatory insulation levels (R-6) prior to burial, be directly or within 3.5 inches of ceiling gypsum board and be surrounded by at least R-30 attic insulation. Moreover, credit is available only for duct runs where the ceiling is level, there is at least 6 inches of space between the duct outer jacket and the roof sheathing, and the attic insulation has uniform depth. Existing ducts are not required to meet the mandatory minimum insulation levels, but to qualify for buried duct credit, they must have greater than R-4.2 insulation before burial.

In addition to the above requirements, deeply buried ducts must be buried by at least 3.5 inches of insulation above the top of the duct insulation jacket and located within a lowered area of the ceiling, a deeply buried containment system, or buried by at least 3.5 inches of uniformly level insulation. Mounding insulation to achieve the 3.5-inch burial level is not allowed.

Deeply buried duct containment systems must be installed such that the walls of the system are at least 7 inches wider than the duct diameter (3.5 inches on each side of duct), the walls extend at least 3.5 inches above the duct outer jacket, and the containment area surrounding the duct must be completely filled with blown insulation.

The duct design shall identify the segments of the duct that meet the requirements for being buried, and these are input into the compliance software separately from non-buried ducts. For each buried duct, the user must enter the duct size, R-value, and length, and determination of whether the duct qualifies as deeply buried. The user must also indicate if a duct uses a deeply buried containment system. The compliance software calculates the weighted average effective duct system R-value based on the user-entered duct information, blown insulation type (cellulose or fiberglass), and R-value.

Duct-effective R-values are broken into three categories: partially, fully, and deeply, with each having different burial levels and requirements. Partially buried ducts have less than 3.5 inches of exposed duct depth, fully buried ducts have insulation depth at least level with the duct jacket, and deeply buried ducts have at least 3.5 inches of insulation above the duct jacket in addition to the above requirements.

Effective duct R-value used by the compliance software are listed in Table 36: Buried Duct Effective R-Values through Table 41: Buried Duct Effective R-Values.

Proposed Design

The compliance software calculates the effective R-value of buried ducts based on user-entered duct size, R-value, and length; attic insulation level and type; and determination of whether the duct meets the requirements of a deeply buried duct by using a lowered ceiling chase or a containment system. This feature must be combined with verified QII, verified duct location, reduced surface area and R-value, and verified minimum airflow. The compliance software will allow any combination of duct runs and the associated buried condition, and the overall duct system effective R-value will be a weighted average of the combination. The default is no buried ducts.

Standard Design

The standard design has no buried ducts.

Verification and Reporting

Buried duct credit is reported in the ECC required verification listing on the Certificate of Compliance.

Table 36: Buried Duct Effective R-Values

R-8 Ducts With Blown Fiberglass Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-18	R-26	R-26	R-26	R-26	R-26
4"	R-13	R-18	R-26	R-26	R-26	R-26
5"	R-13	R-18	R-18	R-26	R-26	R-26
6"	R-13	R-18	R-18	R-18	R-26	R-26
7"	R-13	R-13	R-18	R-18	R-26	R-26
8"	R-8	R-13	R-13	R-18	R-18	R-26
9"	R-8	R-13	R-13	R-13	R-18	R-26
10"	R-8	R-13	R-13	R-13	R-18	R-26
12"	R-8	R-8	R-8	R-13	R-13	R-26
14"	R-8	R-8	R-8	R-8	R-13	R-18
16"	R-8	R-8	R-8	R-8	R-8	R-13
18"	R-8	R-8	R-8	R-8	R-8	R-13
20"	R-8	R-8	R-8	R-8	R-8	R-8
22"	R-8	R-8	R-8	R-8	R-8	R-8
24"	R-8	R-8	R-8	R-8	R-8	R-8

Source: California Energy Commission

Table 37: Buried Duct Effective R-Values

R-8 Ducts with Blown Cellulose Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-14	R-20	R-20	R-20	R-32	R-32
4"	R-14	R-14	R-20	R-20	R-20	R-32
5"	R-8	R-14	R-14	R-20	R-20	R-32
6"	R-8	R-14	R-14	R-14	R-20	R-32
7"	R-8	R-14	R-14	R-14	R-20	R-20
8"	R-8	R-8	R-8	R-14	R-14	R-20
9"	R-8	R-8	R-8	R-8	R-14	R-20
10"	R-8	R-8	R-8	R-8	R-14	R-20
12"	R-8	R-8	R-8	R-8	R-8	R-14
14"	R-8	R-8	R-8	R-8	R-8	R-8
16"	R-8	R-8	R-8	R-8	R-8	R-8
18"	R-8	R-8	R-8	R-8	R-8	R-8
20"	R-8	R-8	R-8	R-8	R-8	R-8
22"	R-8	R-8	R-8	R-8	R-8	R-8
24"	R-8	R-8	R-8	R-8	R-8	R-8

Source: California Energy Commission

Table 38: Buried Duct Effective R-Values

R-6 Ducts with Blown Fiberglass Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-15	R-24	R-24	R-24	R-24	R-24
4"	R-15	R-24	R-24	R-24	R-24	R-24
5"	R-11	R-15	R-24	R-24	R-24	R-24
6"	R-11	R-15	R-15	R-24	R-24	R-24
7"	R-11	R-15	R-15	R-15	R-24	R-24
8"	R-11	R-15	R-15	R-15	R-24	R-24
9"	R-6	R-11	R-11	R-15	R-24	R-24
10"	R-6	R-11	R-11	R-15	R-15	R-24
12"	R-6	R-6	R-11	R-11	R-15	R-24

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
14"	R-6	R-6	R-6	R-6	R-11	R-15
16"	R-6	R-6	R-6	R-6	R-11	R-15
18"	R-6	R-6	R-6	R-6	R-6	R-11
20"	R-6	R-6	R-6	R-6	R-6	R-11
22"	R-6	R-6	R-6	R-6	R-6	R-6
24"	R-6	R-6	R-6	R-6	R-6	R-6

Source: California Energy Commission

Table 39: Buried Duct Effective R-Values

R-6 Ducts with Blown Cellulose Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-12	R-18	R-18	R-18	R-31	R-31
4"	R-12	R-18	R-18	R-18	R-31	R-31
5"	R-12	R-12	R-18	R-18	R-18	R-31
6"	R-6	R-12	R-12	R-18	R-18	R-31
7"	R-6	R-12	R-12	R-12	R-18	R-31
8"	R-6	R-12	R-12	R-12	R-18	R-31
9"	R-6	R-6	R-6	R-12	R-12	R-18
10"	R-6	R-6	R-6	R-6	R-12	R-18
12"	R-6	R-6	R-6	R-6	R-6	R-12
14"	R-6	R-6	R-6	R-6	R-6	R-12
16"	R-6	R-6	R-6	R-6	R-6	R-6
18"	R-6	R-6	R-6	R-6	R-6	R-6
20"	R-6	R-6	R-6	R-6	R-6	R-6
22"	R-6	R-6	R-6	R-6	R-6	R-6
24"	R-6	R-6	R-6	R-6	R-6	R-6

Source: California Energy Commission

Table 40: Buried Duct Effective R-Values

R-4.2 Ducts With Blown Fiberglass Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-13	R-22	R-22	R-22	R-22	R-22
4"	R-13	R-22	R-22	R-22	R-22	R-22
5"	R-13	R-22	R-22	R-22	R-22	R-22
6"	R-13	R-13	R-22	R-22	R-22	R-22
7"	R-9	R-13	R-13	R-22	R-22	R-22
8"	R-9	R-13	R-13	R-13	R-22	R-22
9"	R-9	R-13	R-13	R-13	R-22	R-22
10"	R-4.2	R-9	R-13	R-13	R-13	R-22
12"	R-4.2	R-9	R-9	R-9	R-9	R-22
14"	R-4.2	R-4.2	R-4.2	R-9	R-9	R-22
16"	R-4.2	R-4.2	R-4.2	R-4.2	R-9	R-13
18"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-9
20"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-9
22"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
24"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2

Source: California Energy Commission

Table 41: Buried Duct Effective R-Values

R-4.2 Ducts with Blown Cellulose Attic Insulation

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
3"	R-15	R-15	R-29	R-29	R-29	R-29
4"	R-9	R-15	R-15	R-15	R-29	R-29
5"	R-9	R-15	R-15	R-15	R-29	R-29
6"	R-9	R-9	R-15	R-15	R-15	R-29
7"	R-4.2	R-9	R-9	R-15	R-15	R-29
8"	R-4.2	R-9	R-9	R-9	R-15	R-29
9"	R-4.2	R-9	R-9	R-9	R-15	R-15
10"	R-4.2	R-4.2	R-9	R-9	R-9	R-15
12"	R-4.2	R-4.2	R-4.2	R-4.2	R-9	R-15
14"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-9
16"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-9
18"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2

Duct Diameter	R-30 Ceiling	R-38 Ceiling	R-40 Ceiling	R-43 Ceiling	R-49 Ceiling	R-60 Ceiling
20"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
22"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2
24"	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2	R-4.2

Source: California Energy Commission

6.8.3.11 Duct/Air Handler Leakage

The total duct/air handler leakage shown in Table 43: Individual IAQ System Standard Design Fan Efficacy is used in simulating the duct system. The supply duct leakage for each case is the table value multiplied by 0.585. The return leakage is the table value multiplied by 0.415.

Proposed Design

For each ducted system, the compliance software user specifies one of the duct/air handler leakage cases shown in Table 42: Duct/Air Handler Leakage.

Standard Design

For ducted systems, the standard design is sealed and tested duct systems in existing dwelling units or new duct systems.

Verification and Reporting

Sealed and tested duct systems are listed in the ECC verification section of the Certificate of Compliance. Duct leakage is measured in accordance with procedures and values specified in Reference Appendices, Residential Appendix RA3.

6.8.3.12 Low Leakage Air Handlers

A low-leakage air handler may be specified as well as a lower duct leakage value. (See 6.8.3.11 Duct/Air Handler Leakage.) Installation requires installing one of the list of approved low-leakage air handling units published by the CEC. The manufacturer certifies that the appliance complies with the requirements of Reference Appendices, Joint Appendices JA9.2.1, 9.2.2, 9.2.3, and 9.2.4.

Table 42: Duct/Air Handler Leakage

Case	Duct Leakage	Air Handler Leakage	Total Duct/Air Handler Leakage
Sealed and tested new or altered duct systems in conditioned or unconditioned space in a multifamily dwelling unit	12%	Included in duct leakage	12%
Verified low-leakage ducts in conditioned space	0%	0%	0%

Case	Duct Leakage	Air Handler Leakage	Total Duct/Air Handler Leakage
Low leakage air handlers in combination with sealed and tested new duct systems	5% or as measured	0%	5% or as measured

Source: California Energy Commission

Proposed Design

Credit can be taken for installing a factory-sealed air-handling unit tested by the manufacturer and certified to the CEC to meet the requirements for a low-leakage air-handler. Field verification of the air handler model number is required.

Standard Design

The standard design has a normal air handler.

Verification and Reporting

A low-leakage air handler is reported on the compliance report and field verified in accordance with the procedures specified in Reference Appendices, Residential Appendix RA3.1.4.3.9.

6.8.3.13 Verified Low-Leakage Ducts in Conditioned Space

Proposed Design

For ducted systems, the user may specify that all ducts are entirely in conditioned space, and the compliance software will model the duct system with no leakage and no conduction losses.

Standard Design

The standard design has ducts in the default location.

Verification and Reporting

Systems that have all ducts entirely in conditioned space are reported on the compliance documents and verified by measurements showing duct leakage to outside conditions is equal to or less than 25 CFM when measured in accordance with *Reference Appendices, Residential Appendix RA3*.

6.8.4 Space-Conditioning Fan Subsystems

Fan systems move air for air-conditioning, heating, and ventilation systems. The compliance software allows the user to define the fans to be used for space-conditioning, IAQ, and ventilation cooling. IAQ and ventilation cooling are discussed in Chapter 6.8.6 Ventilation and Heat Recovery.

Proposed Design

For the space-conditioning fan system, the user selects the type of equipment and enters basic information to model the energy use of the equipment. For ducted central air-conditioning and heating systems, the fan efficacy default is the mandatory minimum verified efficacy of 0.45, 0.58, or 0.62 W/CFM, depending on applicable system type (also assumed when there is no cooling system).

Standard Design

The standard design shall assume a verified fan efficacy complying with the mandatory requirement of equal to or less than 0.45, 0.58, or 0.62 watts/CFM, depending on the applicable system type.

Verification and Reporting

Minimum verified fan efficacy is mandatory for all ducted cooling systems. Fan efficacy is reported in the ECC required verification listings on the Certificate of compliance.

6.8.5 Space-Conditioning Systems

This chapter describes the general procedures for heating and cooling systems in multifamily buildings. The system includes the cooling system, the heating system, distribution system, and mechanical fans.

If multiple systems serve a building, each system, and the conditioned space it serves may be modeled in detail separately or the systems may be aggregated and modeled as one large system. If the systems are aggregated, they must be the same type and all meet the same minimum specifications.

6.8.5.1 Multiple System Types Within Building

Proposed Design

For proposed designs using more than one heating system type, equipment type, or fuel type, and the types do not serve the same floor area, the user shall zone the building by system type.

Standard Design

The standard design shall have the same zoning and heating system types as the proposed design.

Verification and Reporting

The heating system type of each zone is shown on the Certificate of Compliance.

6.8.5.2 Multiple Systems Serving Same Area

If a space or a zone is served by more than one heating system, compliance is demonstrated with the most LSC energy-consuming system serving the space or the zone. For spaces or zones that are served by electric resistance heat in addition to other heating systems, the electric resistance heat is deemed the most LSC energy-consuming system unless the supplemental heating meets the exception to Section 170.2(c)3A. See eligibility criteria in *Nonresidential Compliance Manual* Section 11.5.3.2 for conditions under which the supplemental heat may be ignored.

For floor areas served by more than one cooling system, equipment, or fuel type, the system, equipment, and fuel type that satisfy the cooling load are modeled.

6.8.5.3 No Cooling

Proposed Design

When the proposed design has no cooling system, the proposed design is required to model the standard design cooling system defined in Section 170.2 and Table 170.2-K. Since the proposed design system is identical to the standard design system, there is no penalty or credit.

Standard Design

The standard design system is the specified in Section 170.2 and Table 170.2-K for the applicable climate zone.

Verification and Reporting

No cooling is reported as a special feature on the Certificate of Compliance.

6.8.5.4 Zonally Controlled Forced-Air Cooling Systems

Zonally controlled central forced-air cooling systems must be able to deliver, in every zonal control mode, an airflow to the dwelling of > 350 CFM per ton of nominal cooling capacity and operating at an air-handling unit fan efficacy of < 0.45 or 0.58 W/CFM depending on the applicable system type. This is a ECC-verified measure, complying with Reference Appendices, *Residential Appendix RA3.3*.

An exception allows multispeed or variable-speed compressor systems, or single-speed compressor systems to meet the mandatory airflow (CFM/ton) and fan efficacy (watt/CFM) requirements by operating the system at maximum compressor capacity, and system fan speed with all zones calling for conditioning, rather than in every zonal control mode.

Proposed Design

The user selects zonally controlled as a cooling system input.

Standard Design

The standard design building does not have a zonally controlled cooling system.

Verification and Reporting

Zonally controlled forced-air cooling systems are required to have the system bypass duct status verified by a ECC rater according to the procedures in *Reference Appendices, Residential Appendix RA3.1.4.6*, and the fan efficacy and airflow rate are required to be verified according to the procedures in *RA3.3*.

6.8.6 Indoor Air Quality (IAQ) Ventilation

For newly constructed buildings and additions greater than 1,000 ft^2 with dwelling units, the Energy Code requires that all dwelling units meet the IAQ ventilation requirements of ASHRAE Standard 62.2 with California amendments specified in Section 160.2(b)2 and 160.2(c)3. Ventilation for spaces that are not dwelling units within the building should follow the nonresidential ventilation described in Section 120.1 as calculated according to Section 5.6.8 in the ACM Reference Manual. IAQ ventilation is not required for newly constructed buildings that are not dwelling units. Providing acceptable IAQ through mechanical ventilation is one of the requirements of ASHRAE Standard 62.2.

Verification and Reporting

The required ventilation rate to comply with the Energy Code and the means to achieve compliance are indicated on the Certificate of Compliance. The IAQ system characteristics are reported in the ECC required verification listing on the Certificate of Compliance. The diagnostic testing procedures are in Reference Appendices, Residential Appendix RA3.7.

Special features are reported on the Certificate of Compliance when the proposed system has heat or energy recovery or when the proposed fan efficacy is less than the applicable value in Table 43.

6.8.6.1 Design Ventilation Rate

The quantity of ventilation air must be identified for each residential dwelling unit thermal zone.

Proposed Design

The design ventilation rate may be between 95 percent and 110 percent of code-minimum required ventilation rates for multifamily common area in a residential zone group without penalty.

Total common area ventilation rates below 95 percent of the code-minimum required ventilation rate for a residential zone group are not allowed.

The design ventilation rate may be between 100 percent and 125 percent of the code-minimum required ventilation rate for multifamily dwelling units without penalty.

Ventilation rates below the code-minimum required ventilation rate for a multifamily dwelling unit are not allowed.

Standard Design

For common spaces ventilation is provided by a SZHP where the ventilation rate is determined in the same way as for the nonresidential area, see Section 5.6.8.

For multifamily building dwelling units, the standard design ventilation rate is the greater of the code minimum ventilation rate and the proposed design minimum ventilation rate, but subject to a limit of 125% of the code-minimum required ventilation rate.

6.8.6.2 IAQ System Type

Proposed Design

For dwelling units in multifamily buildings, the user identifies the type of IAQ system in the proposed design (supply only or balanced) and whether the supply and/or exhaust are central or individual. System type must be consistent for all dwelling units in a building.

Standard Design

For dwelling units, the standard design mechanical ventilation system type is the same as the proposed design except in Climate Zones 1, 2, 4, 11 through 14, and 16, where the software defaults to balanced with HRV to reflect the prescriptive requirements. System type is determined by whether the supply/exhaust is central (system serving multiple zones) vs. individual (system serving one zone) and the configuration of the system; balanced (supply and exhaust with equal airflow), supply only. The standard design system type, either individual or central, is the same as the proposed design for each type of supply and exhaust stream. For example, if the proposed design has central supply and individual exhaust the standard design will have central supply and individual exhaust.

For multifamily common spaces, ventilation is provided by the standard heating and cooling system described in Table 26: Residential Standard Design HVAC System.

6.8.6.3 Ventilation Source

The dwelling unit and common area thermal zone ventilation source may be forced, through fans. For common areas with no space conditioning system, the ventilation source may be natural through operable openings.

PROPOSED DESIGN

The source of ventilation for a thermal zone is based on the proposed design and is natural, forced, or none.

STANDARD DESIGN

For residential units the standard design ventilation system is forced air.

6.8.6.4 IAQ System Fan Efficacy

PROPOSED DESIGN

All individual systems serving multifamily dwelling units must meet IAQ system fan efficacies based on the following conditions:

Systems with supply ducts (balanced and supply-only) are simulated with increased fan wattage to account for maintenance and installation factors affecting system efficacy. For these systems, fan wattage is increased by a factor of 1.10 (10 percent increase in wattage). For IAQ systems with fault indicator displays (FID) meeting the specifications in Reference Appendices, Joint Appendix JA17, these factors don't apply.

Systems with heat or energy recovery serving a single dwelling unit shall have a fan efficacy of ≤1.0 W/cfm in accordance with Section 160.2(b)2.A.iv.b.1.

STANDARD DESIGN

Table 43: Individual IAQ System Standard Design Fan Efficacy

Climate Zone	Supply Only	Balanced without Heat Recover	Balanced with Heat Recovery
1, 2, 4 and 11 through 14, and_16	0.35 W/cfm	N/A	0.6 W/cfm
5 through 10, and 15 (4+ floors)	0.35 W/cfm	0.7 W/cfm	N/A
5 through 10, and 15 (<4 floors)	0.35 W/cfm	0.4 W/cfm	N/A
3	0.35 W/cfm	0.7 W/cfm	N/A

Source: California Energy Commission

Individual IAQ standard design fan efficacy equals the value in Table 43 based on the proposed system design and climate zone.

Table 44: Central IAQ System Standard Design Fan Efficacy Limits

Type	≤5,000 cfm	>5,000 and ≤10,000 cfm	>10,000 cfm
Supply-Only	0.441 W/cfm	0.476 W/cfm	0.450 W/cfm
Central Supply + Individual Exhaust	0.791 W/cfm	0.826 W/cfm	0.800 W/cfm
Individual Supply + Central Exhaust	0.652 W/cfm	0.636 W/cfm	0.631 W/cfm
Central Supply + Central Exhaust	0.743 W/cfm	0.762 W/cfm	0.731 W/cfm
Central Supply + Central Exhaust + Heat Recovery	1.098 W/cfm	1.069 W/cfm	1.005 W/cfm

Source: California Energy Commission

Central IAQ standard design fan efficacy equals proposed or the limit from Table 44 whichever is lower.
Table 43: Individual IAQ System Standard Design Fan Efficacy

6.8.6.5 Heat/Energy Recovery

Heat/Energy recovery can be specified using recovery effectiveness or adjusted sensible recovery efficiency (ASRE) and sensible recovery efficiency (SRE). For larger AHRI rated equipment, inputs are covered in Section 5.7.7 Heat Recovery.

Proposed Design

Systems serving individual dwelling units with supply ducts (balanced and supply-only) are simulated with reduced recovery efficiency (SRE and ASRE or recovery effectiveness) to account for maintenance and installation factors affecting system efficacy. For these systems, recovery efficiency is reduced by a factor of 0.90 (10 percent decrease in recovery efficiency). For IAQ systems with an FID meeting the specifications in Reference Appendices, Joint Appendix JA17, these factors don't apply.

Standard Design

If the proposed design is a balanced central system, both central supply and central exhaust systems serving multiple dwelling units, in Climate Zones 1, 2, 4, 11 through 14, or 16, in a building with four or more habitable floors, the standard design is a heat recovery ventilation system with a sensible recovery effectiveness of 67% in both heating and cooling modes and includes recovery bypass to directly economize with ventilation air based on the outdoor air temperature limits specified in Table 170.2-G.

If the proposed design is a balanced system serving individual dwelling units in Climate Zones 1, 2, 4, 11 through 14, or 11-16, the standard design is a heat recovery ventilation system with a sensible recovery effectiveness of 67 percent in both heating and cooling modes.

6.8.6.6 Exhaust Air Sensible Heat Recovery Effectiveness

The effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams is defined as:

$$HREFF = \frac{EEA_{db} - ELA_{db}}{EEA_{db} - OSA_{db}}$$

Where:

$\boldsymbol{HREFF}$ - The air-to-air heat exchanger effectiveness
$\boldsymbol{EEA_{db}}$ - The exhaust air dry-bulb temperature entering the heat exchanger
$\boldsymbol{ELA_{db}}$ - The exhaust air dry-bulb temperature leaving the heat exchanger
$\boldsymbol{OSA_{db}}$ - The outside air dry-bulb temperature

This results in two unitless numbers (ratio between 0 and 1), separate for cooling and heating, and is based on the proposed design.

6.8.6.7 Exhaust Air Sensible Part-Load Effectiveness

The effectiveness of an air-to-air heat exchanger between the building exhaust and entering outside air streams at 75 percent of design airflow is defined as:

$$HREFF = \frac{EEA_{db} - ELA_{db}}{EEA_{db} - OSA_{db}}$$

Where:

- $\boldsymbol{HREFF}$ - The air-to-air heat exchanger effectiveness
- $\boldsymbol{EEA_{db}}$ - The exhaust air dry-bulb temperature entering the heat exchanger
- $\boldsymbol{ELA_{db}}$ - The exhaust air dry-bulb temperature leaving the heat exchanger
- $\boldsymbol{OSA_{db}}$ - The outside air dry-bulb temperature

This results in two unitless numbers (ratio between 0 and 1), separate for cooling and heating, and is based on the proposed design.

6.8.6.8 Economizer Enabled during Heat Recovery

All systems with airside heat recovery must identify if the economizer is enabled during heat recovery.

Proposed Design

Indication of whether the economizer is enabled when heat recovery is active is based on the proposed design.

Standard Design

The economizer is disabled if using balance system serving multiple dwelling units in Climate Zones 1, 2, 4, 11 through 14, or 16. Not applicable for Climate Zones 3, 5 through 10, and 15.

For existing buildings, the economizer is disabled if using a balanced system serving multiple dwelling units in Climate Zones 1, 2, 4, 11 through 14, or 16. Not applicable for Climate Zones 3, 5 through 10, and 15.

6.8.6.9 Recovery Type

Systems with airside heat recovery not using ASRE and SRE must identify the heat recovery system type. The type of heat recovery system is identified as sensible, latent, or total (sensible and latent).

6.8.6.10 Tempering Coils

Proposed Design

The proposed design may have tempering coils.

Standard Design

The standard design does not include tempering coils.

6.8.6.11 IAQ System Fault Indicator Display

All balanced and supply ventilation systems serviced from inside the attic or with an HRV/ERV must specify if the system includes an FID that meets the requirements in Reference Appendices, Joint Appendix JA17, Qualification Requirements for Indoor Air Quality System Fault Indicator Displays.

Proposed Design

Selection is based on the proposed design.

Standard Design

The standard design assumes an FID system meeting the requirements of Reference Appendices, Joint Appendix JA17.

6.9 Zones

The compliance software requires the user to enter the characteristics of one or more zones. Subdividing dwelling units into zones for input convenience or increased accuracy is optional.

6.9.1 Zone Type

Proposed Design

The zone is defined as directly conditioned indirectly conditioned, or unconditioned and is further distinguished as dwelling unit, common use space, attic, or crawl space.

Standard Design

The standard design is the same as proposed.

6.9.2 Space Function

PROPOSED DESIGN

The compliance software requires the user to select the space type that most appropriately matches one of the area category occupancy types from Appendix 5.4A.

STANDARD DESIGN

The standard design space function is the same as the proposed design and sets the baseline for various other categories such as number of occupants, ventilation rates, and lighting power allowances.

VERIFICATION AND REPORTING

No special verification or reporting.

6.9.3 Floor Area

The total floor area is the raised floor as well as the slab-on-grade floor area of the spaces measured from the exterior surface of exterior walls. Stairs are included in floor area as the area beneath the stairs and the tread of the stairs.

PROPOSED DESIGN

The compliance software requires the user to enter the total floor area of each zone.

STANDARD DESIGN

The standard design building has the same floor area and same zones as the proposed design.

VERIFICATION AND REPORTING

The floor area of each zone is reported on the Certificate of Compliance.

6.9.4 Number of Floors

6.9.4.1 Number of Floors of the Zone

PROPOSED DESIGN

The number of floors of the zone, integer value greater than 0.

STANDARD DESIGN

The standard design is the same as the proposed design.

6.9.4.2 Ceiling Height

PROPOSED DESIGN

The average ceiling height of the proposed design is the conditioned volume of the building envelope. The volume (in cubic feet) is determined from the total conditioned floor area and the average ceiling height.

STANDARD DESIGN

The volume of the standard design building is the same as the proposed design.

Verification and Reporting

The conditioned volume of each zone is reported on the Certificate of Compliance.

6.9.4.3 Free Ventilation Area

Free ventilation area is the window area adjusted to account for bug screens, window framing and dividers, and other factors.

Proposed Design

Free ventilation area for the proposed design is calculated as 10 percent of the fenestration area (rough opening), assuming all windows are operable.

Standard Design

The standard design value for free ventilation area is the same as the proposed design.

Verification and Reporting

Free ventilation is not reported on the Certificate of Compliance.

6.9.4.4 Ventilation Height Difference

Ventilation height difference is not a user input.

Proposed Design

The default assumption for the proposed design is 2 feet for one-floor buildings or one-floor dwelling units and 8 feet for two or more floors (as derived from number of floors and other zone details).

Standard Design

The standard design modeling assumption for the elevation difference between the inlet and the outlet is 2 feet for one-floor dwelling units and 8 feet for two or more floors.

6.9.4.5 Zone Elevations

The elevation of the top and bottom of each zone is required to set up the airflow network.

Proposed Design

The user enters the height of the top surface the lowest floor of the zone relative to the ground outside as the “bottom” of the zone. The user also enters the ceiling height (the floor-to-floor height [ceiling height plus the thickness of the intermediate floor structure] is calculated by the compliance software).

Underground zones are indicated with the number of feet below grade (e.g., -8).

Standard Design

The standard design has the same vertical zone dimensions as the proposed design.

6.9.4.6 Cooling Ventilation

Cooling ventilation (from windows) is available in dwelling units and residential common areas with windows when needed and available. Spaces shall be zoned by orientation and exposure to prevent cross ventilation through corridors and compartment walls. As shown in the example, multiple zones do not cross the corridor. In zones with windows on one or two sides only, the Natural Ventilation Wind Pressure of each window shall be multiplied by the relevant Wind Pressure Coefficient in Table 48: Wind Pressure Coefficients to reflect the lack of cross ventilation.

Figure 11: Example Floor Plan

Table 45: Wind Pressure Coefficients

Exposures	Coefficient
1	0.25
2	0.5
3 or 4	1.0

The amount of natural ventilation used by computer compliance software for natural cooling is the lesser of the maximum potential amount available and the amount needed to drive the interior zone temperature down to the natural cooling setpoint. When natural cooling is not needed or is unavailable, no natural ventilation is used.

Computer compliance software shall assume that natural cooling is needed when the building is in "cooling mode," when the outside temperature is below the estimated zone temperature, and when the estimated zone temperature is above the natural cooling setpoint temperature. Only the amount of ventilation required to reduce the zone temperature to the natural ventilation setpoint temperature is used, and the natural ventilation setpoint temperature is constrained by the compliance software to be greater than the heating setpoint temperature.

Table 46: Hourly Thermostat Set Points

Hour	Cooling	Venting	Heat Pump Heating	Standard Gas Heating Single-Zone	Zonal Control Gas Heating Living	Zonal Control Gas Heating Sleeping
1	78	Off	68	65	65	65
2	78	Off	68	65	65	65
3	78	Off	68	65	65	65
4	78	Off	68	65	65	65
5	78	Off	68	65	65	65
6	78	68*	68	65	65	65
7	78	68	68	65	65	65
8	78	68	68	68	68	68
9	78	68	68	68	68	68
10	78	68	68	68	68	65
11	78	68	68	68	68	65
12	78	68	68	68	68	65
13	78	68	68	68	68	65
14	78	68	68	68	68	65
15	78	68	68	68	68	65
16	78	68	68	68	68	65
17	78	68	68	68	68	68
18	78	68	68	68	68	68
19	78	68	68	68	68	68
20	78	68	68	68	68	68
21	78	68	68	68	68	68
22	78	68	68	68	68	68
23	78	68	68	68	68	68
24	78	Off	68	65	65	65

**Venting starts in the hour the sun comes up.*

Source: California Energy Commission

6.9.5 Conditioned Zone Assumptions

6.9.5.1 Internal Thermal Mass

Internal mass objects are completely inside a zone so that they do not participate directly in heat flows to other zones or outside. They are connected to the zone radiantly and convectively and participate in the zone energy balance by passively storing and releasing heat as conditions change.

Table 47: Conditioned Zone Thermal Mass Objects shows the standard interior conditioned zone thermal mass objects and the calculation of the simulation inputs that represent them.

Table 47: Conditioned Zone Thermal Mass Objects

Item	Description	Simulation Object
Interior walls	The area of one side of the walls completely inside the conditioned zone is calculated as the conditioned floor area of the zone minus ½ of the area of interior walls adjacent to other conditioned zones. The interior wall is modeled as a construction with 25 percent 2x4 wood framing and sheetrock on both sides.	Wall exposed to the zone on both sides
Interior floors	The area of floors completely inside the conditioned zone is calculated as the difference between the CFA of the zone and the sum of the areas of zone exterior floors and interior floors over other zones. Interior floors are modeled as a surface inside the zone with a construction of carpet, wood decking, 2x12 framing at 16 in. on-center with miscellaneous bridging, electrical, and plumbing, and a sheetrock ceiling below.	Floor/ceiling surface exposed to the zone on both sides
Furniture and heavy contents	Contents of the conditioned zone with significant heat storage capacity and delayed thermal response, for example heavy furniture, bottled drinks, canned goods, contents of dressers, enclosed cabinets. These are represented by a 2 in. thick slab of wood twice as large as the conditioned floor area, exposed to the room on both sides.	Horizontal wood slab exposed to the zone on both sides
Light and thin contents	Contents of the conditioned zone that have a large surface area compared to weight, for example, clothing on hangers, curtains, pots, and pans. These are assumed to be 2 Btu per square foot of conditioned floor area.	Air heat capacity (C_{air}) = CFA * 2

Source: California Energy Commission

PROPOSED DESIGN

The proposed design has standard conditioned zone thermal mass objects (such as gypsum board in walls, cabinets, sinks, and tubs) that are not user-editable and are not a compliance variable. If the proposed design includes specific interior thermal mass elements that are significantly different from what is included in typical wood-frame production housing, such as masonry partition walls, the user may include them. See also Chapter 6.9.7 Exterior Thermal Mass.

Standard Design

The standard design has standard conditioned zone thermal mass objects.

6.9.5.2 Thermostats and Schedules

Thermostat settings are shown in Table 46: Hourly Thermostat Set Points. The values for cooling, venting, and standard heating apply to the standard design run and are the default for the proposed design run. See the explanation later in this chapter regarding the values for zonal control.

Heat pumps equipped with supplementary electric resistance heating are assumed to meet mandatory control requirements specified in Section 110.2(b) and (c).

Systems with no setback required by Section 110.2(c) (gravity gas wall heaters, gravity floor heaters, gravity room heaters, noncentral electric heaters, fireplaces or decorative gas appliances, wood stoves, room air-conditioners, and room air-conditioner heat pumps) are assumed to have a constant heating set point of 68 degrees Fahrenheit. The cooling set point from Table 46: Hourly Thermostat Set Points is assumed in both the proposed design and standard design.

Proposed Design

The proposed design assumes a mandatory setback thermostat meeting the requirements of Section 110.2(c). Systems that are not required to have a setback thermostat are assumed to have no setback capabilities.

Standard Design

The standard design has setback thermostat conditions based on the mandatory requirement for a setback thermostat. For equipment that is not required to meet the setback thermostat requirement, the standard design has no setback thermostat capabilities.

6.9.5.3 Determining Heating Mode vs. Cooling Mode

When the building is in the heating mode, the heating setpoints for each hour are set to the “heating” values in Table 46: Hourly Thermostat Set Points, the cooling setpoint is a constant 78 degrees Fahrenheit (°F), and the ventilation setpoint is set to a constant 77°F. When the building is in the cooling mode, the heating setpoint is a constant 60°F, and the cooling and venting setpoints are set to the values in Table 46: Hourly Thermostat Set Points.

The mode depends upon the outdoor temperature averaged over hours 1 through 24 of eight days prior to the current day through two days prior to the current day. (For example, if the current day is June 21, the mode is based on the average temperature for June 13 through 20.) When this running average temperature is equal to or less than 60°F, the building is in a heating mode. When the running average is greater than 60°F, the building is in a cooling mode.

6.9.6 Internal Gains

Internal gains assumptions are included in Appendix E and consistent with the CASE report on plug loads and lighting (Rubin 2016, see Appendix F). The internal gains assumptions for the standard design building is the same as the proposed design.

6.9.7 Exterior Surfaces

The user enters exterior surfaces to define the envelope of the proposed design. The areas, construction assemblies, orientations, and tilts modeled are consistent with the actual building design and shall equal the overall roof/ceiling area with conditioned space on the inside and unconditioned space on the other side.

6.9.7.1 Ceilings Below Attics

Ceilings below attics are horizontal surfaces between conditioned zones and attics. The area of the attic floor is determined by the total area of ceilings below attics defined in conditioned zones.

Proposed Design

The compliance software allows the user to define ceilings below attic, enter the area, and select a construction assembly for each.

Standard Design

The standard design for newly constructed buildings has the same ceiling below attic area as the proposed design. The standard design is a ceiling constructed with 2x4 framed trusses, insulated at the ceiling and below roof deck with the R-values specified in Section 170.2(a)1Bii and Table 170.2-A, Option B for the applicable climate zone. A radiant barrier and CRRC cool roof are also specified in Table 170.2-A for specific climate zones. The roof surface is a 10 lbs/ft^2 tile roof with an air space when the proposed roof is steep slope or a lightweight roof when the proposed roof is low slope.

Verification and reporting

Ceiling below attic area and constructions are reported on the Certificate of Compliance. SIP assemblies are reported as a special feature on the Certificate of Compliance.

6.9.7.2 Non-Attic (Cathedral) Ceiling and Roof

Non-attic ceilings, also known as cathedral ceilings, are surfaces with roofing on the outside and finished ceiling on the inside but without an attic space.

Proposed Design

The compliance software allows the user to define cathedral ceilings, enter the area, and select a construction assembly for each. The user also enters the roof characteristics of the surface.

Standard Design

The standard design has the same area as the proposed design cathedral ceiling modeled with the features from Section 170.2 and Table 170.2-A or for the applicable climate zone.

The standard design roof and ceiling surfaces are modeled with the same construction assembly and characteristics, aged reflectance, and emittance as Section 170.2, Table 170.2-A for the applicable climate zone.

Verification and reporting

Non-attic ceiling/roof area and constructions are reported on the Certificate of Compliance. SIP assemblies are reported as a special feature on the Certificate of Compliance.

6.9.7.3 Exterior Walls

Proposed Design

The compliance software allows the user to define walls, enter the gross area, and select a construction assembly for each. The user also enters the plan orientation (front, left, back, or right) or plan azimuth (value relative to the front, which is represented as zero degrees) and tilt of the wall.

The wall areas modeled are consistent with the actual building design, and the total wall area is equal to the gross wall area with conditioned space on the inside and unconditioned space or exterior conditions on the other side. Underground mass walls are defined with inside and outside insulation and the number of feet below grade. Walls separating conditioned from unconditioned spaces, which have no solar gains, are entered as an interior wall with the zone on the other side specified as an unconditioned zone, and the compliance software treats that wall as a demising wall.

Standard Design

The standard design building has high-performance walls modeled with the same area of framed walls as is in the proposed design separating conditioned space and the exterior, with a U-factor equivalent to that as specified in Section 170.2 and Table 170.2-A for the applicable climate zone, wall assembly type, and required fire rating.

The total gross exterior wall area in the standard design is equal to the total gross exterior wall area of the proposed design for each wall type and for each orientation. Window and door areas are subtracted from the gross wall area to determine the net wall area in each orientation.

Verification and reporting

Exterior wall area and construction details are reported on the Certificate of Compliance. Metal-framed and SIP assemblies are reported as a special feature on the Certificate of Compliance.

6.9.7.4 Exterior Thermal Mass

Constructions for standard exterior mass are supported but not implemented beyond the assumptions for typical mass.

The performance approach assumes that both the proposed design and standard design building have a minimum mass as a function of the conditioned area of slab floor and non-slab-floor. (See Chapter 6.9.5 Internal Thermal Mass.)

Mass such as concrete slab floors, masonry walls, double gypsum board, and other special mass elements can be modeled. When the proposed design has more than the typical assumptions for mass in a building, then each element of heavy mass is modeled in the proposed design, otherwise; the proposed design is modeled with the same thermal mass as the standard design.

Proposed Design

The proposed design may be modeled with the default 20 percent exposed mass/80 percent covered mass or with actual mass areas modeled as separate covered and exposed mass surfaces. Exposed mass surfaces covered with flooring material that is in direct contact with the slab can be modeled as exposed mass. Examples of such materials are tile, stone, vinyl, linoleum, and hardwood.

Standard Design

The conditioned slab floor in the standard design is assumed to be 20 percent exposed slab and 80 percent slab covered by carpet or casework. Interior mass assumptions as described in Chapter 6.9.5 Internal Thermal Mass are also assumed. No other mass elements are modeled in the standard design. The standard design mass is modeled with the following characteristics:

> The conditioned slab floor area (slab area) shall have a thickness of 3.5 inches, a volumetric heat capacity of 28 Btu/ft^3-°F, and a conductivity of 0.98 Btu-in/hr-ft^2-°F. The exposed portion shall have a surface conductance of 1.3 Btu/h-ft^2-°F (no thermal resistance on the surface), and the covered portion shall have a surface conductance of 0.50 Btu/h-ft^2-°F, typical of a carpet and pad. The “exposed” portion of the conditioned non-slab floor area shall have a thickness of 2.0 inches, a volumetric heat capacity of 28 Btu/ft^3-°F, a conductivity of 0.98 Btu-in/hr- ft^2-ºF; and a surface conductance of 1.3 Btu/h- ft^2-°F (no added thermal resistance on the surface). These thermal mass properties apply to the “exposed” portion of non-slab floors for both the proposed design and standard design. The covered portion of non-slab floors is assumed to have no thermal mass.

Verification and Reporting

Exposed mass greater than 20 percent exposed slab on grade, and any other mass modeled by the user is reported as a special feature on the Certificate of Compliance.

6.9.7.5 Opaque Doors

Doors are defined as an opening in a building envelope. If the rough opening of a door includes fenestration equal to 25 percent or more of glass or fenestration, it is fenestration. (See Chapter 6.9.7 Fenestration.) Doors with less than 25 percent fenestration are considered an opaque door.

Proposed Design

The compliance software shall allow users to enter doors specifying the U-factor, area, and orientation. Doors to the exterior or to unconditioned zones are modeled as part of the conditioned zone. For doors with less than 25 percent glass area, the U-factor shall come from Reference Appendices, Joint Appendix *JA4, Table 4.5.1* (default U-factor 0.20) or from National Fenestration Rating Council (NFRC) certification data for the entire door. For unrated doors, the glass area of the door, calculated as the sum of all glass surfaces plus 2 inches on all sides of the glass (to account for a frame), is modeled under the rules for fenestrations; the opaque area of the door is considered the total door area minus this calculated glass area. Doors with 25 percent or more glass area are modeled under the rules for fenestrations using the total area of the door.

When modeling a garage zone, large garage doors (metal roll-up or wood) are modeled with a 1.0 U-factor.

Standard Design

The standard design has the same door area for each dwelling unit as the proposed design. The U-factor for the standard design is taken from Section 170.2 and Table 170.2-A. All swinging opaque doors are assumed to have a U-factor of 0.20. The net opaque wall area is reduced by the door area in the standard design.

Verification and reporting

Door area and U-factor are reported on the Certificate of Compliance.

6.9.7.6 Fenestration

Fenestration is modeled with a U-factor, solar heat gain coefficient (SHGC), and visible transmittance (VT). Acceptable sources of these values are National Fenestration Rating Council (NFRC), default tables from Section 110.6 of the Energy Code, and *Reference Appendices, Nonresidential Appendix NA6*.

In limited cases for certain site-built fenestration that is field fabricated, the performance factors (U-factor, SHGC) may come from *Reference Appendices, Nonresidential Appendix NA6* as described in Exception 3 to Section 170.2(a)3Aii.

There is no detailed model of chromogenic fenestration available. As allowed by Exception 2 to Section 170.2(a)3Aii, the lower-rated labeled U-factor and SHGC may be used only when installed with automatic controls as noted in the exception. Chromogenic fenestration cannot be averaged with nonchromogenic fenestration.

Proposed Design

The compliance software allows users to enter individual skylights and fenestration types, the U-factor, SHGC, VT, area, orientation, and tilt.

Performance datum (U-factors, SHGC, and VT) are from NFRC values or from the CEC default tables from Section 110.6 of the Energy Code. Solar gains from windows or skylights use the California Simulation Engine (CSE) default solar gain targeting or similar calculation method approved by the Energy Commission.

Skylights are a fenestration with a slope of 60 degrees or more. Skylights are modeled as part of a roof.

Standard Design

If the proposed design fenestration area is less than 20 percent of the conditioned floor area, and less than 40 percent of the exterior wall area, the standard design fenestration area is set equal to the proposed design fenestration area for each orientation Otherwise, the standard design fenestration area is set equal to 20 percent of the conditioned floor area, or 40 percent of the exterior wall area, whichever is smaller, and the area is proportionally distributed for each orientation to match the proposed fenestration distribution.

The standard design has no skylights.

The net wall area on each orientation is reduced by the fenestration area and door area on each façade. The U-factor, SHGC, and VT performance factors for the standard design are taken from Section 170.2 and Table 170.2-A. In cases where the SHGC is “NR” the standard design is equal to 0.35.

Verification and Reporting

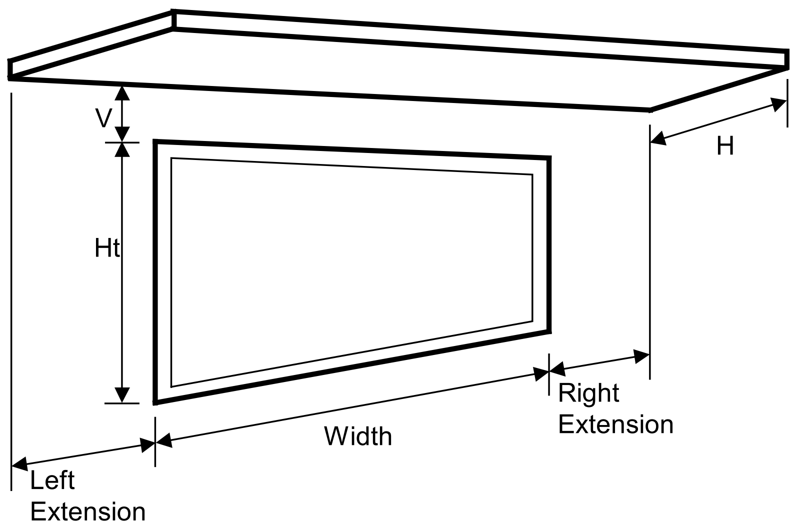
Fenestration area, U-factor, SHGC, VT, and orientation, are reported on the Certificate of Compliance. SHGC is reported on the Certificate of Compliance as an allowable maximum and minimum for each window calculated as the SHGC entered by the user plus or minus 0.01.

6.9.7.7 Overhangs and Sidefins

PROPOSED DESIGN

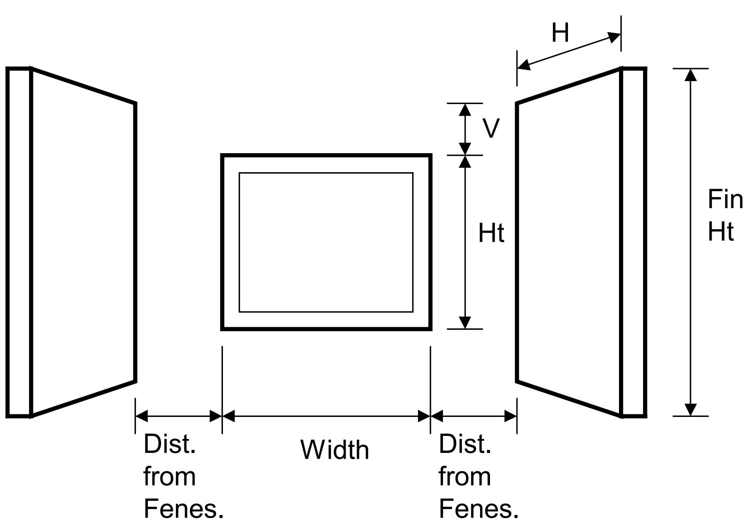
Compliance software users enter a set of basic parameters for a description of an overhang and sidefin for each individual fenestration or window area entry. The basic parameters include fenestration height, overhang/sidefin length, and overhang/sidefin height. Compliance software user entries for overhangs may also include fenestration width, overhang left extension, and overhang right extension. Compliance software user entries for sidefins may also include fin left extension and fin right extension for both left and right fins. Walls at right angles to windows may be modeled as sidefins.

Figure 12: Overhang Dimensions



Source: California Energy Commission

Figure 13: Sidefin Dimensions



Source: California Energy Commission

Standard Design

The standard design does not have overhangs or sidefins.

Verification and Reporting

Overhang and fin dimensions are reported on the Certificate of Compliance.

6.9.7.8 Interior Shading Devices

For both the proposed and standard design, all windows are assumed to have draperies, and skylights are assumed to have no interior shading. Window medium drapes are closed at night and half open in the daytime hours. Interior shading is not a compliance variable and is not user-editable.

6.9.7.9 Exterior Shading

For both the proposed and standard design, all windows are assumed to have bug screens, and skylights are assumed to have no exterior shading. Exterior shading is modeled as an additional glazing system layer using the ASHRAE Window Attachment (ASHWAT) calculation or approved method showing minimum energy equivalency.

Proposed Design

The compliance software shall require the user to accept the default exterior shading devices, which are bug screens for windows and none for skylights. Credit for shading devices that are allowable for prescriptive compliance are not allowable in performance compliance.

Standard Design

The standard design shall assume bug screens. The standard design does not have skylights.

6.9.7.10 Slab on Grade Floors

Proposed Design

The compliance software allows users to enter areas and exterior perimeter of slabs that are heated or unheated, covered, or exposed, and with or without slab-edge insulation. Perimeter is the length of wall between conditioned space and the exterior, but it does not include edges that cannot be insulated, such as between the house and the garage. The default condition for the proposed design is that 80 percent of each slab area is carpeted or covered by walls and cabinets, and 20 percent is exposed. Inputs other than the default condition require that carpet and exposed slab conditions are documented on the construction plans.

When the proposed heating distribution is radiant floor heating (heated slab), the compliance software user will identify that the slab is heated and model the proposed slab edge insulation. The mandatory minimum requirement is R-5 insulation in Climate Zones 1-15 and R-10 in Climate Zone 16 (Section 110.8(g), Table 110.8-A).

Standard Design

The standard design perimeter lengths and slab on grade areas are the same as the proposed design. 80 percent of standard design slab area is carpeted, and 20 percent is exposed. For the standard design, an unheated slab edge has no insulation with the exception of Climate Zone 16, which assumes R-7 to a depth of 16 inches. The standard design for a heated slab is a heated slab with the mandatory slab edge insulation of R-5 in Climate Zones 1-15 and R-10 in Climate Zone 16.

Verification and Reporting

Slab areas, perimeter lengths, and inputs of other than the default condition are reported on the Certificate of Compliance.

6.9.7.11 Underground Floors

Proposed Design

The compliance software allows users to enter areas and depth below grade of slab floors occurring below grade. Unlike slab-on-grade floors, there is no perimeter length associated with underground floors.

Standard Design

The standard design underground floor areas are the same as the proposed design.

6.9.7.12 Raised Floors

Proposed Design

The compliance software allows the user to input floor areas and constructions for raised floors over a crawl space, over exterior (garage or unconditioned), and concrete raised floors. The proposed floor area and constructions are consistent with the actual building design.

Standard Design

The standard design has the same area and type of construction as the proposed design. The thermal characteristics meet Section 170.2 and Table 170.2-A. For floor areas that are framed construction, the standard design floor has R-19 in 2x6 wood framing, 16-in. on center (0.037 U-factor). For floor areas that are concrete raised floors, the standard design floor is 6 inches of normal weight concrete with R-8 continuous insulation in Climate Zones 1, 2, 11, 13, 14, 16; Climate Zones 12 and 15 have R-4; Climate Zones 3-10 have R-0.

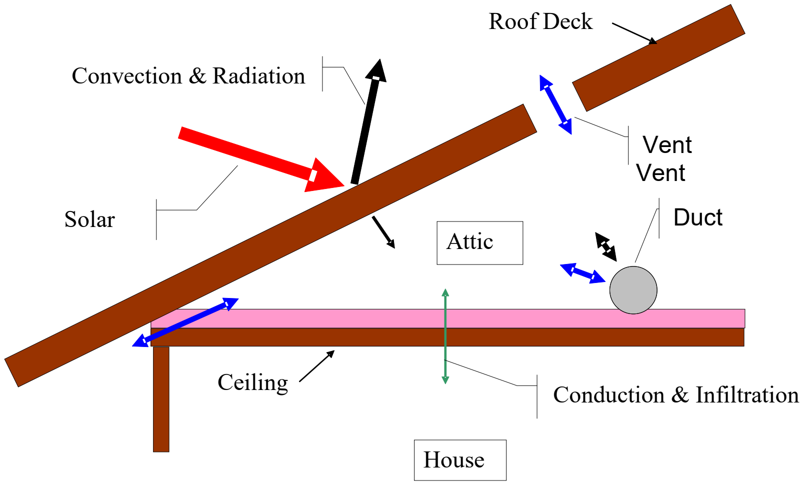
Verification and Reporting

Raised floor areas and constructions are reported on the Certificate of Compliance.

6.10Attics

The compliance software models attics as a separate thermal zone and includes the interaction with the air distribution ducts, infiltration exchange between the attic and the house, the solar gains on the roof deck, and other factors. These interactions are illustrated in Figure 14: Attic Model Components.

Figure 14: Attic Model Components



Source: California Energy Commission

6.10.1 Attic Components

6.10.1.1 Roof Rise

The roof rise is the ratio of rise to run (or pitch) and refers to the number of feet the roof rises vertically for every 12 feet horizontally. For roofs with multiple pitches, the roof rise that makes up the largest roof area is used.

6.10.1.2 Vent Area

This value is the vent area as a fraction of attic floor area. This value is not a compliance variable and is assumed set equal to attic floor area divided by 300.

6.10.1.3 Fraction High

The fraction of the vent area that is high due to the presence of ridge, roof, or gable end-mounted vents. Soffit vents are considered low ventilation. The default value is zero for attics with standard ventilation. Attics with radiant barriers are required to have a vent high fraction of at least 0.3.

6.10.1.4 Roof Deck/Surface Construction

Typical roof construction types are concrete or clay tile, metal tile, gravel, ballast, or other steep- or low-sloped roofing types.

6.10.1.5 Solar Reflectance

This input is a fraction that specifies the certified aged reflectance of the roofing material or 0.1 default value for uncertified materials. The installed value must be equal to or higher than the value specified in the proposed model. Roof construction with a roof membrane mass of at least 25 lbs/ft^2, or a roof area that has integrated solar collectors, is assumed to meet the minimum solar reflectance.

6.10.1.6 Thermal Emittance

Thermal emittance is the certified aged thermal emittance (or emissivity) of the roofing material, or a default value. Unless a default value is modeled, the installed value must be equal to or greater than the value modeled. The default value is 0.85 if certified aged thermal emittance value is not available from the [Cool Roof Rating Council (CRRC)](http://www.coolroofs.org), www.coolroofs.org. Roof construction with a roof membrane mass of at least 25 lbs/ft^2 or roof area incorporated integrated solar collectors is assumed to meet the minimal, default, thermal emittance.

PROPOSED DESIGN

The conditioning is either ventilated or unventilated. Each characteristic of the roof is modeled to reflect the proposed construction. Values for solar reflectance and thermal emittance shall be default or from the CRRC.

Roofs with solar collectors or with thermal mass over the roof membrane with a weight of at least 25 lbs/ft^2 may model the prescriptive values for solar reflectance and thermal emittance.

STANDARD DESIGN

The standard design depends on the variables of the climate zone and roof slope. Low-sloped roofs (with a roof rise of 2 feet in 12 or less) in Climate Zones 13 and 15 will have a standard design aged solar reflectance of 0.63 and a thermal emittance of 0.85.

Steep-sloped roofs in Climate Zones 10-15 will have a standard design roof with an aged solar reflectance of 0.20 and a minimum thermal emittance of 0.85.

Roofs with solar collectors or with thermal mass over the roof membrane with a weight of at least 25 lbs/ft^2 are assumed to meet the standard design values for solar reflectance and thermal emittance.

VERIFICATION AND REPORTING

A reflectance of 0.20 or higher is reported as a cool roof. A value higher than the default but less than 0.20 is reported as a non-standard roof reflectance value.

6.10.2 Ceiling Below Attic

PROPOSED DESIGN

For each conditioned zone, the user enters the area and construction of each ceiling surface that is below an attic space. The compliance software shall allow a user to enter multiple ceiling constructions. Surfaces that tilt 60 degrees or more are treated as knee walls and are not included as ceilings. The sum of areas shall equal the overall ceiling area with conditioned space on the inside and unconditioned attic space on the other side.

The compliance software creates an attic zone with a floor area equal to the sum of the areas of all the user input ceilings below an attic in the building. The user specifies the framing and spacing, the materials of the frame path, and the R-value of the insulation path for each ceiling construction.

The user inputs the proposed insulation R-value rounded to the nearest whole R-value. For simulation, all ceiling below attic insulation is assumed to have nominal properties of R-2.6 per inch, a density of 0.5 lb/ft^3, and a specific heat of 0.2 Btu/lb.

STANDARD DESIGN

The standard design shall have the same area of ceiling below attic as the proposed design. The ceiling/framing construction is based on the prescriptive requirement and standard framing is assumed to be 2x4 wood trusses at 24 inches on center.

Verification and Reporting

The area, insulation R-value, and layer of each construction are reported on the Certificate of Compliance.

6.10.3 Attic Roof Surface and Pitch

Proposed Design

The roof pitch is the ratio of rise to run, (for example, 4:12 or 5:12). If the proposed design has more than one roof pitch, the pitch of the largest area is used.

The compliance software creates an attic zone roof. The roof area is calculated as the ceiling below attic area divided by the cosine of the roof slope where the roof slope is an angle in degrees from the horizontal. The roof area is then divided into four equal sections with each section sloping in one of the cardinal directions (north, east, south, and west). Gable walls, dormers, or other exterior vertical surfaces that enclose the attic are ignored.

If the user specifies a roof with a pitch less than 2:12, the compliance software creates an attic with a flat roof that is 30 inches above the ceiling.

Standard Design

The standard design shall have the same roof pitch, roof surface area, and orientations as the proposed design.

Verification and Reporting

The roof pitch is reported on the Certificate of Compliance.

6.10.4 Attic Conditioning

Attics may be ventilated or unventilated. Insulation in a ventilated attic must be installed at the ceiling level. Unventilated attics usually have insulation at the roof deck and sometimes on the ceiling (Section 160.1[a]).

In an unventilated attic, the roof system becomes part of the insulated building enclosure. Local building jurisdictions may impose additional requirements.

Proposed Design

A conventional attic is modeled as ventilated. When an attic will not be vented, attic conditioning is modeled as unventilated.

Standard Design

Attic ventilation is set to ventilated for the standard design.

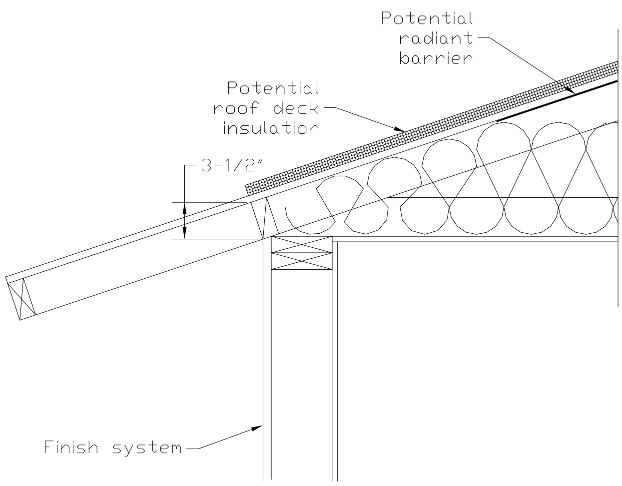
Verification and Reporting

The attic conditioning (ventilated or unventilated) is reported on the Certificate of Compliance.

6.10.5 Attic Edge

With a standard roof truss (Figure 15: Section at Attic Edge with Standard Truss), the depth of the ceiling insulation is restricted to the space left between the roof deck and the wall top plate for the insulation path, and the space between the bottom and top chord of the truss in the framing path. If the modeled insulation completely fills this space, there is no attic air space at the edge of the roof. Heat flow through the ceiling in this attic edge area is directly to the outside both horizontally and vertically, instead of to the attic space. Measures that depend on an attic air space, such as radiant barriers or ventilation, do not affect the heat flows in the attic edge area.

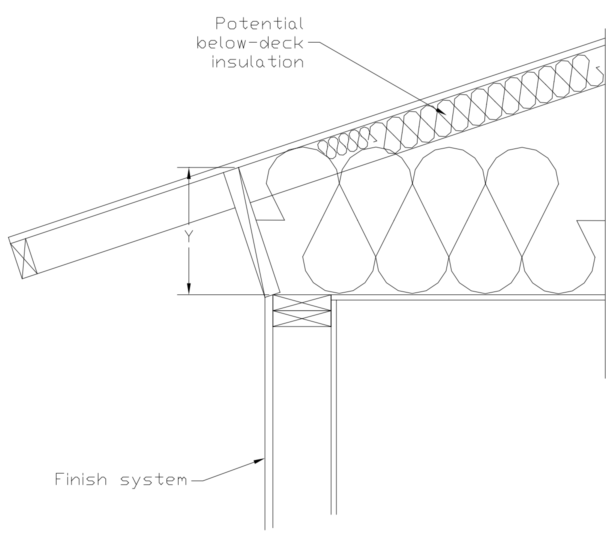
Figure 15: Section at Attic Edge with Standard Truss



Source: California Energy Commission

A raised heel truss (Figure 16: Section at Attic Edge with a Raised Heel Truss) provides additional height at the attic edge that, depending on the height Y and the ceiling insulation R, can either reduce or eliminate the attic edge area and its thermal impact.

Figure 16: Section at Attic Edge with a Raised Heel Truss



Source: California Energy Commission

For cases where the depth of insulation (including below-deck insulation depth) is greater than the available height at the attic edge, the compliance software automatically creates cathedral ceiling surfaces to represent the attic edge area and adjusts the dimensions of the attic air space using the algorithms contained in Appendix G. If above-deck insulation is modeled, it is included in the attic edge cathedral ceiling constructions, but radiant barriers below the roof deck are not.

Proposed Design

The compliance software shall allow the user to specify that a raised heel truss will be used (as supported by construction drawings), with the default being a standard truss as shown in Figure 15: Section at Attic Edge with Standard Truss. If the user selects a raised heel truss, the compliance software will require the user to specify the vertical distance between the wall top plate and the bottom of the roof deck (Y in Figure 16: Section at Attic Edge with a Raised Heel Truss).

Standard Design

The standard design shall have a standard truss with the default vertical distance of 3.5 inches between wall top plate and roof deck.

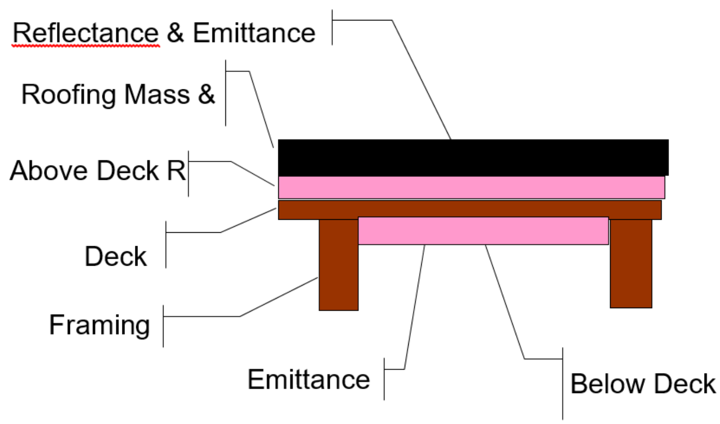
Verification and Reporting

A raised heel truss is a special feature, and the vertical height above the top plate will be included on the Certificate of Compliance.

6.10.6 The Roof Deck

The roof deck is the construction at the top of the attic and includes the solar optic properties of the exterior surface, the roofing type, the framing, insulation, air gaps, and other features. These are illustrated in Figure 17: Components of the Attic Through Roof Deck, which shows a detailed section through the roof deck.

Figure 17: Components of the Attic Through Roof Deck



Source: California Energy Commission

6.10.6.1 Radiant Barrier

Radiant barriers are used to reduce heat flow at the bottom of the roof deck in the attic. A 0.05 emittance is modeled at the bottom surface of the roof deck if radiant barriers are used. If no radiant barrier is used, the value modeled is 0.9. If radiant barrier is installed over existing skip sheathing in a reroofing application, 0.5 is modeled.

Proposed Design

The user shall specify whether the proposed design has:

A radiant Barrier
No Radiant Barrier

Standard Design

The standard design shall have a radiant barrier if required by the prescriptive Energy Code (Section 170.2 and Table 170.2-A) for the applicable climate zone.

Verification and Reporting

Radiant barriers are reported as a special feature on the Certificate of Compliance.

6.10.6.2 Below Deck Insulation

Below-deck insulation is insulation that will be installed below the roof deck between the roof trusses or rafters.

Proposed Design

The compliance software shall allow the user to specify the R-value of insulation that will be installed below the roof deck between the roof trusses or rafters. The default is an uninsulated roof deck.

Standard Design

The standard design has below-deck insulation as specified in Chapter 6.10.2 Ceilings Below Attics.

Verification and Reporting

The R-value of any below-deck insulation is reported as a special feature on the Certificate of Compliance.

6.10.6.3 Roof Deck and Framing

The roof deck is the structural surface that supports the roofing. The compliance software assumes a standard wood deck, and this is not a compliance variable. The size, spacing, and material of the roof deck framing are compliance variables.

Proposed Design

The roof deck is wood siding/sheathing/decking. The compliance software shall default the roof deck framing to 2x4 trusses at 24 in. on center. The compliance software shall allow the user to specify alternative framing size, material, and framing spacing.

Standard Design

The standard design is 2x4 trusses at 24 in. on center.

Verification and Reporting

Nonstandard roof deck framing or spacing is reported as a special feature on the Certificate of Compliance.

6.10.6.4 Above Deck Insulation

Above-deck insulation represents the insulation value of the air gap in “concrete or clay tile” or “metal tile or wood shakes.” The R-value of any user modeled insulation layers between the roof-deck and the roofing is added to the air gap value.

Proposed Design

This input defaults to R-0.85 for “concrete or clay tile” or for “metal tile or wood shakes” to represent the benefit of the air gap but no additional insulation. The compliance software shall allow the user to specify the R-value of additional above-deck insulation in any roof-deck construction assembly.

Standard Design

The standard design accounts for the air gap based on roofing type but has no additional above-deck insulation.

Verification and Reporting

Above-deck insulation R-value is reported as a special feature on the Certificate of Compliance.

6.10.6.5 Roofing Type and Mass

Proposed Design

The choice of roofing type determines the air gap characteristics between the roofing material and the deck and establishes whether other inputs are needed, as described below. The choices for roof type are shown below.

Concrete or clay tile. Both types have significant thermal mass and an air gap between the deck and the tiles.

Metal tile or wood shakes. These are lightweight with an air gap between the tiles or shakes and the deck. Note that tapered cedar shingles do not qualify and are treated as a conventional roof surface.

Other steep-slope roofing types. These include asphalt and composite shingles and tapered cedar shingles. These products have no air gap between the shingles and the structural roof deck.

Low-slope membranes. These are basically flat roofs with a slope of less than 2:12.

Above-deck mass. The above-deck mass depends on the roofing type. The mass is 10 lbs/ft² for concrete and clay tile and 5 lbs/ft² for metal tile, wood shakes, or other steep-slope roofing types. For low-slope roofs, the additional thermal mass is assumed to be gravel or stone, and the user chooses one of the following inputs that is equal to or less than the weight of the material being installed above the roof deck:

No mass (asphalt)

5 lbs/ft²

10 lbs/ft²

15 lbs/ft^2
25 lbs/ft^2

Standard Design

The roof slope shall match the proposed design. The roof type for a steep slope roof is 10 lbs/ft^2 tile. The roof type for low-slope roof is lightweight roof.

Verification and Reporting

The roof type is reported on the Certificate of Compliance.

6.10.6.6 Solar Reflectance and Thermal Emittance

Proposed Design

The compliance software shall allow the user to default the solar reflectance and thermal emittance of the roofing. The solar reflectance product default is 0.10 for all roof types. The thermal emittance default is 0.85.

The compliance software shall allow the user to input aged solar reflectance and thermal emittance of roofing material that are rated by the CRRC. The installed value must be equal to or higher than the value specified here. Roof construction with a roof membrane mass of at least 25 lbs/ft^2 or roof area incorporated integrated solar collectors are assumed to meet the minimal solar reflectance.

Standard Design

The solar reflectance and thermal emittance of the standard design roofing are as specified in Table 170.2-A of the prescriptive standards.

Verification and Reporting

Thermal emittance and solar reflectance shall be reported on the Certificate of Compliance. A reflectance of 0.20 or higher is reported as a cool roof. A value higher than the default but less than 0.20 is reported as a nonstandard roof reflectance value.

6.11Domestic Hot Water (DHW)

Water heating energy use is based on the number of dwelling units, number of bedrooms, fuel type, distribution system, water heater type, and conditioned floor area. Detailed calculation information is included in Appendix B: Water Heating Calculation Method of the Residential ACM Reference Manual.

Proposed Design

The water heating system is defined by the heater type (gas, electric resistance, or heat pump), tank type, dwelling-unit distribution type, efficiency (either uniform energy factor (UEF) or recovery efficiency with the standby loss), tank volume, exterior insulation R-value (only for indirect), rated input, and tank location (for electric resistance and heat pump water heater only).

Unitary heat pump water heaters are defined by UEF (and optionally E_{50} and E_{95}), and volume, or, for Northwest Energy Efficiency Alliance Advanced Water Heating Specification (AWHS) qualified heat pumps, by selecting the Tier qualification level, entering the UEF (and optionally E_{50} and E_{95}) or the specific heater brand and model.

Water heater and tank types include:

- Consumer storage: ≤ 75,000 Btu/h gas/propane, ≤ 12 kW electric, or ≤ 24 amps heat pump, rated with UEF.
- Consumer instantaneous: ≤ 200,000 Btu/h gas or propane, or ≤ 12 kW electric. An instantaneous water heater is a water heater with an input rating of ≥ 4,000 Btu/h/gallon of stored water, rated with a UEF.
- Residential-duty commercial storage: > 75,000 Btu/h, ≤ 105,000 Btu/h gas/propane, ≤ 12 kW electric, ≤ 24 amps heat pump, and rated storage volume < 120 gallons, rated with a UEF.
- Residential-duty commercial instantaneous: ≤ 200,000 Btu/h gas/propane, ≤ 58.6 kW electric, rated storage volume ≤ 2 gallons, rated with a UEF.
- Commercial storage: > 75,000 Btu/h gas/propane, >105,000 Btu/h oil, or > 12 kW electric, rated with thermal efficiency and standby loss.
- Commercial instantaneous: >200,000 Btu/h gas/propane, > 12 kW electric. Instantaneous water heater is a water heater with an input rating of ≥ 4,000 Btu/h per gallon of stored water, rated with thermal efficiency.
- Unitary heat pump water heater: ≤ 24 amps AWHS rating or rated with UEF.
- Mini-tank (modeled only in conjunction with an instantaneous gas water heater): a small electric storage buffering tank that may be installed downstream of an instantaneous gas water heater to mitigate delivered water temperatures (e.g., cold water sandwich effect). If the standby loss of this aftermarket tank is not listed in the CEC appliance database, a standby loss of 35 W must be assumed.
- Indirect: a tank with no heating element or combustion device used in combination with a boiler or other device serving as the heating element.
- Boiler: a water boiler that supplies hot water, rated with thermal efficiency or AFUE.

Heater element type includes:

- Electric resistance.
- Gas.
- Heat pump.

Dwelling unit distribution system types for systems serving individual dwelling units include:

- Standard (all piping and plumbing appurtenances for domestic hot water systems shall be insulated and insulation shall be continuous).
- Point of use.
- Central parallel piping.
- Recirculation with nondemand control (continuous pumping).
- Recirculation with demand control, push button.
- Recirculation with demand control, occupancy/motion sensor.

- ECC-required pipe insulation, all lines including the first 8 ft of inlet cold water piping from storage tank. If pipe insulation is not verified per Residential Reference Appendix RA3.6.3, then an energy compliance penalty is applied based on Appendix B Table B-6 to reflect imperfect insulation.
- ECC-required central parallel piping.
- ECC-required recirculation, demand control, push button.
- ECC-required recirculation with demand control, occupancy/motion sensor.

Some distribution systems can increase the amount of credit received if the option for ECC verification is selected. See Appendix B for the amount of credit and Reference Appendices, Residential Appendix Table RA2-6 for a summary of inspection requirements.

When a multifamily building has central water heating, both a dwelling unit and a central system distribution type must be specified. Dwelling unit distribution types for this case include:

- Standard (all distribution pipes insulated).
- ECC-required pipe insulation, all lines.

Multifamily central hot water heating central system distribution types include:

- No loops or recirculation system pump.
- Recirculation with no control (continuous pumping).

Pipe Sizing

California Plumbing Code (CPC) Appendix M establishes that the standard design pipe sizing methodology be used for all distribution piping. If CPC Appendix A methodology is followed, then an energy compliance penalty is applied based on Appendix B Table B-6.

6.11.1 Distribution Compactness

Applicable to single dwelling units or multifamily with individual water heater in each dwelling unit. Distribution compactness identifies the proximity between the water heater and use points. The distribution compactness of the water heating system must be specified. The choices include:

- None.
- Compact distribution basic credit.
- Compact distribution expanded credit (ECC).

Once basic credit or expanded credit is specified, either the plan view fixture distances (to master bathroom, kitchen, and furthest fixture) will need to be input for the DHW system or, if the distances are unknown, allow a user input compactness factor to be used.

If the fixture distances are specified, the compliance software will determine if the distances qualify for the credit.

If the fixture distances are not specified, compliance with the user input compactness factor will be verified on the Certificate of Installation where the actual fixture distances for the design will need to be specified.

6.11.2 Drain Water Heat Recovery

Drain water heat recovery (DWHR) is a system where the waste heat from shower drains is used to preheat the cold inlet water. The preheated water can serve a shower, water heater, or both.

The user specifies the DHWR device for the water heating system. The rated efficiency of the DWHR device, the number of shower(s) served, and the configuration must be specified. The configuration choices include:

- Equal flow to shower and water heater: The potable-side heat exchanger output feeds both the fixture and the water heater inlet. Potable and drain flow rates are equal, assuming no other simultaneous hot water draws.
- Unequal flow to shower: The potable-side heat exchanger output feeds the inlet(s) of the water heater(s) that are part of the parent DHW system. (The inlet temperature is adjusted to reflect recovered heat.)
- Unequal flow to water heater: The potable-side heat exchanger output feeds only the associated fixture.

Multiple DHWR devices can be used for a water heater system.

Drain water heat recovery is a ECC-verified measure.

6.11.3 Individual Water Heaters Serving Dwelling Units – - Standard Design

Multifamily buildings three habitable floors or less:

When calculating the LSC the standard design for all climate zones is a single HPWH with a 2.0 UEF. If the proposed building has an attached garage, then the standard design HPWH location is in the garage. If the proposed building does not have an attached garage, then the standard design HPWH location is in an exterior closet with louvers open to the exterior.

In climate zones 1 or 16 the standard design will include a compact distribution system meeting the requirements of RA4.4.6. In climate zone 16 the standard design will include both a compact distribution system and a drain water heat recovery system.

When calculating the source energy, the domestic water heating system is a gas tankless water heater with an input of 200,000 BTU/h, a high draw pattern, and 0.81 UEF.

Multifamily buildings four habitable floors or greater:

If the proposed design uses electricity as the fuel source, the standard design is a single heat pump water heater with a 2.0 UEF with compact distribution basic credit in Climate Zones 1 and 16, and a drain water heat recovery system in Climate Zone 16.

If the proposed building has an attached garage, then the standard design HPWH location is the garage. If the proposed building does not have an attached garage, then the standard design HPWH location is in the conditioned space with the air inlet and outlet ducted to the outside.

If the proposed design is gas, then the standard design is a single gas or propane consumer instantaneous water heater for each dwelling unit. The single consumer instantaneous water heater is modeled with an input of 200,000 Btu/h, a tank volume of zero gallons, a high draw pattern, and a UEF meeting the minimum federal standards. The current minimum federal standard for a high-draw-pattern instantaneous water heater is 0.81 UEF.

6.11.4 Multiple Dwelling Units – Central Water Heating Standard Design

The energy performance of central water heating systems is determined by the primary heating equipment, primary heating storage volume, location, secondary heating equipment, secondary heating storage volume, set point controls, and the way in which the components are plumbed.

Water-heating device

If the proposed central water heating device uses electricity as the fuel source, the standard design is a central split heat pump water heater system that includes the following:

Primary single-pass, split-system heat pump plumbed to a primary storage volume. The standard design heat pump water heater output capacity and the primary storage tank capacity are automatically sized so that the heat pump and primary storage volume jointly meet the peak water used on the design (coldest) day. The algorithm sizes the primary tank volume to meet the peak water draw period and the heat pump output capacity so that the system runs for approximately sixteen hours on the design days. The primary single-pass heat pump is a generic heat pump, based on the R-134 refrigerant operating cycle, with minimum output capacity as determined above.

In the standard design, the recirculation loop is decoupled from the primary system. The secondary heater and tank are connected to the primary system in series and both the primary tank outlet and hot water circulation return are connected to the bottom of the secondary tank.

The secondary tank is an electric resistance water heater with output heating capacity calculated as follows:

Output Capacity (watts) = 1.75 * 100 * Number of Dwelling Units

The secondary tank storage volume is determined by the following:

Tank Volume (gallons) = 80 if Number of Dwelling Units < 48

Tank Volume (gallons = 120 if Number of Dwelling Units > 48

Both the primary and secondary storage tanks have insulation R-values of 16 (°F ft^2 hr/BTU)

The locations for the standard design storage tanks and heat pumps are the same as the proposed design.

The temperature setpoints are:

Primary single-pass HPWH: 135 °F
Secondary water heater: 125 °F

Thermostatic mixing valve outlet: 125 °F. If the proposed central water heating device uses gas or propane as the fuel source, the standard design uses natural gas-fired or propane commercial packaged boiler. In Climate 1 through 9, if the total installed water heating input capacity is 1 MMBtu/hr or greater, the standard design gas water-heating equipment thermal efficiency is 90 percent.

The appropriate efficiencies and standby losses for each standard water-heating device are then assigned to match the minimum federal requirements. The standards for consumer water heaters, as defined by 42 U.S.C 6291(16), are specified in 10 CFR 430.32(d); the standards for commercial water heaters, as defined by 42 U.S.C 6291(16), are specified in 10 CFR 431.110.

Recirculating system. If the central water-heating system has recirculation loops, the standard design includes a recirculation system with no controls and one recirculation loop.

Master Mixing Valve

Thermostatic master mixing valve is the standard design used for central water heating systems. A correction factor is used to adjust the energy usage simulated based on the system characteristics. A 1.0 correction factor represents no energy credit or penalty, while correction factors greater than 1.0 result in increased energy usage penalties for the system. Table 48: Heat Pump Water Heater System Correction Factor, Table 49: Gas-Fired Water Heater System Correction Factor. This factor is dependent on the heating plant characteristics based on the heating source, heater and storage tank configuration, and heating plant hot water outlet and recirculation return temperature. The correction factor is also dependent on whether a mechanical master mixing valve, digital master mixing valve or no master mixing valve is specified. The standard design assumes a mechanical master mixing valve with a correction factor of 1.0.

Table 48: Heat Pump Water Heater System Correction Factor

Heat Pump Water Heater Systems	Digital Master Mixing Valve	Mechanical Master Mixing Valve	No Master Mixing Valve
Multi-Pass Integrate HPWH 1 °F < ∆T(Outlet Return) < 7 °F	1	1	1.15
Multi-Pass Integrated HPWH 7 °F < ∆T	1	1	1.12
Single-Pass Primary HP with Recirculation Return to Primary Tank 1 °F < ∆T < 7 °F	0.96	1	1.14
Single-Pass Primary HP with Recirculation Return to Primary Tank 7 °F < ∆T	1	1	1.09
Multi-Pass Primary HP with Recirculation Return to Primary Tank 1 °F < ∆T < 7 °F	0.96	1	1.15
Multi-Pass Primary HP with Recirculation Return to Primary Tank 7 °F < ∆T	0.98	1	1.12
Single-Pass Primary HP with Recirculation Return to Series Electric Resistance Water Heater 1 °F < ∆T < 7 °F	0.96	1	1.08
Single-Pass Primary HP with Recirculation Return to Series Electric Resistance Water Heater 7 °F < ∆T	0.99	1	1.05
Single-Pass Primary HP with Recirculation Return to Secondary Parallel HPWH 1 °F < ∆T < 7 °F	0.96	1	1.10

Single-Pass Primary HP with Recirculation Return to Secondary Parallel HPWH 7 °F < ∆T	0.96	1	1.10

Table 49: Gas-Fired Water Heater System Correction Factor

Heat Pump Water Heater Systems	Digital Master Mixing Valve	Mechanical Master Mixing Valve	No Master Mixing Valve
Integrated Gas Atmospheric Water Heater	1	1	1.03
Integrated Gas Condensing Water Heater	1	1	1.03
Multi-Pass Primary Gas Atmospheric Water Heater with Recirculation Return to Primary Tank	1	1	1.03
Multi-Pass Primary Gas Condensing Water Heater with Recirculation Return to Primary Tank	1	1	1.03

Solar thermal water-heating system. If the proposed system uses gas or propane water heater, the standard design has a solar water heating system meeting the installation criteria specified in *Reference Residential Appendix RA4* and with a minimum solar savings fraction of 0.20 in Climate Zones 1-9, or 0.35 in Climate Zones 10-16. If a drain water heat recovery system is installed, These solar savings fractions are reduced to 0.15 in Climate Zones 1-9 or 0.30 in Climate Zones 10-16.

Verification and Reporting

All modeled features and the number of devices modeled for the water heating system are reported on the Certificate of Compliance. Electric resistance and heat pump water heaters indicate the location of the water heater. NEEA-rated heat pumps are identified by the brand and model, which must be verified by the building inspector.

Where water heating system features or distribution systems specify or require ECC verification, those features are listed in the ECC required verification listings on the Certificate of Compliance.

6.11.5 Solar Thermal Water Heating Credit

When a water heating system has a solar thermal system to provide part of the water heating, the user enters information about the Solar Rating and Certification Corporation approved collector (manufacturer, brand, model number), including details of the installation (azimuth, tilt).

Alternatively, the solar fraction (SF) is determined using the CEC Solar Water Heating Calculator, or approved method showing minimum energy equivalency, OG-100 calculation method, or the certified OG-300 rating. The calculation method requires that the user specify the climate zone and conditioned floor area, in addition to published data for the solar thermal water heating system.

6.11.6 JA13 Basic Control Credit

The Reference Appendices, Joint Appendix JA13 HPWH Basic Control Credit provides compliance credit for systems that provide daily load shifting for the purpose of bill reductions, maximization of solar self-utilization, and grid harmonization. The Basic Control Credits are based on CBECC modeling of typical HPWHs, where the control turns the water heater on and off at optimal times for maximum LSC benefits without exceeding the user set point temperature. Variation by climate zone is dependent on LSC values and climate conditions such as ambient air and ground water temperatures in each climate zone.

Any HPWH compliant with Reference Appendices, Joint Appendix JA13 will receive an LSC percentage credit which is climate zone specific as specified in Table 50: JA13 HPWH Basic Control Credit. The LSC percentage reduction is applied to the Proposed Design water heating annual LSC budget which is part of the efficiency LSC, upon the completion of the compliance simulation run.

Table 50: JA13 HPWH Basic Control Credit

Climate Zone	JA13 Basic Control Credit (%)
1	6.7
2	3.7
3	7.6
4	4.0
5	8.5
6	6.8
7	8.8
8	4.4

9	4.4
10	4.4
11	4.2
12	4.7
13	8.0
14	3.1
15	8.2
16	2.7

6.12Additions/Alterations

Addition and alteration compliance is based on Energy Code, Section 180.0, Section 180.1, Section 180.2, and Section 180.3. The energy budget for additions and alterations is based on LSC energy. Alterations must model the entire dwelling unit. Additions may be modeled as addition alone, alteration alone, or as "ExistingAdditionAndAlteration".

The standard design and tradeoffs are not included for the following features:

- Cool roof when an addition is 300 ft^2 or less.
- Ventilation cooling for additions that are 1,000 ft^2 or less.
- Solar generation/PV requirements.

6.12.1 Whole Building

The entire proposed building, including all additions or alterations or both, is modeled the same as a newly constructed building. The building complies if the proposed design uses equal to or less energy than the standard design.

6.12.2 Alteration-Alone Approach

The proposed alteration alone floor area is modeled. The alteration requirements of Section 180.2 are applied to any new features.

6.12.3 Addition-Alone Approach

The proposed addition alone is modeled the same as a newly constructed building except that the internal gains are prorated based on the size of the dwelling. None of the exceptions included for prescriptive additions, which are implemented in the existing plus addition plus alteration compliance approach (Chapter 6.12.4 Existing+ Addition Alteration Approach), are given to the addition alone approach. (See Energy Code, Section 180.1(b)2.) The addition complies if the proposed design LSC energy consumption is less than the standard design energy budget. Additions are not required to meet a source energy budget.

The addition-alone approach shall not be used when alterations to the existing building are proposed. Modifications to any surfaces between the existing building and the addition are part of the addition and are not considered alterations.

Proposed Design

The user shall indicate that an addition alone is being modeled and enter the conditioned floor area of the addition. Any surfaces that are between the existing building and the addition are not modeled or are treated as adiabatic surfaces. All other features of the addition shall be modeled the same as a newly constructed building.

When an existing HVAC system is extended to serve the addition, the standard design shall assume the same efficiency for the HVAC equipment as the proposed design. (See Chapter 6.8.1 Heating Subsystems and Chapter 6.8.2 Cooling Subsystems.)

When a dual-glazed greenhouse or garden window is installed in an addition or alteration, the proposed design U-factor can be assumed to be 0.30.

Standard Design

The addition alone is modeled the same as a newly constructed building, with the following exceptions:

- When roofing requirements are included in Table 170.2-A, they are included in the standard design if the added conditioned floor area is greater than 300 ft^2.
- When compliance with IAQ requirements of Section 160.2 apply to an addition with greater than 1,000 ft^2 added, the conditioned floor area of the entire dwelling unit shall be used to determine the required ventilation airflow. For additions with 1,000 ft^2 or less of added conditioned floor area, no IAQ requirements apply.
- PV requirements are not included.
- For dwelling units with water heaters serving individual dwelling units, the standard design DHW system is a heat pump water heater with a 2.0 UEF. In climate zone 3, 4, 13 and 14, if the proposed design is gas, the standard design DHW system is a natural gas tankless (or propane if natural gas is not available) water heating system. See Chapter 6.11.3 Individual Dwelling Units for equipment efficiencies and operating details for each type of water heater.

6.12.4 ExistingAdditionAndAlteration Approach

Energy Code Section 180.1 contains the provisions for additions and Section 180.2 for alterations when the existing building is included in the calculations. These provisions are the

"ExistingAdditionAndAlteration" performance approach. The proposed existing + addition + alteration design complies if the LSC energy consumption is less than the standard design energy budget.

PROPOSED DESIGN

The proposed design is modeled by identifying each energy feature as part of the existing building (as existing, altered, or new), or as part of the addition. The compliance software uses this information to create an ExistingAdditionAndAlteration standard design using the rules in the Energy Code that take into account whether altered components meet or exceed the threshold at which they receive a compliance credit and whether any related measures are triggered by altering a given component.

For building surfaces and systems designated below, all compliance software must provide an input field with labels for the proposed design, which define how the standard design requirements are established based on the option selected by the compliance software user:

> Existing: The surface or system remains unchanged within the proposed design. (Both standard design and proposed design have the same features and characteristics.)
> Altered: the surface or system is altered in the proposed design. New: a new surface or system is added in the proposed design (may be in the existing building or the addition).

Deleted features are not included in the proposed design.

Section 180.2, Table 180.2-B specifies the details of the standard design for altered components.

6.12.4.1 QII

STANDARD DESIGN

For multifamily building up to three habitable floors, the standard design includes QII for additions greater than 700 ft^2 in multifamily building in Climate Zones 1-6 and 8-16 (Section 180.1(a)1Bv).

The provisions of Section 180.1(a)1Aiv, as applied to converting an existing unconditioned space to conditioned space, are accommodations made by the ECC rater in the field. No adjustments to the energy budget are made.

6.12.4.2 PV

STANDARD DESIGN

The standard design does not include PV for additions and alterations.

6.12.4.3 Roof/Ceilings

STANDARD DESIGN

The standard design roof/ceiling construction assembly is based on the proposed design assembly type as shown in Table 51: Standard Design for Roofs/Ceilings**.** For additions equal to or less than 700 ft^2, radiant barrier requirements follow Option C (Section 170.2(a)1Bii). The standard design for unaltered ceilings and roofs is the existing condition.

Table 51: Standard Design for Roofs/Ceilings

Proposed Design Roof/Ceiling Types	**Addition < 300 ft^2**	**Addition > 300 ft^2 and < 700 ft**	**Addition > 700 ft^2**	**Altered**
Roof Deck Insulation (below-deck, where required) at vented attic	NR	NR	CZ 4, 8, 9, 11-15 = R-19, CZ 10, 16 = R-13	CZ 4, 8, 9, 11-15 = R-19, CZ 10, 16 = R-13
Ceilings Below Attic	CZ 1, 2, 8-16 = R-38 CZ 3, 5-7 = R-30	CZ 1, 2, 4, 8-16 = R-38 CZ 3, 5-7 = R-30	CZ 1, 2, 4, 8-16 = R-38 CZ 3, 5-7 = R-30	CZ 5-7 = R-19 CZ 1-4, 8-16 = R-49
Non-Attic (Cathedral) Ceilings and Roofs	R-22/U-0.043	R-22/U-0.043	Same as above	R-19/U-0.054
Radiant Barrier	CZ 2-15 REQ CZ 1, 16 NR	CZ 2-15 REQ CZ 1, 16 NR	CZ 2, 3, 5-7 REQ CZ 1, 4, 8-16 NR	NR
Roofing Surface (Cool Roof) Steep-Sloped	NR	CZ 10-15 =0.20 Reflectance, =0.75 Emittance	CZ 10-15 =0.20 Reflectance, =0.75 Emittance	CZ 4, 8-15 =0.20 Reflectance =0.75 Emittance
Roofing Surface (Cool Roof) Low Slope	NR	CZ 13, 15 = 0.63 Reflectance, =0.75 Emittance	CZ 13, 15 = 0.63 Reflectance, =0.75 Emittance	CZ 4, 6-15 =0.63 Reflectance =0.75 Emittance
Above Deck Insulation, Low-Sloped	NR	NR	NR	CZ 1, 2, 4, 8-16 R-14 continuous

Source: California Energy Commission

6.12.4.4 Exterior Walls and Doors

The compliance software allows the user to indicate whether a new wall in an addition is an extension of an existing wood-framed wall and, if so, the dimensions of the existing wall. The standard design exterior wall construction assembly is based on a wood-framed wall with R-15 cavity insulation for existing 2x4 walls or R-21 cavity insulation for existing 2x6 walls.

The compliance software allows the user to indicate if a wall is existing, where siding is not removed or replaced. The user also identifies if the walls have 2x4 or 2x6 framing. The standard design exterior wall construction assembly is based on a wood-framed wall with R-15 cavity insulation for existing 2x4 walls or R-21 cavity insulation for existing 2x6 walls.

Proposed Design

Existing structures with insulated wood-framed walls that are being converted to conditioned space using an E+A+A approach are allowed to show compliance using the existing wall framing, without having to upgrade to current prescriptive continuous insulation requirements. The walls are modeled as an assembly with the existing framing and either R-15 (in 2x4 framing) or R-21 (in 2x6 framing) insulation (Exception to Section 160.1(b) and Section 180.1(a)1).

Standard Design

The areas, orientation, and tilt of existing, new, and altered net exterior wall areas (with windows and doors subtracted) are the same in the existing and addition portions of standard design as in the proposed design.

The gross exterior wall areas (wall area without subtracting window area) and orientations of the standard design match the proposed design.

The standard design exterior wall construction assembly is based on the proposed design assembly type as shown in Table 52: Addition Standard Design for Walls and Doors are modeled as 16-in. on center wood framing. The standard design for unaltered walls is the existing condition.

The standard design for exterior opaque or swinging doors is 0.20 U-factor. Fire-rated doors (from the house to garage) use the proposed design door U-factor as the standard design U-factor.

Table 52: Addition Standard Design for Walls and Doors

Proposed Design Exterior Wall Assembly Type or Door	Addition	Altered
Framed & Non-Mass Exterior Walls (≤1hr fire rating)	CZ 1-5, 8-16 = R-21+R-4 in 2x6 (U-0.051) CZ 6-7 = R-15+R-4 in 2x4 (U-0.065)	R-13 in 2x4 R-20 in 2x6
Framed & Non-Mass Exterior Walls (>1hr fire rating)	CZ 1-5, 8-10, 12, 13 = (U-0.059) CZ 6, 7 = (U-0.065) CZ 11, 14-16 = (U-0.051)	R-13 in 2x4 R-20 in 2x6

Proposed Design Exterior Wall Assembly Type or Door	Addition	Altered
Wood Framed Existing Walls where Siding is not Removed Extension of an Existing Wall	R-15 in 2x4 R-21 in 2x6	R-13 in 2x4 R-20 in 2x6
Framed Wall Separating Conditioned and Unconditioned Space (e.g., Demising or Garage Wall)	R-15 in 2x4 R-21 in 2x6	R-13 in 2x4 R-20 in 2x6
Above Grade Mass Interior Insulated	CZ 1-15 = R-13 (0.077) CZ 16 = R-17 (0.059)	N/R Mandatory requirements have no insulation for mass walls
Below Grade Mass Interior Insulation	CZ 1-15 = R-13 CZ 16 = R-15	N/R Mandatory requirements have no insulation for mass walls
Swinging Doors	0.20	0.20

Source: California Energy Commission

6.12.4.5 Fenestration

PROPOSED DESIGN

Fenestration areas are modeled in the addition as new. In an existing building, they may be existing, altered, or new. Altered (replacement) fenestration is defined in Section 180.2(b)1.C as "existing fenestration area in an existing wall or roof [which is] replaced with a new manufactured fenestration product. Up to the total fenestration area removed in the existing wall or roof...." Altered also includes fenestration installed in the same existing wall, even if in a different location on that wall. Added fenestration area in an existing wall or roof is fenestration that did not previously exist and is modeled as new.

STANDARD DESIGN

Standard design fenestration U-factor and SHGC are based on the values shown in Table 53: Standard Design for Fenestration (in Walls and Roofs). Vertical glazing includes all fenestration in exterior walls such as windows, clerestories, and glazed doors. Skylights include all glazed openings in roofs and ceilings.

New fenestration in an alteration is modeled with the same U-factor and SHGC as required for an addition.

West-facing limitations are combined with the maximum fenestration allowed and are not an additional allowance.

The standard design is set for fenestration areas and orientations as shown in Table 53: Standard Design for Fenestration (in Walls and Roofs):

Proposed design < allowed percentage of total fenestration area:

In the existing building, the standard design uses the same area and orientation of each existing or altered fenestration area (in the respective existing or altered wall or roof.)

In an addition, the standard design uses the same area and orientation of new fenestration up to the allowed fenestration.

Proposed design > allowed percentage of total fenestration area:

The standard design first calculates the allowed total fenestration area as the total existing and altered fenestration area in existing or altered walls and roofs. Added to this is the percent of fenestration allowed in the addition, based on the conditioned floor area of the addition.

Table 53: Standard Design for Fenestration (in Walls and Roofs)

Proposed Design Fenestration Type	**Addition < 400 ft^2**	**Addition > 400 and < 700 ft^2**	**Addition > 700 ft^2**	**Altered**
Vertical Glazing: Area and Orientation	75 ft^2 or 30%	Min of 20% WWR or 40% WFR	Min of 20% WWR or 40% WFR	Min of 20% WWR or 40% WFR
West Facing Maximum Allowed	CZ 2, 4, 6 - 15=60 ft^2	CZ 2, 4, 6 - 15=60 ft^2	CZ 2, 4, 6 - 15=70 ft^2 or 5%	NR
Vertical Glazing: U-Factor	CZ 1, 3-5,11, 13-16 = 0.28 CZ 2, 6, 8-10, 12 = 0.30 CZ7 = 0.34	CZ 1, 3-5,11, 13-16 = 0.28 CZ 2, 6, 8-10, 12 = 0.30 CZ7 = 0.34	CZ 1, 3-5,11, 13-16 = 0.28 CZ 2, 6, 8-10, 12 = 0.30 CZ7 = 0.34	CZ 1, 3-5,11, 13-16 = 0.28 CZ 2, 6, 8-10, 12 = 0.30 CZ7 = 0.34
Vertical Glazing: SHGC	CZ 1, 3, 5, 16 = NR CZ 2, 4, 6-15 = 0.23	CZ 1, 3, 5, 16 = NR CZ 2, 4, 6-15 = 0.23	CZ 1, 3, 5, 16 = NR CZ 2, 4, 6-15 = 0.23	CZ 1, 3, 5, 16 = NR CZ 2, 4, 6-15 = 0.23
Skylight: Area and Orientation	5%	5%	5%	5%

Proposed Design Fenestration Type	Addition < 400 ft²	Addition > 400 and < 700 ft²	Addition > 700 ft²	Altered
Skylight: U-Factor	0.30	0.30	0.30	0.55
Skylight: SHGC	CZ 2, 4, 6 -15=0.25 CZ 1,3 5 & 16=0.35	CZ 2, 4, 6 -15=0.25 CZ 1,3 5 & 16=0.35	CZ 2, 4, 6 -15=0.23 CZ 1,3 5 & 16=0.35	CZ 2, 4, 6 -15=0.25 CZ 1,3 5 & 16=0.35

Source: California Energy Commission

6.12.4.6 Overhangs, Sidefins and Other Exterior Shading

STANDARD DESIGN

The standard design for a proposed building with overhangs, sidefins, and exterior shades is shown in Table 54: Standard Design for Overhangs, Sidefins, and Other Exterior Shading Exterior shading (limited to bug screens) is treated differently than fixed overhangs and sidefins, as explained in Chapter 6.9.7 Exterior Shading.

Table 54: Standard Design for Overhangs, Sidefins, and Other Exterior Shading

Proposed Design Shading Type	Addition	Altered
Overhangs and Sidefins	No overhangs or sidefins	Proposed altered condition
Exterior Shading	Standard (bug screens on fenestration, none on skylights)	Proposed altered condition
Window Film	No window film	Proposed altered condition

Source: California Energy Commission

6.12.4.7 Window Film

PROPOSED DESIGN

A window film must have at least a 15-year warranty and is treated as a window replacement. The values modeled are either the default values from Tables 110.6-A and 110.6-B or the NFRC Window Film Energy Performance Label.

6.12.4.8 Floors

STANDARD DESIGN

The standard design for floors is shown in Table 55: Standard Design for Floors.

Table 55: Standard Design for Floors

Proposed Design Floor Type	Addition	Altered (mandatory)
Raised Floor Over Crawl Space or Over Exterior	R-19 in 2x6 16” o.c. wood framing	R-19 in 2x6 16” o.c. wood framing
Slab-on-Grade: Unheated	CZ1-15: R-0 CZ16: R-7 16” vertical	R-0
Slab-on-Grade: Heated	CZ1-15: R-5 16” vertical CZ 16: R-10 16” vertical	CZ1-15: R-5 16” vertical CZ 16: R-10 16” vertical
Raised Concrete Slab	CZ1,2,11,13,14,16: R-8 CZ3-10: R-0 CZ12,15: R-4	R-0

Source: California Energy Commission

6.12.4.9 Thermal Mass

STANDARD DESIGN

The standard design for thermal mass in existing plus addition plus alteration calculations is the same as for all newly constructed buildings as explained in Chapter 6.9.5 Internal Thermal Mass.

6.12.4.10 Air Leakage and Infiltration

STANDARD DESIGN

Standard design air leakage and infiltration is shown in Table 56: Standard Design for Air Leakage and Infiltration.

Table 56: Standard Design for Air Leakage and Infiltration

Proposed Air Leakage and Infiltration	Addition	Altered
Multifamily Buildings	7 ACH50	7 ACH50

Source: California Energy Commission

6.12.4.11 Space Conditioning System

PROPOSED DESIGN

STANDARD DESIGN

The standard design for space-conditioning systems is shown in Table 57: Standard Design for Space Conditioning Systems.

Table 57: Standard Design for Space Conditioning Systems

Proposed Design Space-Conditioning System Type	Addition	Altered
Heating System	Same as newly constructed.	For common areas, same as newly constructed. For dwelling units, proposed heating fuel type and equipment type/efficiency. If the existing equipment is electric resistance and none of the exceptions in Section 180.2(b)2Av are met, the Standard Design system shall be a heat pump meeting the same requirements as newly constructed.
Cooling System	Same as newly constructed.	Same as newly constructed.
Refrigerant Charge	CZ 2, 8-15: Yes CZ 1, 3-7: No	Same as Addition

Source: California Energy Commission

6.12.4.12 Duct System

PROPOSED DESIGN

Duct insulation shall be based on the new or replacement R-value input by the user. Duct leakage shall be based on the tested duct leakage rate entered by the user or a default rate of 30 percent.

STANDARD DESIGN

Table 58: Standard Design for Duct Systems

Proposed Design Duct System Type	Standard Design
Altered or Extended Ducts serving existing space	CZ 1-2, 4, 8-16: Duct insulation R-8 and duct leakage of 15% CZ 3, 5-7: Duct insulation R-6 and duct leakage of 15%
New Ducts	CZ 1-2, 4, 8-16: Duct insulation R-8 and duct leakage of 12% CZ 3, 5-7: Duct insulation R-6 and duct leakage of 12%

Based on Table 180.2-C

Note 1: Refer to Section 180.2(b)2Aii for definition of an "Entirely New or Complete Replacement Duct System."

Source: California Energy Commission

6.12.4.13 Indoor Air Quality & Local Mechanical Ventilation

Indoor Air Quality (IAQ) requirements apply to an addition when either adding an entirely new dwelling unit that is not considered a Junior Accessory dwelling unit (JADU) or constructing an addition to an existing dwelling unit greater than 1,000 ft^2. When an addition to a dwelling unit with greater than 1,000 ft^2 of added conditioned floor area, the conditioned floor area of the entire dwelling unit is used to determine the required ventilation airflow. For additions with 1,000 ft^2 or less of added conditioned floor area, no IAQ requirements shall apply.

Alterations of IAQ systems include new or complete replacements of an existing system and component alterations only. An example of an IAQ system component is a fan serving an HRV system.

Dwelling unit air leakage test is not required for IAQ alterations or additions.

PROPOSED DESIGN

IAQ system type and specifications identified by the user or a default system based on the standard design for the system type. Identification of new or replacement kitchen ventilation system to identify compliance with local mechanical exhaust requirements.

STANDARD DESIGN

IAQ ventilation requirements for additions and alterations are the same as for newly constructed buildings for supply and balanced IAQ system types. Altered IAQ systems, both complete replacement and altered components, can install an exhaust-only ventilation system if the existing system is exhaust-only.

Local kitchen mechanical exhaust requirements, when triggered by the user as part of the addition or alteration, are the same as newly constructed building requirements.

6.12.4.14 Water Heating System

STANDARD DESIGN

Table 59: Standard Design for Water Heater Systems

Proposed Design Water Heating System Type	Addition (adding water heater)	Altered
Multifamily Individual Water Heater for Each Dwelling Unit	Prescriptive water heating system for each dwelling unit (see Chapter 6.11 Domestic Hot Water)	Same as proposed fuel type, proposed tank type, mandatory requirements (excluding any solar)
Multifamily Central Water Heating System	Central water heating system (see Chapter 6.11 Domestic Hot Water)	Mandatory requirements of Section 110.3 only. Standard design system same as proposed design.

Source: California Energy Commission

6.13Documentation

The compliance software shall be capable of displaying and printing an output of the energy use summary and a text file of the building features. These are the same features as shown on the Certificate of Compliance when generated using the report manager.

See public domain software user guide or vendor software guide for detailed modeling rules.

APPENDIX A – SPECIAL FEATURES

Measure, CF1R Documentation Requirement

General

Battery System kWh, Special feature

Community Solar: kWdc of [utility and project name], Special feature

Controlled-Ventilation Crawlspace (CVC), Not yet implemented

PV System kWdc, Special feature

PV module type: Premium, Special feature

PV module type: Thin Film, Special feature

PV array type: Tracking (one axis), Special feature

PV array type: Tracking (two axis), Special feature

PV power electronics: Microinverters, Special feature

PV power electronics: DC power optimizers, Special feature

PV exception 1: Effective solar access < 80 ft2, Special feature

PV exception 2: Smaller of solar access and home area-based size (CZ 15 only), Special feature

PV exception 3: 2 habitable stories, Special feature

PV exception 4: 3 habitable stories, Special feature

PV exception 5: 80-200 ft2 solar ready zone approved before 1/1/20, Special feature

PV exception 6: AB 178 Declared emergency area, Special feature

Self-utilization credit, Special feature

Zonal heating controls, Special feature

Envelope

Insulation above roof deck, Special feature

Advanced wall framing (see opaque surface constructions), Special feature

Insulation below roof deck, Special feature

Building air leakage/reduced infiltration, Energy Code Compliance (ECC) verification of reported ACH50 value

Ceiling has high level of insulation, Special feature

Cool roof, Special feature

Dynamic glazing, Not yet implemented

Exterior shading device, Not yet implemented

Exposed slab floor in conditioned zone, Special feature

Metal-framed assembly, Special feature

Window overhangs and sidefins, Special feature

Quality insulation installation (QII), ECC verification

High R-value Spray Foam Insulation, ECC verification

Raised heel truss (height above top plate), Special feature

Structurally insulated panel (SIP) assembly, Special feature

Mechanical

Fan Efficacy Watts/CFM, ECC verification

Minimum Airflow, ECC verification

Central fan ventilation cooling, fixed speed, ECC verification

Central fan ventilation cooling, variable speed, ECC verification

Verified EER, ECC verification

Evaporatively-cooled condenser, ECC verification

Evaporative cooling, indirect, indirect/direct, Not yet implemented

Verified heat pump rated heating capacity, ECC verification

Verified HSPF, ECC verification

Verified SEER, ECC verification

Indoor air quality mechanical ventilation, ECC verification

Indoor air quality, balanced fan, Special feature

Kitchen range hood, ECC verificationNo cooling system installed, Special feature

Pre-cooling credit, Special feature

Verified Refrigerant Charge), ECC verification

Refrigerant charge verification required if a refrigerant containing component is altered, ECC verification

Whole house fan airflow and fan efficacy, ECC verification

Whole house fan, Special feature

Ducts

Duct design specifies buried duct, ECC verification

Bypass duct conditions in zonal system(s), ECC verification

Duct design specifies deeply buried duct, ECC verification

Duct leakage testing, ECC verification

Ducts located entirely in conditioned space confirmed by duct leakage testing, ECC verification

Ducts in crawl space, Special feature

Duct sealing required if a duct system component, plenum, or air handling unit is altered, ECC verification

Ducts with high level of insulation, Special feature

Low leakage air handling unit, ECC verification

Verified low leakage ducts in conditioned space must meet maximum 25 cfm leakage to outside (RA3.1.4.3.8), ECC verification

New ductwork added is less than 40 ft. in length, Special feature

Non-standard duct leakage target, ECC verification

Non-standard duct location (any location other than attic), Special feature

Verified duct design (RA3.1.4.1.1), ECC verification

Water Heating

Compact distribution system basic credit, Special feature

Compact distribution system expanded credit, ECC verification

Drain water heat recovery system, ECC verification

Multifamily: Drain water heat recovery system, ECC verification

Multifamily: Recirculating demand control, Special feature

Multifamily: No loops or recirc pump, Special feature

Multifamily: Recirculating with no control (continuous pumping), Special feature

Multifamily: Recirculating with temperature modulation, Special feature

Multifamily: Recirculating with temperature modulation and monitoring, Special feature

Solar water heating credit, Multi-family, Special feature

Central parallel piping, Special feature

Central parallel piping, ECC verification

Pipe Insulation, All Lines, ECC verification

Point of use, Special feature

Recirculating with demand control, occupancy/ motion sensor, Special feature

Recirculation, demand control occupancy/motion, ECC verification

Recirculating with demand control, push button, Special feature

Recirculation, demand control push button, ECC verification

Recirculating with non-demand control (continuous pumping), Special feature

Solar water heating credit, single family, Special feature

Northwest Energy Efficiency Alliance (NEEA) rated heat pump water heater; specific brand/model, or equivalent, must be installed, Special feature

Additions/Alterations

Verified existing conditions, ECC verification

APPENDIX B: Water Heating Calculation Method

B1. Purpose and Scope

This appendix documents the methods and assumptions used for calculating the hourly energy use for residential water heating systems for the proposed design and the standard design. The hourly fuel and electricity energy use for water heating will be combined with hourly space heating and cooling energy use to come up with the hourly total fuel and electricity energy use to be factored by the hourly long-term system cost (LSC) factor. The calculation procedure applies to low-rise single-family, low-rise multifamily, and high-rise residential.

Calculations are described below for gas and electric water heaters. The internal water heater modeling is performed within the California Simulation Engine (CSE). The compliance modeling rules documented here are implemented in the (California Building Energy Code Compliance) CBECC-Res ruleset and determine the input values passed to CSE.

When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

The following diagrams illustrate the domestic hot water (DHW) system distribution types that shall be recognized by the compliance software.

Table B-1: Distribution Systems Within a Dwelling Unit with One or More Water Heaters

Option #	Description
1	One distribution system with one or multiple water heaters serving a single dwelling unit. The system might include recirculation loops within the dwelling unit.
2	Two water heaters with independent distribution systems serving a single dwelling unit. One or more of the distribution systems may include a recirculation loop within the dwelling unit.

Option #	Description
3	One distribution system without recirculation loop and with one or multiple water heaters serving multiple dwelling units.
4	One distribution system with one or multiple recirculation loops and with one or multiple water heaters serving multiple dwelling units.

Source: California Energy Commission

B2. Water Heating Systems

Water heating distribution systems may serve more than one dwelling unit and may have more than one water heater and more than one water heating system. The energy used by a water heating system is calculated as the sum of the energy used by each water heater in the system. Energy used for the whole building is calculated as the sum of the energy used by each of the water heating systems. To calculate the energy used by each water heater and water heating system, the following variables are used.

CFA — Conditioned floor area, ft^2, of the building.

NFloor — Number of floors in the building

Nunit — Number of dwelling units in the building

NK — Number of water heating systems in the building

NWH_k — Number of water heaters in the k^{th} system

$NLoop_k$ — Number of recirculation loops in the k^{th} system (multiunit dwellings only)

CFA_i — Conditioned floor area of the i^{th} dwelling unit, ft^2

$CFAU_k$ — Average dwelling unit conditioned floor area served by kth system, ft^2

NL_k — number of unfired- or indirectly fired storage tanks in the k^{th} system

B3. Hot Water Consumption

The schedule of hot water use that drives energy calculations is derived from measured data as described in Appendix F (Kruis, 2019). That analysis produced 365 day sets of fixture water draw events for dwelling units having a range of number of bedrooms. The draws are defined in the file DHWDU.TXT (for single-family) that installs with CBECC-Res. Each draw is characterized by a start time, duration, flow rate, and end use. The flow rates given are the total flow at the point of use (fixture or appliance). This detailed representation allows derivation of draw patterns at 1-minute intervals as is required for realistic simulation of heat pump water heaters.

The fixture flow events are converted to water heater (hot water) draws by (1) accounting for mixing at the point of use and (2) accounting for waste and distribution heat losses:

$$VSk - VDk\ x \int dur\ x\ VQk\ x \int hot\mathrm{V} \quad \text{Equation 1}$$

Where

VS_k =	Hot water draw at the k[th] water heating system's delivery point (gal)
VD_k =	Mixed water draw duration at an appliance or fixture (min) served by the k[th] water heating system, as specified by input schedule
VQ_k =	Mixed water flow at an appliance or fixture (gpm) served by the k[th] water heating system, as specified by input schedule
f_{hot}, f_{dur}, f_q =	End-use-specific factors from the following:

Shower/bath

f_{hot}	$\frac{105-T_{inlet}}{T_s-T_{inlet}}$
f_{dur}	$WF_k \times DLM_k$

Faucet

f_{hot}	0.50
f_{dur}	1

Clothes washer

f_{hot}	0.22
f_{dur}	1

Dish washer

f_{hot}	1
f_{dur}	1

T_s =	Hot water supply temperature (ºF); assumed to be 115°F
T_{inlet} =	Cold water inlet temperature (°F) as defined in Section B1.2. Note that T_{inlet} may be tempered by drain water heat recovery (DWHR).
WF_k =	Hot water waste factor

- WF_k = 0.9 for within-dwelling-unit pumped circulation systems (see Table B-2)
- WF_k = 1.0 otherwise

DLM_k = Distribution loss multiplier (unitless), see *Equation 5*

The individual water heater draws are combined to derive the overall demand for hot water.

For each hour of the simulation, all water heater draws are allocated to 1-minute bins using the starting time and duration of each draw. This yields a set of 60 $VS_{k,t}$ values for each hour that is used as input to the detailed heat pump water heater (HPWH) and instantaneous water heater models in later sections. For hourly efficiency-based models used for some water heater types, the minute-by-minute values are summed to give an hourly hot water requirement:

$$GPH_k = \sum_{t=1}^{60} VS_{k,t} \qquad \text{Equation 2}$$

In cases where multiple dwelling units are served by a common water heating system, the dwelling unit draws are summed.

In cases where there are multiple water heating systems within a dwelling unit, the draws are divided equally among the systems. For minute-by-minute draws, this allocation is accomplished by assigning draws to systems in rotation within each end use weighted by the number of fixtures of each type are served by each system. This assignment ensures that some peak draw events within each end use get assigned to each system. Since heat pump water heater performance is nonlinear with load (due to activation of resistance backup), allocation of entire events to systems is essential. The assignment scheme allocates draws by end use as opposed to specific draws to specific systems. Explicit draw assignment would require plumbing layout information — capturing that is deemed to impose an unacceptable user input burden.

B4. Hourly Adjusted Recovery Load

The hourly adjusted recovery load for the kth water heating system is calculated as:

$$HARL_k = HSEU_k + HRDL_k + \sum_{1}^{NL_k} HJL_l + HPPL_k \qquad \text{Equation 3}$$

Where

$HSEU_k$ = Hourly standard end use at all use points (Btu), see Equation 4

HRDLk = Hourly recirculation distribution loss (Btu), see Equation 14

15; $HRDL_k$ is nonzero only for multifamily central water heating systems

NL_k = Number of unfired or indirectly fired storage tanks in the k^{th} system

HJL_l = Tank surface losses of the l^{th} unfired tank of the k^{th} system (Btu), see Equation 41

$HPPL_k$= Hourly water heating plant pipe heat loss (Btu), see Equation 45

Equation 4 calculates the hourly standard end use (HSEU). The heat content of the water delivered at the fixture is the draw volume in gallons (GPH) times the temperature rise DT (difference between the cold water inlet temperature and the hot water supply temperature) times the heat required to elevate a gallon of water 1°F (the 8.345 constant).

$$\boldsymbol{HSEU_k = 8.345 \times GPH_k \times (T_s - T_{inlet})}$$ *Equation 4*

Where

$HSEU_k$ = Hourly standard end use (Btu)

GPH_k = Hourly hot water consumption (gallons) from *Equation 2*

Equation 5 calculates the distribution loss multiplier (DLM), which combines the standard distribution loss multiplier (SDLM), which depends on the floor area of the dwelling unit and the distribution system multiplier (DSM).

$$\boldsymbol{DLM_k = 1 + (SDLM_k - 1) \times DSM_k}$$ *Equation 5*

Where

DLM_k = Distribution loss multiplier (unitless)

$SDLM_k$ = Standard distribution loss multiplier (unitless). See *Equation 6*

DSM_k = Distribution system multiplier (unitless). See Section Distribution Losses Withing the Dwelling Unit. Several relationships depend on CFA_k, the floor area served (see below).

Equation 6 calculates the standard distribution loss multiplier (SDLM) based on dwelling unit floor area. In *Equation 6*, that floor area $CFAU_k$ is capped at 2500 ft^2. Without that limit, *Equation 6* produces unrealistic $SDLM_k$ values for large floor areas.

$$SDLM_k = 1.0032 = 0.0001864 \text{ x } CFAU_k - 0.00000002165 \text{ x } CFAU_k^2$$ *Equation 6*

Where

$SDLM_k$= Standard distribution loss multiplier (unitless).

$CFAU_k$= Dwelling unit conditioned floor area (ft^2) served by the kth system, calculated using methods specified in *Equation 7*.

Single dwelling unit,

$$CFAU_k = CFA/NK$$

For multiple dwelling units served by a central system:

$$CFAU_k = \frac{\sum_{\text{all units served by system k}} CFA_i}{Nunit_k}$$

Alternatively, if the system-to-unit relationships not known:

$$CFAU_k = \frac{\sum_{\text{all units served by any central system}} CFA_i}{\text{Number of units served by any central system}}$$ *Equation 7*

Method WH-CFAU

Note: "Method" designations are invariant tags that facilitate cross-references from comments in implementation code.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater, as shown in *Equation 8.*

$$HARL_j = \frac{HARL_k}{NWH_k} \qquad \text{Equation 8}$$

Where

$HARL_j$ = Hourly adjusted recovery load for the j^{th} water heater of the k^{th} system (Btu)

$HARL_k$ = Hourly adjusted total recovery load for the k^{th} system (Btu)

NWH_k = The number of water heaters in the k^{th} system

Distribution Losses Within the Dwelling Unit

The distribution system multiplier (DSM, unitless) is an adjustment for alternative water heating distribution systems within the dwelling unit. A DSM value of 1.00 will be reached in "standard" distribution systems, defined as a nonrecirculating system, with the full length of distribution piping insulated in accordance with Section 150.0(j)2.

$$DSM_k = ADSM_k \times CF_k \qquad \text{Equation 9}$$

Where

$ADSM_k$ = Assigned Distribution System Multiplier, see below.

CF_k = Compactness factor (unitless), default value is 1.0, calculated according to Section 5.6.2.4 of the *Residential Compliance Manual*.

ADSM values for alternative distribution systems are given in Table B-2. Improved ADSM values are available for cases where voluntary Energy Code Compliance (ECC) inspections are completed, as per the eligibility criteria shown in Reference Residential Appendix RA4.4. Detailed descriptions of all of the distribution system measures are found in Residential Appendix RA 4.4.

Table B-2: Distribution System Multipliers Within a Dwelling Unit With One or More Water Heaters

Distribution System Types	Assigned Distribution System Multiplier (ADSM)	System Types 1 and 2	System Type 3 and 4
No ECC Inspection Required			
Trunk and Branch -Standard (STD)	1.0	Yes	Yes
Central Parallel Piping (PP)	1.10	Yes	
Point of Use (POU)	0.30	Yes	
Recirculation: Nondemand Control Options (R-ND)	9.80*	Yes	
Recirculation with Manual Demand Control (R-DRmc)	1.75*	Yes	
Recirculation with Motion Sensor Demand Control (R-DRsc)	2.60*	Yes	
Optional Cases: ECC Inspection Required			
Pipe Insulation (PIC-H)	0.85	Yes	Yes
Central Parallel Piping with 5' maximum length (PP-H)	1.00	Yes	
Compact Design (CHWDS-H)	0.70	Yes	
Recirculation with Manual Demand Control (R-DRmc-H)	1.60*	Yes	
Recirculation with Motion Sensor Demand Control (RDRsc-H)	2.40*	Yes	

***Recirculation ADSMs reflect the effect of reduced hot water consumption associated with recirculation systems.**

Source: California Energy Commission

Cold Water Inlet Temperature

The water heater inlet temperature is assumed to vary daily and depends on mains water temperature, drain water heat recovery, and solar preheating.

For each day of the year, T_{mains} is calculated as follows:

$$Tmain = Tground\ x\ 0.65 + Tavg31\ x\ 0.035 \qquad \textit{Equation 10}$$

T_{avg31} = Outdoor dry-bulb temperature averaged over all hours of the previous 31 days (for January days, weather data from December will be used.)

T_{ground} = Ground temperature (°F) for current day of year, calculated using: *Equation 11*.

each day (q = 1 TO 365)

$$T_{ground}(\theta) = TyrAve - 0.5 \times (TyrMax - TyrMin) \times COS(2 \times \pi \times ((\theta - 1)/PB) - PO - PHI) \times GM$$

Equation 11

Where

TyrAve	=	average annual temperature, °F
TyrMin	=	the lowest average monthly temperature, °F
TyrMax	=	the highest average monthly temperature, °F
PB	=	365
PO	=	0.6
DIF	=	0.025 ft^2/hr
BETA	=	SQR(p/(DIF*PB*24))*10
XB	=	EXP(-BETA)
CB	=	COS(BETA)
SB	=	SIN(BETA)
GM	=	SQR((XB*XB - 2.*XB*CB + 1)/(2.*BETA*BETA))
PHI	=	ATN((1.-XB*(CB+SB)) / (1.-XB*(CB-SB)))

The water heater inlet temperature, T_{inlet}, is calculated as follows:

$$T_{inlet} = (1 - SSF_k)(T_{mains} + \Delta T_{dwhr}) + SSF_k \times T_s \qquad \textit{Equation 11}$$

Where

SSF_k = Solar savings fraction for k^{th} system (see below), unitless

ΔT_{dwhr} = Water temperature increase due to drain water heat recovery, °F (0 if no DWHR). See Section 0

T_s = Hot water supply temperature

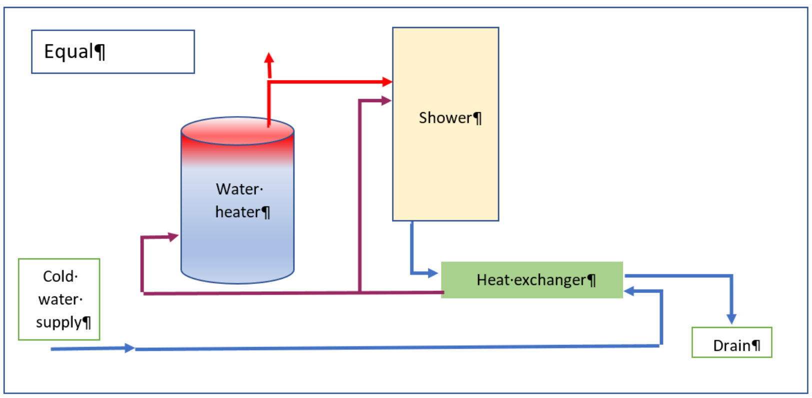
All water heaters in a water heating system are assumed to have the same T_{inlet}.

The hourly solar savings fraction for the k^{th} water heating system, SSF_k, is the fraction of the total water heating load that is provided by solar hot water heating. The annual average value for SSF is provided from the results generated by the California Energy Commission-approved calculations approaches for the OG-100 and OG-300 test procedure. A Commission-approved method shall be used to convert the annual average value for SSF to hourly SSFk values for use in compliance calculations.

Drain Water Heat Recovery

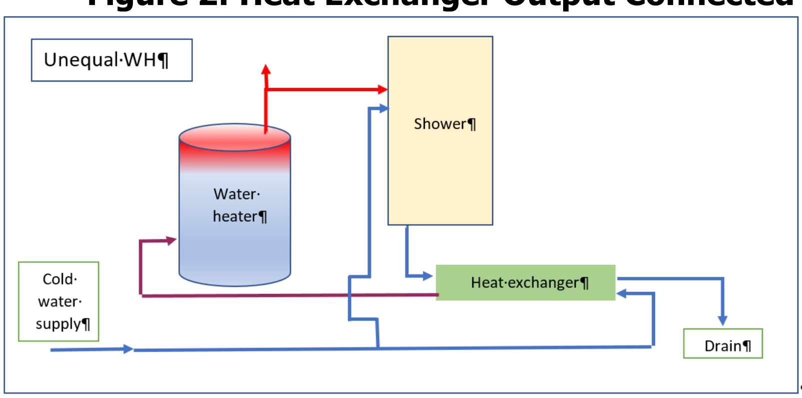
Drain water heat recovery (DWHR) devices are heat exchangers that transfer heat from warm drain water to incoming cold (mains) water. These operate on draws where supply and drain flow are simultaneous — for example, showers (as opposed to dishwashers). In CBECC-Res, only shower draws support DWHR. Several plumbing configurations are possible.

Figure 1: Heat Exchanger Output Connected to Both Shower Water Heater Cold Sides



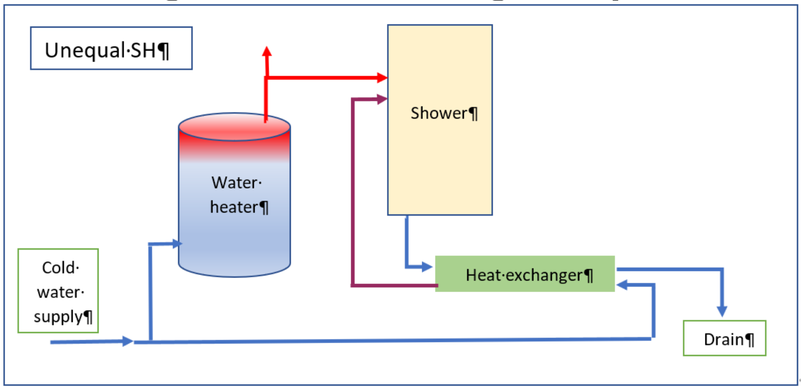
Source: California Energy Commission

Figure 2: Heat Exchanger Output Connected to Water Heater Cold Side



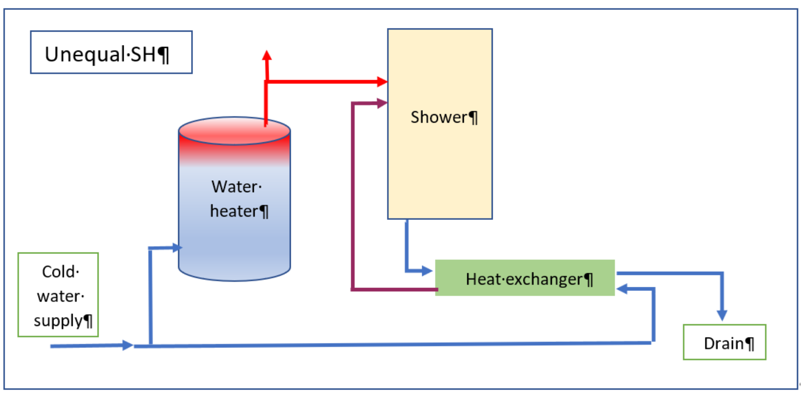
Source: California Energy Commission

Figure 3: Heat Exchanger Output Connected to Shower Cold Side



Source: California Energy Commission

Figure 4: Heat Exchanger Output Connected to Both Shower Water Heater Cold Side



Source: California Energy Commission

In practice, there are many combination plumbing configurations that are possible. For example, only some showers may drain via DWHR devices, or more than one shower may drain via a shared DHWR device. CBECC-Res input structure allows flexible specification of such arrangements.

The drain water heat recovery temperature increase, ΔT_{dwhr}, is modeled within CSE using effectiveness derived using correlations presented in:

- *Drain Water Heat Recovery – Final Report*. Measure Number: 2019-RES-DHW2-F. Available at http://title24stakeholders.com/wp-content/uploads/2017/09/2019-T24-CASE-Report_DWHR_Final_September-2017.pdf
- *Explanation of Drain Water Heat Recovery Calculations*. NegaWatt Consulting. Dec. 13, 2017.

DWHR is supported only for shower draws. Based on experimental data, the effectiveness correlation is function of potable water flow rate, potable water entering temperature, and drain water flow rate, as shown here:

$$
\begin{aligned}
t_{pi} &= \min(t_{mains}, 81) \\
f_t &= \left(-3.06\times10^{-5} t_{pi}^{2} + 4.96\times10^{-3} t_{pi} + 0.281\right)\Big/0.466 \\
f_v &= -6.98484455\times10^{-4} v_p^{4} + 1.28561447\times10^{-2} v_p^{3} - 7.02399803\times10^{-2} v_p^{2} \\
&\quad + 1.33657748\times10^{-2} v_p + 1.23339312 \\
\varepsilon &= \left[0, \left(1 + 0.3452 \ln(v_d / v_p\right) f_t f_v \varepsilon_{rated}, 0.95\right]
\end{aligned}
$$

Equation 12

Where

t_{pi} = DWHR potable water inlet temperature, °F

v_p = Potable volume flow rate, gpm. v_p depends on the plumbing configuration and is various combinations of the fixture hot water draw, the fixture cold water draw, and the total hot water draw.

v_d = Drain volume flow rate, gpm. The drain volume is equal to the total (mixed) draws of fixture(s) evaluated *not including* f_{dur} (see Equation 1) since no heat can be recovered during warmup.

e = DWHR effectiveness under current conditions, unitless

e_{rated} = DWHR-rated effectiveness = efficiency/100, rated at CSA B55.1 conditions (9.5 lpm, equal flow)

The effectiveness, *e*, is used to calculate the potable water temperature increase.

$$\Delta T_{dwhr} = \frac{\varepsilon\, min(v_p, v_d)(t_d - t_{pi})}{v_p}$$

Equation 13

Where

t_d = DWHR drain-side entering temperature, °F = shower use temperature (105°F) – 4.6°F. The latter adjustment approximates heat loss between the shower and the DWHR device.

In this model with some plumbing configurations, effectiveness depends on v_p, and v_p depends on effectiveness. An iterative solution technique is required to find consistent conditions.

When only some shower fixtures within a dwelling unit drain via a DWHR system, savings are assumed proportional to the number of included shower fixtures. This is implemented by assigning shower draws in rotation to DWHR or non-DWHR arrangements.

B5. Hourly Distribution Loss for Central Water Heating Systems

This section is applicable to the DHW system Types 3 and 4, as defined in B1. The distribution losses accounted for in the distribution loss multiplier (DLM), Equation *5*, reflect distribution heat loss within each dwelling unit. Additional distribution losses occur outside dwelling units and include losses from recirculation loop pipes and branch piping feeding dwelling units. The hourly values of these losses, HRDL, shall be calculated according to Equation 17

. Compliance software shall provide input for specifying recirculation system designs and controls according to the following algorithms.

$$HRDL_k = NLoop_k \times HRLL_k + HRBL_k \quad \textit{Equation 14}$$

Where

$HRDL_k$= Hourly central system distribution loss for k^{th} system (Btu).

$HRLL_k$= Hourly recirculation loop pipe heat loss (Btu). This component is only applicable to system Type 4, see Equation 15

$HRBL_k$= Hourly recirculation branch pipe heat loss (Btu), see Equation 23

$NLoop_k$= Number of recirculation loops in water heating system k; this component is only applicable to system Type 4, see Section 0

A recirculation loop usually includes multiple pipe sections, not necessarily having the same diameter, that are exposed to different ambient conditions. The compliance software shall provide input entries for up to six pipe sections, with three sections for supply piping and three sections for return piping for users to describe the configurations of the recirculation loop. For each of the six pipe sections, input entries shall include pipe diameter (inch), pipe length (ft), and ambient conditions. Ambient condition input shall include three options: outside air, underground, conditioned or semi conditioned air. Modeling rules for dealing with recirculation loop designs are provided in Section 0

Outside air includes crawl spaces, unconditioned garages, unconditioned equipment rooms, as well as the actual outside air. Solar radiation gains are not included in the calculation because the effect of radiation gains is relatively minimal compared to other effects. Furthermore, the differences in solar gains for the various conditions (for example, extra insulation vs. minimum insulation) are even less significant.

The ground condition includes any portion of the distribution piping that is underground, including that in or under a slab. Insulation in contact with the ground must meet all the requirements of Section 150.0(j), Part 6, of Title 24.

The losses to conditioned or semi conditioned air include losses from any distribution system piping that is in an attic space, within walls (interior, exterior, or between conditioned and unconditioned spaces), within chases on the interior of the building, or within horizontal spaces between or above conditioned spaces. It does not include the pipes within the residence. The distribution piping stops at the point where it first meets the boundaries of the dwelling unit.

Hourly Recirculation Loop Pipe Heat Loss Calculation

Hourly recirculation loop pipe heat loss ($HRLL_k$) is the hourly heat loss from all six pipe sections. There are two pipe heat loss modes — pipe heat loss with nonzero water flow (PLWF) and pipe heat loss without hot water flow (PLCD). The latter happens when the recirculation pump is turned off by a control system and there are no hot water draw flows, such as in recirculation return pipes.

Compliance software shall provide four options of recirculation system controls listed in

Table B-3 or Table B-4. A proposed design shall select a control type from one of the four options. The standard design shall use demand control.

Table B-3: Recirculation Loop Supply Temperature and Pump Operation Schedule (With No Control or Demand Control)

Hour	No Control Temperature	No Control Input for $SCH_{k,m}$	Demand Control Temperature	Demand Control Input for $SCH_{k,m}$
1 through 24	130	1	130	0.2

Source: California Energy Commission

Table B-4. Recirculation Loop Supply Temperature and Pump Operation Schedule (With Temperature Modulation Control)

Hour	Without Continuous Monitoring Temperature	Without Continuous Monitoring Input for $SCH_{k,m}$	With Continuous Monitoring Temperature	With Continuous Monitoring Input for $SCH_{k,m}$
1 through 5	120	1	115	1
6	125	1	120	1
7 through 23	130	1	125	1
24	125	1	120	1

Source: California Energy Commission

Pipe heat loss modes are determined by recirculation control schedules and hot water draw schedules. For each pipe section, hourly pipe heat loss is the sum of heat loss from the two heat loss modes.

Hourly heat loss for the whole recirculation loop ($HRLL_k$) is the heat loss from all six pipe sections, according to the following equation:

$$HRLL_k = \sum_n [PLWF_n + PLCD_n] \qquad \text{Equation 15}$$

Where

$PLWF_n$= Hourly pipe heat loss with non-zero water flow (Btu/hr), see Equation 16

$PLCD_n$= Hourly pipe heat loss without water flow (Btu/hr), see Equation 21

n= Recirculation pipe section index, 1 through 6

$$PLWF_n = Flow_n \times \left(1 - f_{noflow,n}\right) \times \rho \times C_p \times \left(T_{n,in} - T_{n,out}\right) \qquad \text{Equation 16}$$

Where

$Flow_n$ = $Flow_{recirc}$ + $Flow_{n,draw}$ (gph), assuming

$Flow_{n,draw}$ = Average hourly hot water draw flow (gph); for supply sections, n=1, 2, or 3, $Flow_{n,draw}$ = $GPH_k/NLoop_k$; for return pipes, n=4, 5, and 6, $Flow_{n,draw}$ = 0

$Flow_{recirc}$ = Hourly recirculation flow (gph), shall be calculated as $Nunit_k/Nfloor_k$ x 0.5 x 60 x F_{bv}. F_{bv} is the balancing valve and variable speed recirculation pump flow reduction factor. For the standard design, f_{BV} is 1.0. For the proposed design, if the recirculation system meets all criteria of Reference Residential Appendix RA 4.4.3, f_{BV} is 0.6. Otherwise, f_{BV} is 1.0.

$f_{noflow,n}$ = Fraction of the hour for pipe section n to have zero water flow, see Equation 17

ρ = Density of water, 8.345 (lb/gal)

C_p = Specific heat of water, 1 (Btu/lb-˚F)

$T_{n,in}$ = Input temperature of section n (˚F); for the first section (n=1), $T_{1,in}$ shall be determined based on

Table B-3. The control schedule of the proposed design shall be based on user input. The standard design is demand control. For other sections, input temperature is the same as the output temperature the proceeding pipe section, $T_{n,in}$ = $T_{n-1,out}$

$T_{n,out}$ = Output temperature of section n (˚F), see Equation 18

$$f_{noflow,n} = \left(1 - SCH_{k,m}\right) \times NoDraw_n$$

Equation 17

Where

$NoDraw_n$ = Fraction of the hour that is assumed to have no hot water draw flow for pipe section n; $NoDraw_1$ = 0.2, $NoDraw_2$ = 0.4, $NoDraw_3$ = 0.6, $NoDraw_4$ = $NoDraw_5$ = $NoDraw_6$ = 1

$SCH_{k,m}$ = Recirculation pump operation schedule, representing the fraction of the hour that the recirculation pump is turned off, see

Table B-3 or Table B-3. $SCH_{k,m}$ for the proposed design shall be based on proposed recirculation system controls. Recirculation system control for the standard design is demand control.

$$T_{out,n} = T_{amb,n} + \left(T_{in,n} - T_{amb,n}\right) \times e^{-\frac{UA_n}{\rho C_p Flow_n}}$$

Equation 18

Where

$T_{Amb,n}$ = Ambient temperature of section n (˚F), which can be outside air, underground, conditioned, or semiconditioned air. Outside air temperatures shall be the dry-bulb temperature from the weather file. Underground temperatures shall be obtained from **Error! Reference source not found.**Equation 11. Hourly conditioned air temperatures shall be the same as conditioned space temperature. For the proposed design, $T_{amb,n}$ options shall be based on user input. The standard design assumes all pipes are in conditioned air.

UA_n = Heat loss rate of section n (Btu/hr-°F), see Equation 19

$$UA_n = Len_n \times min\left(U_{bare,n}, f_{UA} \times U_{insul,n}\right)$$

Equation 19

Where

Len_n = Section n pipe length (ft); for the proposed design, use user input; for the standard design, see

$U_{bare,n}$, $U_{insul,n}$ = Loss rates for bare (uninsulated) and insulated pipe (Btu/hr-ft-˚F), evaluated using Equation 20 with section-specific values, as follows:

Dia_n = Section n pipe nominal diameter (inch); for the proposed design, use user input; for the standard design, see.

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h·sf·F)

h_n = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-°F) assumed = 1.5

f_{UA} = Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculation. For the standard design, f_{UA} is 2.0. For proposed designs, f_{UA} is 2.0 if the pipe insulation installation is verified per Residential Reference Appendix RA 3.6.3. Otherwise, f_{UA} is 2.4.

Equation 20 defines general relationships used to calculate heat loss rates for both loop and branches using appropriate parameters.

$$Dia_o = Dia + 0.125$$

$$U_{bare} = h \times \pi \times \frac{Dia_o}{12}$$

$$Dia_x = Dia_o + 2 \times Thick$$

$$U_{insul} = \frac{\pi}{\frac{ln\left(\frac{Dia_x}{Dia\ o}\right)}{\frac{2 \times Cond}{12}} + \frac{12}{h \times Dia_x}}$$

Equation 20

Where

Dia = Pipe nominal size (in)

Dia_o = Pipe outside diameter (in)

Dia_x = Pipe + insulation outside diameter (in)

Thick = Pipe insulation thickness (in)

Cond = Insulation conductivity (Btu in/hr-ft^2- °F)

h = Combined convective/radiant surface coefficient (Btu/hr-ft^2- °F)

Pipe heat loss without water flow shall be calculated according to the following equations:

$$PLCD_n = Vol_n \times \rho \times C_p \times \left(T_{n,start} - T_{n,end}\right)$$

Equation 21

Where

Vol_n = Volume of section n (gal) is calculated as 7.48 x π x $\left(\frac{Dia_o}{24}\right)^2$ x Len_n where 7.48 is the volumetric unit conversion factor from cubic feet to gallons. Note that the volume of the pipe wall is included to approximate the heat capacity of the pipe material.

$T_{n,start}$ = Average pipe temperature (°F) of pipe section n at the beginning of the hour. It is the average of $T_{n,in}$ and $T_{n,out}$ calculated according to Equation 18 and associated procedures.

$T_{n,end}$ = Average pipe temperature (°F) of pipe section n at the end of pipe cool down, see Equation 22

$$T_{n,end} = T_{amb,n} + \left(T_{n,start} - T_{amb,n}\right) \times e^{-\frac{UA_n \times f_{noflow,n}}{Vol_n \times \rho \times C_p}}$$ Equation 22

Equation 22 calculates average pipe temperature after cooling down, so the pipe heat loss calculated by Equation 21 is for pipe with zero flow for fraction $f_{noflow,n}$ of an hour. Recirculation pumps are usually turned off for less than an hour and there could be hot water draw flows in the pipe. As a result, recirculation pipes usually cool down for less than an hour. The factor $f_{noflow,n}$ calculated according to Equation 17 is used to reflect this effect in Equation 22.

Hourly Recirculation Branch Pipe Heat Loss Calculation

The proposed design and standard design shall use the same branch pipe heat loss assumptions. Branch pipe heat loss is made up of two components. First, pipe heat losses occur when hot water is in use (HBUL). Second, there could be losses associated with hot water waste (HBWL) when hot water was used to displace cold water in branch pipes and hot water is left in pipe to cool down after hot water draws and must be dumped down the drain.

The total hourly branch losses ($HRBL_k$) shall include both components and be calculated as:

$$HRBL_k = Nbranch_k \times (HBUL + HBWL)$$ Equation 23

Where

HBUL = Hourly pipe loss for one branch when water is in use (Btu/hr), see Equation 24

HBWL = Hourly pipe loss for one branch due to hot water waste (Btu/hr), see Equation 27

$Nbranch_k$ = Number of branches in water heating system k, see Equation 32

The hourly branch pipe loss while water is flowing is calculated in the same way as recirculation pipe heat loss with nonzero water flow (PLWF) using the following equations:

$$HBUL = \left(\frac{GPH_k}{NBranch_k}\right) \times \rho \times C_p \times \left(T_{b,in} - T_{b,out}\right)$$ Equation 24

Where

$T_{b,in}$ = Average branch input temperature (°F). It is assumed to be equal to the output temperature of the first recirculation loop section, $T_{1,out}$

$T_{b,out}$ = Average branch output temperature (˚F), see Equation 25

$$T_{b,out} = T_{amb,b} + \left(T_{b,in} - T_{amb,b}\right) \times e^{-\frac{UA_b}{\rho \times C_p \times Flow_b}}$$

Equation 25

Where

$T_{amb,b}$ = Branch pipe ambient temperature (°F). Branch pipes are assumed to be located in the conditioned or semiconditioned air.

UA_b = Branch pipe heat loss rate (Btu/hr-°F), see Equation 26

$Flow_b$ = Branch hot water flow rate during use (gal/hr). It is assumed to be 2 gpm or 120 gal/hr.

The branch pipe heat loss rate is

$$UA_b = Len_b \times U_{insul,b}$$

Equation 26

Where

Len_b = Branch pipe length (ft), see

$U_{insul,b}$ = Loss rate for insulated pipe (Btu/hr-ft-˚F), evaluated using Equation 20 with branch-specific values, as follows:

Dia_b = Branch pipe diameter (inch), see

$Thick_b$ = Branch pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system.

$Cond_b$ = Branch insulation conductivity, assumed = 0.26 Btu in/hr-ft^2- ˚F

h_b = Branch combined convective/radiant surface coefficient (Btu/hr-ft^2- ˚F) assumed = 1.5

The hourly pipe loss for one branch due to hot water waste is calculated as follows:

$$HBWL = N_{waste} \times SCH_{waste,m} \times f_{vol} \times 7.48 \times \pi \times \left(\frac{Dia_b + 0.125}{24}\right)^2 \times Len_b \times \rho \times C_p \times (T_{b,in} - T_{inlet})$$

Equation 27

Where

N_{waste} = Number of times in a day for which water is dumped before use. This number depends on the number of dwelling units served by a branch. Statistically, the number of times of hot water waste is wasted is inversely proportional to the number of units a branch serves, see Equation 28*.*

$SCH_{waste,m}$ = Hourly schedule of water waste, see Table B-5

f_{vol} = The volume of hot water waste is more than just the volume of branch pipes, due to branch pipe heating, imperfect mixing, and user behaviors. This multiplier is applied to include these effects and is assumed to be 1.4.

$T_{in,b}$ = Average branch input temperature (°F) is assumed to equal the output temperature of the first recirculation loop section, $T_{OUT,1}$

T_{inlet} = The cold water inlet temperature (°F) according to Section 3.3 Cold Water Inlet Temperature

$$N_{waste} = 19.84 \times e^{-0.544 \times Nunit_b}$$

Equation 28

Method WH-BRWF

Where

$Nunit_b$= Number of dwelling units served by the branch, calculated using Equation 29 ($Nunit_b$ is not necessarily integral).

$$Nunit_b = \frac{Nfloor}{2}$$ Equation 29

Method WH-BRNU

Table B-5: Branch Water Waste Schedule

Hour	$SCH_{waste,m}$
1	0.01
2	0.02
3	0.05
4	0.22
5	0.25
6	0.22
7	0.06
8	0.01
9	0.01
10	0.01
11	0.01
12	0.01
13	0.01
14	0.01
15	0.01
16	0.01
17	0.01
18	0.01
19	0.01
20	0.01
21	0.01
22	0.01
23	0.01
24	0.01

Source: California Energy Commission

Recirculation System Plumbing Designs

A recirculation system consists of multiple pipes, which are connected in sequence to form a loop. Within a recirculation loop, there can be multiple parallel flow paths formed by riser pipes between supply and return pipes. The compliance software shall use six pipe sections, with three supply pipe sections and three return pipe sections, to represent a recirculation loop. The compliance software shall model recirculation systems according to the piping design described in the following sections. This piping design is based on typical recirculation system piping layout practices and pipe sizing methods defined in California Plumbing Code Appendix A and Appendix M.

Supply pipes start from the water heating plant master mixing valve outlet located on the first floor and are routed to the corridor ceiling. Supply pipes run horizontally to each end of the building. Horizontal riser pipes connected to supply pipes bring hot water to each first-floor dwelling unit. Each horizontal riser is connected to vertical riser pipes to bring hot water to dwelling units on upper floors. In the ceiling of the top floor, vertical riser pipes are connected to horizontal riser pipes, which bring hot water to recirculation return pipes in the corridor ceiling. A vertical recirculation return pipe brings hot water to the heating plant on the first floor to complete the loop. This recirculation loop design uses risers to bring hot water to each dwelling unit and, therefore, branch pipes for connecting riser pipes and pipes leading to individual hot water fixtures are relatively short.

All supply pipes and the bottom half of riser pipes are converted into three sections of supply pipes in the default recirculation loop design. All return pipes and the top half of riser pipes are converted into three sections of return pipes in the default recirculation loop design. The first pipe section includes pipes from the water heating plant master mixing valve outlet to the first riser. The second pipe section includes supply pipes for the first half risers and the bottom half of these first half risers. The third pipe section includes the remaining supply pipes and the bottom half of the second half risers. The first pipe section represents pipes for supplying the whole building and, therefore, has the largest pipe diameter. The second section has a smaller pipe diameter because it represents the supply pipes and riser pipes with smaller pipe diameters. Pipe diameter for the third section is smallest because it represents pipes serving the fewest dwelling units. Return pipe sections (4, 5, and 6) represent return pipes and the top half of riser pipes in a similar way as supply pipe sections. Each return pipe section has the same pipe length as the corresponding supply pipe section. Pipe diameters for all return pipe sections are 0.75 inch.

For both the standard and proposed design, pipe section lengths are calculated as follows:

Length of recirculation pipe sections (ft):

$$Len_1 = Len_6 = 0.3 \times Nunit_k + 4 \qquad \text{Equation 30}$$

$$Len_2 = Len_3 = Len_4 = Len_5 = 5.5 \times Nunit_k \qquad \text{Equation 31}$$

Method WH-LOOPLEN

Pipe diameters for recirculation loop supply sections depend on the number of dwelling units being served and return section diameters depend only on building type, as follows:

> Dia_1, Dia_2, and Dia_3: derived from Table B-6. The standard design shall use values listed under California Plumbing Code Appendix M Pipe Sizing Method in Table B-6. Proposed designs shall use the same values as the standard design if pipes are sized using California Plumbing Code Appendix M Pipe Sizing Method. Otherwise, values listed under California Plumbing Code Appendix A Pipe Sizing Method shall be used.
>
> $Dia_4 = Dia_5 = Dia_6 = 0.75$ in

Method WH-LOOPSZ

Branch pipe parameters include number of branches, branch length, and branch diameter. The number of branches in water heating system k is calculated as (note: not necessarily an integer):

$$Nbranch_k = Nunit_k \qquad \text{Equation 32}$$

Method WH-BRN

The branch pipe diameter, Dia_b, shall be 0.75 in.

Method WH-BRSZ

Branch pipes connect riser pipes to pipes connected to individual hot water fixtures in dwelling units. The branch length, Len_b, shall be 2 feet.

Method WH-BRLEN

Proposed designs shall use the same branch configurations as those in the standard design.

Table B-6: Pipe Size Schedule for Supply Pipe Sections

Number of dwelling units served $NUnit_n$	CPC Appendix A Dia1 (in)	CPC Appendix A Dia2 (in)	CPC Appendix A Dia3 (in)	CPC Appendix M Dia1	CPC Appendix M Dia2	CPC Appendix M Dia3
< 5	1	0.75	0.75	1	0.75	0.75
5 ≤ N < 8	1.5	1	0.75	1.5	1	0.75
8 ≤ N < 21	2	1.5	1.5	1.5	1.5	1
21 ≤ N < 36	2.5	1.5	1.5	1.5	1.5	1
36 ≤ N < 68	3	1.5	1.5	2	1.5	1
68 ≤ N < 101	3.5	2	1.5	3	1.5	1
101 ≤ N < 145	4	2	1.5	3	1.5	1
145 ≤ N < 198	5	2	1.5	3	1.5	1
N >= 198	6	2	1.5	3	1.5	1

Source: California Energy Commission

B6. High-Rise Residential Buildings, Hotels and Motels

Simulations for high-rise residential buildings, hotels, and motels shall follow all the rules for central or individual water heating with the following exceptions:

- For central systems that do not use recirculation but use electric trace heaters, the program shall assume equivalency between the recirculation system and the electric trace heaters.
- For individual water heater systems that use electric trace heating instead of gas, the program shall assume equivalency.

B7. Energy Use of Water Heaters

Once the hourly adjusted recovery load is determined for each water heater, the energy use for each water heater is calculated as described below and summed.

Consumer or Residential-Duty Commercial Storage Water Heaters

Storage water heaters are rated either by EF (energy factor) or the newer UEF (Uniform Energy Factor). The calculation algorithm for these devices derives a Load Dependent Energy Factor (LDEF) from EF. For water heaters rated with UEF, CBECC-Res calculates an equivalent EF.

The hourly energy use of storage gas water heaters is given by the following equation.

$$WHEU_j = \frac{HARL_j \times HPAF_j}{LDEF_j}$$ Equation 33

Where

WHEU$_j$ = Hourly energy use of the water heater (Btu for fuel or kWh for electric); Equation 33 provides a value in units of Btu. For electric water heaters, the calculation result needs to be converted to the unit of kWh by dividing 3413 Btu/kWh.

HARL$_j$ = Hourly adjusted recovery load (Btu)

HPAF$_j$ = 1 for all non-heat-pump water heaters

LDEF$_j$ = The hourly Load Dependent Energy Factor (LDEF) is given by

$$LDEF_j = min\left[LDEF\ max\left(LDEF\ ln\left(\frac{AAHARL_j \times 24}{1000}\right)(a \times EF_j + b)(c \times EF_j + d)_{min}()\right)_{max}\right]$$

Equation 34. This equation adjusts the nominal EF rating for storage water heaters for different load conditions.

$$LDEF_j = min\left[LDEF\ max\left(LDEF\ ln\left(\frac{AAHARL_j \times 24}{1000}\right)(a \times EF_j + b)(c \times EF_j + d)_{min}()\right)_{max}\right]$$ Equation 34

Where

a,b,c,d = Coefficients from the table below based on the water heater type

Table B-7: LDEF Coefficients

Coefficient	Storage Gas
A	-0.098311
B	0.240182
C	1.356491
D	-0.872446
$LDEF_{min}$	.1
$LDEF_{max}$	.90

Source: California Energy Commission

$AAHARL_j$ = Annual average hourly adjusted load (Btu) = $\frac{1}{8760}\sum_1^{8760} HARL_j$; calculation of $AAHARL_j$ requires a preliminary annual simulation that sums $HARL_j$ values for each hour.

EF_j = Energy factor of the water heater (unitless). This is based on the DOE test procedure. EF for storage gas water heaters with volume less than 20 gallons must be assumed to be 0.58 unless the manufacturer has voluntarily reported an actual EF to the California Energy Commission.

CBECC-Res derives EF_j from UEF for water heaters that are rated using updated DOE procedures.

Consumer and Residential-Duty Commercial Water Heaters

UEF-rated consumer and residential-duty commercial instantaneous water heaters (gas and electric) are modeled on a minute-by-minute basis using procedures documented by Lutz (2019).

Small Instantaneous Gas Water Heaters

The hourly energy use for instantaneous gas or oil water heaters is given by Equation 35, where the nominal rating is multiplied by 0.92 to reflect the effects of heat exchanger cycling under real-world load patterns.

$$WHEU_j = \frac{HARL_j}{EF_j \times 0.92} \quad \text{Equation 35}$$

Where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu)

$HARL_j$ = Hourly adjusted recovery load

EF_j = Energy factor from the DOE test procedure (unitless) taken from manufacturers' literature or from the CEC Appliance Database

0.92 = Efficiency adjustment factor

Small Instantaneous Electric Water Heaters

The hourly energy use for consumer instantaneous electric water heaters is given by the following equation.

$$WHEU_{j,elec} = \frac{HARL_j}{EF_j \cdot 0.92 \cdot 3413} \qquad \text{Equation 36}$$

Where

$WHEU_{j,elec}$ = Hourly electric energy use of the water heater (kWh)

$HARL_j$ = Hourly adjusted recovery load (Btu)

EF_j = Energy factor from DOE test procedure (unitless)

0.92 = Adjustment factor to adjust for overall performance

3413 = Unit conversion factor (Btu/kWh)

Mini-Tank Electric Water Heater

Mini-tank electric heaters are occasionally used with gas tankless water heaters to mitigate hot water delivery problems related to temperature fluctuations that may occur between draws. If mini-tank electric heaters are installed, the installed units must be listed in the CEC Appliance Database and their reported standby loss (in Watts) will be modeled to occur each hour of the year. (If the unit is not listed in the CEC Appliance Database, a standby power consumption of 35 W should be assumed.)

$$WHEU_{j,elec} = MTSBL_j / 1000 \qquad \text{Equation 37}$$

Where

$WHEU_{j,elec}$ = Hourly standby electrical energy use of mini-tank electric water heaters (kWh)

$MTSBL_j$ = Mini-tank standby power (W) for tank j (if not listed in CEC Appliance directory, assume 35 W)

Large/Commercial Gas Storage Water Heaters

Energy use for large storage gas is determined by the following equations. Large storage gas water heaters are defined as any gas storage water heater with a minimum input rate of 75,000 Btu/h.

$$WHEU_j = \frac{HARL_j}{EFF_j} + SBL_j \qquad \text{Equation 38}$$

Where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu)

$HARL_j$ = Hourly adjusted recovery load (Btu)

SBL_j = Total standby loss (Btu/hr). Obtain from CEC Appliance Database or from AHRI certification database. This value includes tank losses and pilot energy. If standby rating is not available from either of the two databases, it shall be calculated as per Table F-2 of the 2015 Appliance Efficiency Regulations, as follows:

SBL = Q/800 + 110 $(V)^{1/2}$, where Q is the input rating in Btu/hour, and V is the tank volume in gallons.

EFF_j = Efficiency (fraction, not %). Obtained from CEC Appliance Database or from manufacturer’s literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

Large/Commercial Instantaneous, Indirect Gas, and Hot Water Supply Boilers

Energy use for these types of water heaters is given as follows:

$$WHEU_j = \frac{HARL_j}{EFF_j \times 0.92} + PILOT_j \qquad \text{Equation 39}$$

Where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section B3.

EFF_j = Efficiency (fraction, not %) to be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

$PILOT_j$ = Pilot light energy (Btu/h) for large instantaneous. For large instantaneous water heaters, and hot water supply boilers with efficiency less than 89 percent assume the default is 750 Btu/hr if no information is provided in manufacturer’s literature or CEC Appliance Database.

0.92 = Adjustment factor used when system is not supplying a storage system.

Consumer Storage Electric or Heat Pump Water Heaters

Energy use for small electric water heaters is calculated as described in the HPWHsim Project Report (Ecotope, 2016) and in documents specified in Section B6. (See also study by NEEA referenced in Appendix F.) The HPWH model uses a detailed, physically based, multinode model that operates on a one-minute time step implemented using a suitable loop at the time-step level within CSE. Tank heat losses and heat pump source temperatures are linked to the CSE zone heat balance as appropriate. Thus, for example, the modeled air temperature of a garage containing a heat pump water heater will reflect the heat extracted.

HPWHsim can model three classes of equipment:

- Specific air-source heat pump water heaters identified by manufacturer and model. These units have been tested by Ecotope, and measured parameters are built into the HPWH code.
- Generic air-source heat pump water heaters, characterized by EF and tank volume. This approach provides compliance flexibility. The performance characteristics of the generic model are tuned to use somewhat more energy than any specific unit across a realistic range of UEF values.
- Electric resistance water heaters, characterized by EF, tank volume, and resistance element power.

Several issues arise from integration of a detailed, short time-step model into an hourly framework. HPWH is driven by water draw quantities, not energy requirements. Thus, to approximate central system distribution and unfired tank losses, fictitious draws are added to the scheduled water uses, as follows:

$$V_{j,t} = \frac{VS_{k,t} + \dfrac{HRDL_k + \sum_{1}^{NL_k} HJL_l}{60 \times 8.345 \times (t_s - t_{inlet})}}{NWH_k}$$

Equation 40

Where

HRDL$_k$ = Hourly recirculation distribution loss (Btu), see Equation 14; HRDL$_k$ is nonzero only for multifamily central water heating systems

HJL$_l$ = Tank surface losses of the lth unfired tank of the kth system (Btu), see Equation 41

VS$_k$ = Hot water draw at the kth water heating system's delivery point (gal)

V$_{j,t}$ = Hot water draw (gal) on jth water heater for minute t

Another issue is that the HPWH hot water output temperature varies based on factors such as control hysteresis and tank mixing. For compliance applications, it is required that all system alternatives deliver the same energy. To address this, the HPWH tank setup point is modeled at 125°F, and delivered water is tempered to t_s. If the HPWH output temperature is above t_s, it is assumed that inlet water is mixed with it (thus reducing $V_{i,t}$). If the output temperature is below t_s, sufficient electrical resistance heating is supplied to bring the temperature up to t_s (preventing undersizing from being exploited as a compliance advantage).

Jacket Loss

The hourly jacket loss for the lth unfired tank or indirectly fired storage tank in the kth system is calculated as:

$$HJL_l = \frac{TSA_l \times \Delta TS}{RTI_l + REI_l} + FTL_l$$ Equation 41

Where

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system

TSA_l = Tank surface area (ft^2), see Equation 42

ΔTS = Temperature difference between ambient surrounding tank and hot water supply temperature (°F). Hot water supply temperature shall be 124°F. For tanks located inside conditioned space use 75°F for the ambient temperature. For tanks in outside conditions, use hourly dry bulb temperature ambient.

FTL_l = Fitting losses; a constant 61.4 Btu/h

REI_l = R-value of exterior insulating wrap; no less than R-12 is required

RTI_l = R-value of insulation internal to water heater; assume 0 without documentation

Tank surface area (TSA) is used to calculate the hourly jacket loss (HJL) for unfired or indirectly fired tanks. TSA is given in the following equation as a function of the tank volume.

$$TSA_l = (1.254 \times VOL_l^{0.33} + .531)^2$$ Equation 42

Where

VOL_l = Tank capacity (gal)

Water Heating Plant Pipe Heat Loss

Pipes in the heating plan connect water heating equipment, hot water storage equipment, and the master mixing valve. The hourly pipe heat loss of water heating plant in the k^{th} system is calculated as:

$$HPPL_k = (PSA_{plant,k} \times f_{A,plant}) \times (U_{plant,k} \times f_{U,plant}) \times (T_{plant,k} - T_{Amb_{plant},k})$$ Equation 43

Where

$PSA_{plant,k}$ = Pipe surface area (ft^2) of pipes in the heat plant. Note that pipes downstream of the master mixing valve are considered part of the hot water distribution system. It is calculated based on the number of dwelling units, $Nunit_k$, served by the heating system k as follows:

2.4 x $Nunit_k$ for heat pump water heater-based heating plant

3.5 x $Nunit_k$ for natural gas water heater or boiler-based heating plant

$f_{A,plant}$ = Correction factor to reflect improvement in pipe surface area reduction by using smaller pipes according to California Plumbing Code Appendix M. For the standard design, $f_{A,plant}$ is 0.8. For the proposed design, the default value is 1.0. If plant pipes in the proposed design are sized according to the California Plumbing Code Appendix M and the number of dwelling units served by the heating plan, $Nunit_k$ is more than 8, $f_{A,plant}$ is 0.8.

$U_{plant,k}$ = Average heat transfer coefficient between pipes and the ambient air, 25.2 Btu/hr-ft^2-°F.

$F_{U,plant}$ = Correction factor to reflect field installation quality of pipe insulation. For the standard design, $F_{u,plant}$ is 1. For proposed design, the default value is 1.4. If pipe insulation is field inspected and verified by a ECC rater per Residential Reference Appendix RA2.2, $f_{U,plant}$ is 1.

$T_{plant,k}$ = Average pipe surface temperature for pipes in the heat plant, 125 °F.

$T_{Amb\_plant,k}$ = Ambient temperature of the water heating plant, which can be the temperature of outside air or unconditioned air. Outside air temperatures shall be the dry-bulb temperature from the weather file. Hourly unconditioned air temperatures shall be the average of outside air dry-bulb temperature and conditioned air dry-bulb temperature. The standard design shall have the same water heating plant ambient temperature as the proposed design. For proposed designs, the water heating plant ambient temperature shall be based on user input of the water heating plant location.

Electricity Use for Circulation Pumping

For single-family recirculation systems, hourly pumping energy is fixed as shown in Table B-8.

Multifamily recirculation systems typically have larger pump sizes, and, therefore, electrical energy use is calculated based on the installed pump size. The hourly recirculation pump electricity use (HEUP) is calculated by the hourly pumping schedule and the power of the pump motor as in the following equation.

$$HEUP_k = \frac{0.746 \times PUMP_k \times SCH_{k,m,}}{\eta_k}$$ Equation 44

Where

$HEUP_k$ = Hourly electricity use for the circulation pump (kWh)

$PUMP_k$ = Pump brake horsepower (bhp)

η_k = Pump motor efficiency

$SCH_{k,m}$ = Operating schedule of the circulation pump. (See

Table B-3.) The operating schedule for the proposed design shall be based on user input control method. The standard design operation schedule is demand control.

Table B-8: Single-Family Recirculation Energy Use (kWh) by Hour of Day

Hour	Non-Demand-Controlled Recirculation	Demand-Controlled Recirculation
1	0.040	0.0010
2	0.040	0.0005
3	0.040	0.0006
4	0.040	0.0006
5	0.040	0.0012
6	0.040	0.0024
7	0.040	0.0045
8	0.040	0.0057
9	0.040	0.0054
10	0.040	0.0045
11	0.040	0.0037
12	0.040	0.0028
13	0.040	0.0025
14	0.040	0.0023
15	0.040	0.0021
16	0.040	0.0019
17	0.040	0.0028
18	0.040	0.0032
19	0.040	0.0033
20	0.040	0.0031
21	0.040	0.0027
22	0.040	0.0025
23	0.040	0.0023
24	0.040	0.0015
Annual Total	350	23

Source: California Energy Commission

B8. Energy Use of Central Heat Pump Water Heater Systems

Energy use for central heat pump water heater (CHPWH) systems is calculated by HPWHsim in a way similar to consumer electric heat pump water heaters. The HPWH model uses a detailed, physically based, multinode model that operates on a 1-minute time step. This model is implemented using a suitable loop at the time-step level within CSE. Unlike with consumer electric HPWH, the central HPWH systems are built from several components selected by the building designer. The energy performance of central water heating systems is determined by these components: the primary heating equipment, primary heating storage volume, location, secondary heating equipment, secondary heating storage volume, set point controls, and the way in which the components are plumbed.

To calculate the energy use, CBECC uses information regarding the characteristics of the central HPWH system defined in the following tables and lists.

Table B-9: DHW Central/Recirculation Type

Name	DHW System Description
Non-Central	A system with a water heater for each dwelling unit.
Central, no Recirculation	A DHW system with equipment providing hot water for all dwelling units in the building. No hot water temperature maintenance recirculation loop is used.
Central with Recirculation	A DHW system with equipment providing hot water for all dwelling units in the building. Hot water temperature maintenance recirculation loop is used. Plumbing of recirculation loop in relation to central heating equipment is specified.

Source: California Energy Commission

Table B-10: Central HPWH Primary System Type

Name	HPWH Description
Single-Pass Primary	A split-system HPWH that regulates flow such that it heats cold water to setpoint in a single trip through the heating equipment.
Multi-Pass Primary	A split-system HPWH with constant flow that incrementally heats water through multiple trips through the heating equipment.
Integrated/Packaged System	A HPWH that contains the heat pump components and storage tank in one device. These may also contain one or two electric resistance heating elements.

Source: California Energy Commission

For single-pass primary/multi-pass primary either primary or secondary types:

- **HPWH/Compressor Model** — The manufacturer and model number of the HPWH, with heating capacity provided 40˚F ambient air.

- **Compressor/Heater Count** — Number of single-pass primary or multi-pass compressors, either primary or secondary.
- **Total Tank Volume** — Total storage volume of all tanks, either primary or secondary.
- **Tank Count** — The number of storage tanks that the total tank volume is distributed over, either primary or secondary.
- **Tank R-Value** — The R-Value of the insulation around the storage tanks, either primary or secondary.

Table B-11 applies to integrated/packaged system, either primary or secondary types.

Table B-11: Integrated/Packaged Type

Name	Integrated/Packaged Type Description
Residential (NEEA rated) Product	An integrated/packaged HPWH listed in NEEA's Residential Unitary Qualified Products List.
Commercial Product	An integrated/packaged HPWH of storage volume greater than or equal to 120 gallons or heating capacity greater than 6 kW.

Source: California Energy Commission

For residential (NEEA-rated) product:

- **NEEA HPWH Brand/Model** — The manufacturer and model number of the HPWH, provided with the nominal storage capacity, for either the primary or secondary type.
- **NEEA HPWH Count** — An integer number of residential (NEEA-rated) integrated/packaged HPWHs, this includes the storage tank and the heating elements.

For commercial product:

- **Commercial HPWH Product** — The manufacturer and model number of the HPWH, provided with the nominal storage capacity, for either the primary or secondary type.
- **HPWH Count** — An integer number of commercial integrated/packaged HPWHs, this includes the storage tank and the heating elements.

For all HPWH types as either primary or secondary:

- **Tank Location** — The location of the storage tanks, either outside or a specific zone, for the primary or secondary tank.
- **Source Air From** — The location that the HPWH draws air from, either outside or a specific zone. For a split-system single-pass or multi-pass HPWH the HPWH may be

located in a separate location than the tank location, or for an integrated/packaged type, the source air can be ducted from a separate location.

Table B-12: Secondary Tank Configuration

Name	Secondary Tank Configuration Description
None (Return to Primary)	No secondary or loop tank for the recirculation loop to return to. The recirculation loop is returned to the bottom of the primary tank.
Series (Swing)	A tank where the outlet of the primary tank is piped to the bottom of the secondary tank, to mix the secondary tank through thermal buoyancy effects. The recirculation loop is piped to the bottom of the secondary tank.
Parallel	A tank where the outlet of the primary tank is piped to the top of the secondary tank, to maintain thermal stratification in the secondary tank. The recirculation loop is piped to the bottom of the secondary tank.

Source: California Energy Commission

The secondary tank type is largely the same as the primary system type but includes the option for an electric resistance heater.

Table B-13: Secondary Tank Type

Name	Secondary Tank Type Description
Electric Resistance	An electric resistance water heater with two resistance elements. The total heating capacity is 350 W per apartment unit in the building, and it has a set point of 136˚F to supply a minimum of 125˚F water with a 10˚ F deadband.
Integrated/Packaged System	A HPWH that contains the heat pump components and storage tank in one device. These also contain one or two electric resistance heating elements.
Single Pass Primary	A split-system HPWH that regulates flow such that it heats cold water to set point in a single trip through the heating equipment.

Multi Pass Primary	A split-system HPWH with constant flow that incrementally heats water through multiple trips through the heating equipment.

Source: California Energy Commission

In CHPWH systems, there is always a primary system type and, optionally, a secondary system type. The primary system heats incoming cold water to the primary tank setpoint. If a recirculation loop is present, the primary system may be configured to heat return water from the recirculation loop. In that case, the recirculation loop is returned to the bottom of the primary tank storage volume. Alternatively, a secondary heating system may be used. In which case, the recirculation loop is returned to the secondary tank.

CBECC is designed to simulate all the following CHPWH system alternatives. The temperature set points are fixed within the simulation based on the HPWH type and application:

- Single-pass primary (not CO_2 refrigerant): 140˚F
- Single-pass primary (CO_2 refrigerant): 149˚F
- Multi-pass primary: 140˚F
- Integrated/packaged primary: 135˚F
- Secondary (not CO_2 refrigerant): 136˚F
- Secondary (CO_2 refrigerant): 149˚F

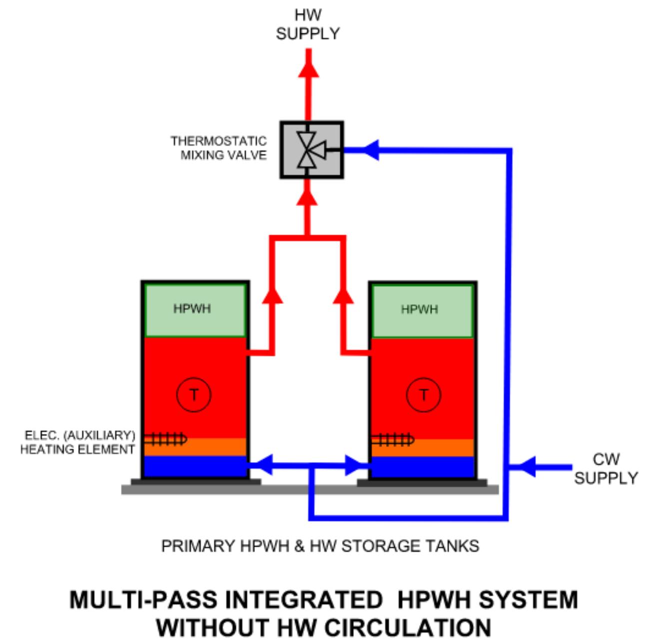
Like consumer HPWH, hot water output temperature varies based on factors such as control hysteresis and tank mixing. For compliance applications, it is required that all system alternatives deliver the same energy. To address this, the HPWH tank setup point is modeled above the delivered water temperature, which is tempered to 125˚F (t_s) with a thermostatic mixing valve. If the HPWH output temperature is above t_s, it is assumed that inlet water is mixed with it (thus reducing $V_{i,t}$). If the output temperature is below t_s, sufficient electrical resistance heating is supplied to bring the temperature up to t_s (preventing under sizing from being exploited as a compliance advantage).

The particular components, piping configuration, control, and system sizing possibilities are described in the subsequent sections for each hot water configuration.

Multi-Pass Integrated HPWH System Without Hot Water Circulation

Narrative: This schematic is applicable for use with integrated HPWH equipment. One or more integrated HPWHs may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. There is no hot water circulation system present in this system configuration.

Figure 5: Multi-Pass Integrated HPWH System Without Hot Water Circulation



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the integrated HPWH equipment. Outgoing hot water is connected to the upper portion of the integrated HPWH equipment. When multiple integrated HPWHs are specified, the incoming cold water supply to the HPWH equipment and outgoing hot water supply from the HWPH equipment are split and configured to supply equal flow to all integrated HPWH units. The outgoing hot water from the integrated HPWH(s) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

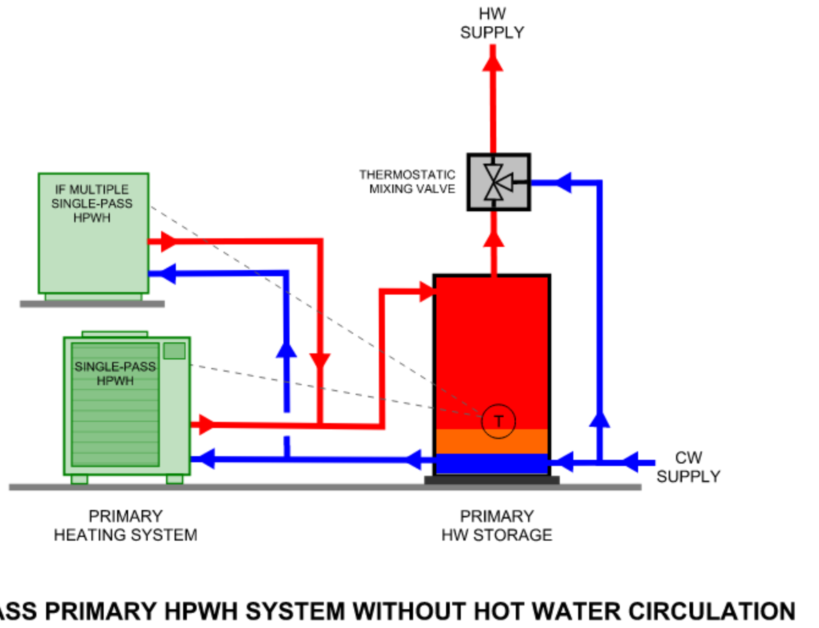
Control: The integrated HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use.

System Sizing: The integrated HPWH equipment is sized to meet the domestic hot water load. Several integrated HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Single-Pass Primary HPWH System Without Hot Water Circulation

Narrative: This schematic is applicable for use with single-pass HPWH equipment. One or more heat pumps (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. There is no hot water circulation system present in this system configuration.

Figure 6: Single-Pass Primary HPWH System Without Hot Water Circulation



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the storage tank. Outgoing hot water is connected to the upper portion of the storage tank. The single-pass split system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water to temperature, and supply to the upper portion of the storage tank. When multiple storage tanks are specified, the storage tanks are configured in series with the top of the first tank connected to the bottom of the second tank. This top-to-bottom connection is repeated for all storage tanks in series. The cold water is supplied to the lower portion of the first tank, and the outgoing hot water is supplied from the upper portion of the last storage tank in series. The outgoing hot water from the storage tank (or last storage tank in series) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

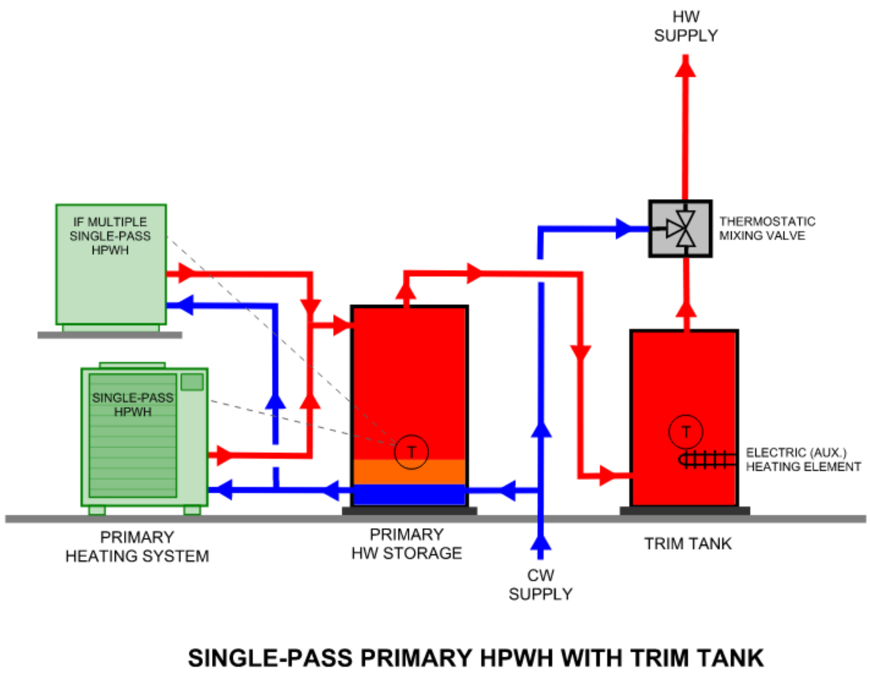
Control: The single-pass split system HPWH(s) are controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage.

System Sizing: The HPWH equipment is sized to meet the domestic hot water load. Multiple HPWHs are specified when a single HPWH cannot meet the load.

Single-Pass Primary HPWH System with Secondary Electric Resistance Trim Heater Tank and Without Hot Water Circulation

Narrative: This schematic is applicable for use with single-pass HPWH equipment in combination with a secondary electric resistance trim tank. One or more heat pumps (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. There is no hot water circulation system present in this system configuration.

Figure 7: Single-Pass Primary HPWH with Trim Tank



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the storage tank. Outgoing hot water is connected to the upper portion of the storage tank and passes through a secondary electric resistance trim tank. The single-pass split system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water to temperature, and supply it to the upper portion of the storage tank. When multiple storage tanks are specified, the storage tanks are configured in series with the top of the first tank connected to the bottom of the second tank. This top-to-bottom connection is repeated for all storage tanks in series. The cold water is supplied to the lower portion of the first tank, and the outgoing hot water is supplied from the upper portion of the last storage tank in series. The outgoing hot water from the storage tank (or last storage tank in series) is connected to a secondary electric resistance water heater pipped in series. The outgoing hot water connection from the secondary electric resistance heater is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

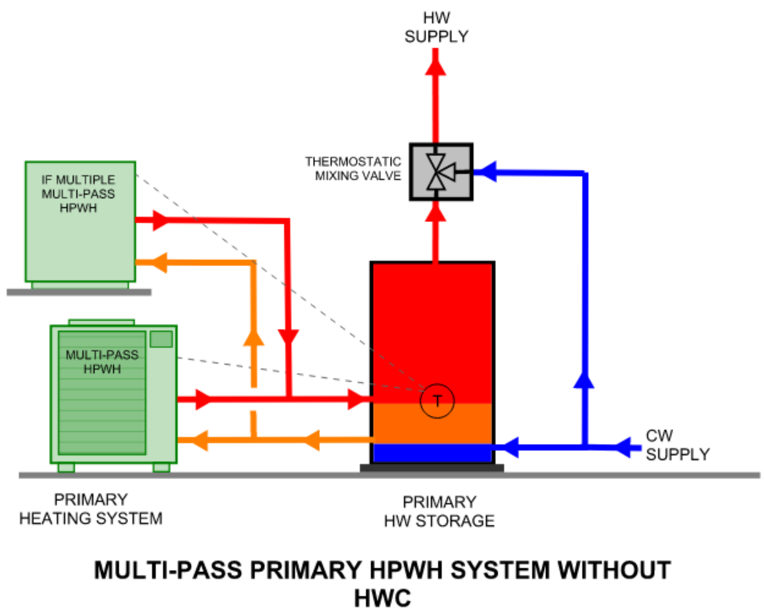
Control: The single-pass split system HPWH(s) is controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage.

System Sizing: The HPWH equipment is sized to meet the domestic hot water load. Multiple HPWHs are specified when a single HPWH cannot meet the load. A secondary electric resistance tank is provided for backup or redundancy and sized to meet the domestic hot water load.

Multi-Pass Primary HPWH System Without Hot Water Circulation

Narrative: This schematic is applicable for use with multi-pass HPWH equipment. One or more heat pumps (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. There is no hot water circulation system present in this system configuration.

Figure 8: Multi-Pass Primary HPWH System Without Hot Water Circulation



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the storage tank. Outgoing hot water is connected to the upper portion of the storage tank. The multi-pass split system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water approximately 10°F, and supply it to the middle portion of the storage tank. When multiple storage tanks are specified, the storage tanks are configured in parallel with equal flow through all parallel storage tanks. The outgoing hot water from the storage tank(s) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

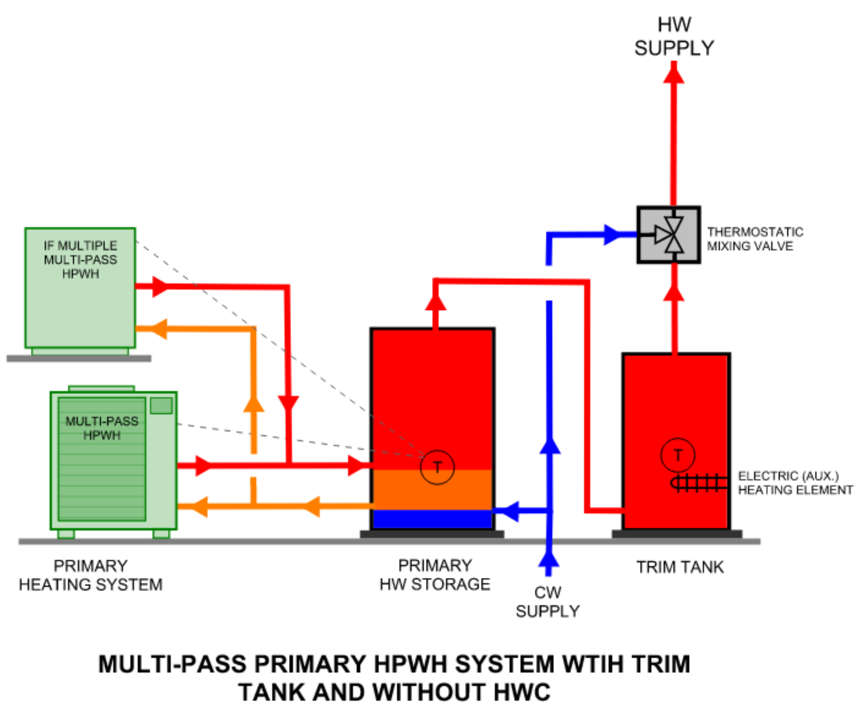
Control: The multi-pass split system HPWH(s) is controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage.

System Sizing: The HPWH equipment is sized to meet the domestic hot water load. Multiple HPWHs are specified when a single HPWH equipment cannot meet the load.

Multi-Pass Primary HPWH System with Secondary Electric Resistance Trim Heater Tank and Without Hot Water Circulation

Narrative: This schematic is applicable for use with multi-pass HPWH equipment in combination with a secondary electric resistance trim tank. One or more heat pumps (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. There is no hot water circulation system present in this system configuration.

Figure 9: Multi-Pass Primary HPWH System with Trim Tank and Without Hot Water Circulation



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the storage tank. Outgoing hot water is connected to the upper portion of the storage tank and passes through a secondary electric resistance trim tank. The multi-pass split system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water about 10°F, and supply it to the middle portion of the storage tank. When multiple storage tanks are specified, the storage tanks are configured in parallel with equal flow through all parallel storage tanks. The outgoing hot water from the storage tank(s) is connected to a secondary electric water heater piped in series. The outgoing hot water connection from the secondary electric resistance heater is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

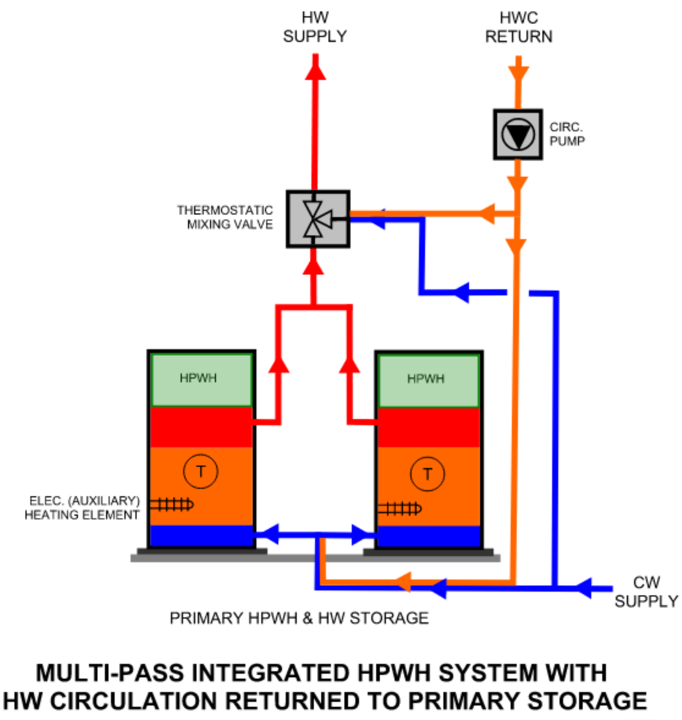
Control: The multi-pass split system HPWH(s) is controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage.

System Sizing: The HPWH equipment is sized to meet the domestic hot water load. Multiple HPWHs are specified when a single HPWH equipment cannot meet the load. A secondary electric resistance tank is provided for backup or redundancy and sized to meet the domestic hot water load.

Multi-Pass Integrated HPWH System with Hot Water Circulation

Narrative: This schematic is applicable for use with integrated HPWH equipment. One or more integrated HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system. The return water from the hot water circulation system is piped back to the primary heating system.

Figure 10: Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Primary Storage



Source: California Energy Commission

Piping Configuration: Cold water and return water from the hot water circulation system is supplied to the lower portion of the integrated HPWH equipment. Outgoing hot water is connected to the upper portion of the integrated HPWH equipment. When multiple integrated HPWHs are specified, the incoming cold water and return water from the hot water circulation system is supplied to the HPWH equipment, and outgoing hot water supply from the HWPH equipment is split and configured to supply equal flow to all integrated HPWH units. The outgoing hot water from the integrated HPWH(s) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

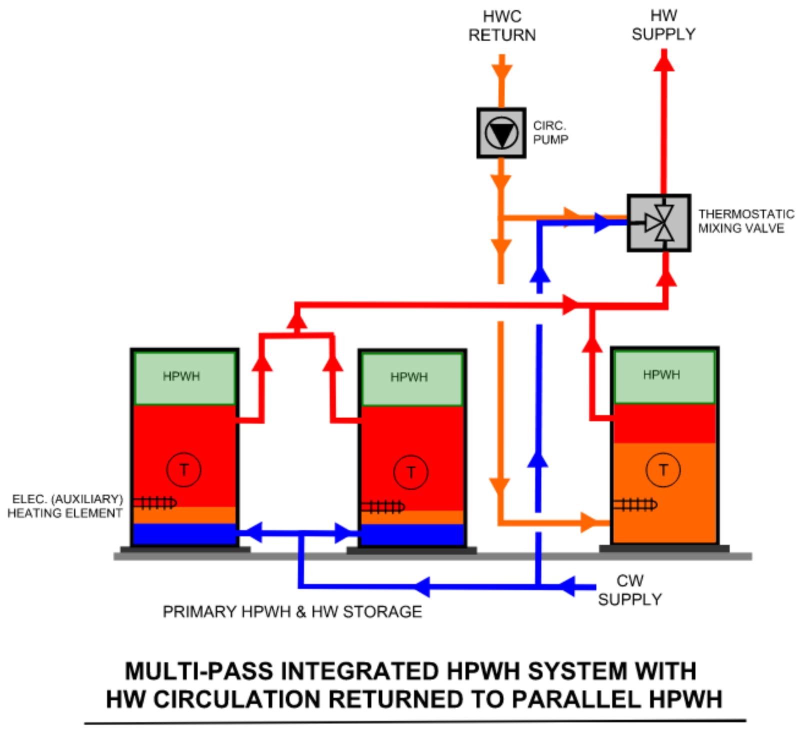
Control: The integrated HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use.

System Sizing: The integrated HPWH equipment is sized to meet the primary and temperature maintenance domestic hot water loads. Multiple integrated HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Parallel HPWH

Narrative: This schematic is applicable for use with integrated HPWH equipment serving the primary heating load in combination with a dedicated integrated HPWH in parallel to serve the temperature maintenance hot water circulation load. One or more integrated HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A dedicated integrated HPWH is configured in parallel with the primary HPWHs to treat the temperature maintenance load. The return water from the hot water circulation system is fed directly to the dedicated temperature maintenance HPWH. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 11: Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Parallel HPWH



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the integrated HPWH. Outgoing hot water is connected to the upper portion of the integrated HPWH. When multiple integrated HPWHs are specified to serve the primary heating load, the HPWHs are configured in parallel to supply equal flow rates through all integrated HPWH units. The outgoing hot water from the integrated HPWH(s) is connected to the hot supply side of the mixing valve. A dedicated integrated HPWH is configured in parallel with the primary HPWHs and serves the temperature maintenance load from the hot water circulation system. The two systems are piped together before connecting to the hot supply side of the thermostatic mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

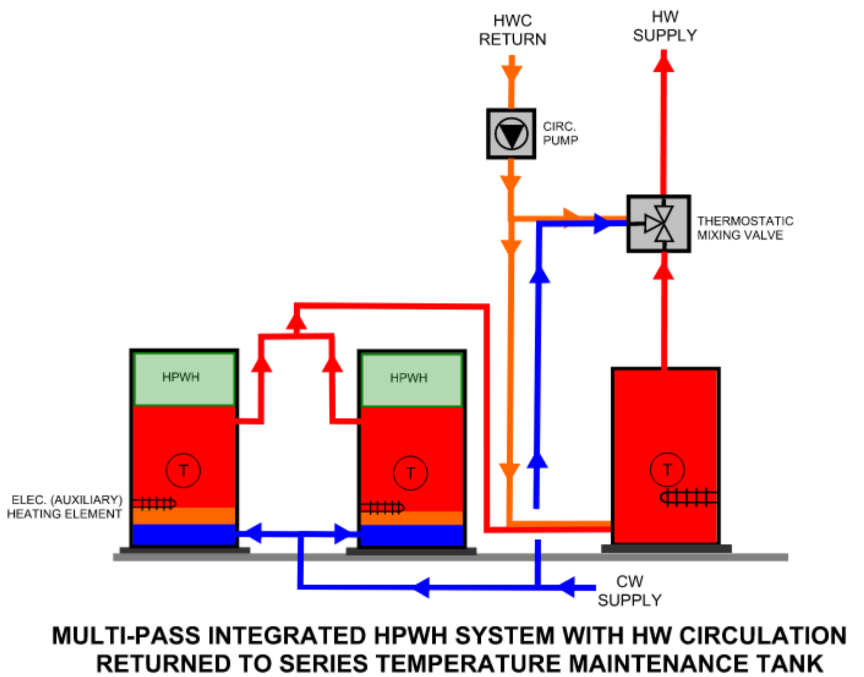
Control: The integrated HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use.

System Sizing: The integrated HPWH equipment is sized to meet the primary domestic hot water load. A dedicated integrated HPWH is also provided and sized to meet the temperature maintenance hot water circulation load. Multiple integrated HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Series Temperature Maintenance Tank

Narrative: This schematic is applicable for use with integrated HPWH equipment serving the primary heating load in combination with a dedicated in-series temperature maintenance tank (swing tank) to serve hot water circulation load. One or more integrated HPWHs (compressors) may be specified and are be piped in parallel. When multiple HPWHs are specified, they are piped in parallel. A dedicated electric water heater (swing tank) is configured in series with the primary HPWHs to treat the temperature maintenance load. The return water from the hot water circulation system is fed directly to the dedicated temperature maintenance tank. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 12: Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Series Temperature Maintenance Tank



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the integrated HPWH equipment. Outgoing hot water is connected to the upper portion of the integrated HPWH equipment. When multiple integrated HPWHs are specified to serve the primary heating load, the HPWHs are configured in parallel to supply equal flow rates through all integrated HPWH units. The outgoing hot water from the integrated HPWH(s) is connected to the bottom of the temperature maintenance tank (swing tank) so that it is in series with the primary system. The hot water outlet of the temperature maintenance tank (swing tank) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

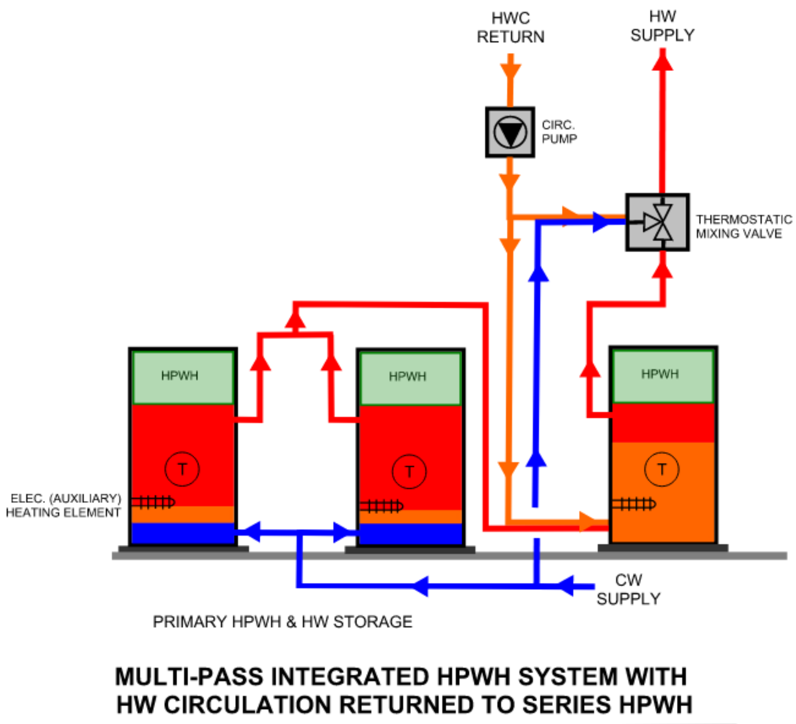
Control: The integrated HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use. The temperature maintenance tank includes an electric resistance heat element and is controlled by the internal electric water heater control system.

System Sizing: The integrated HPWH equipment is sized to meet the primary and temperature maintenance hot water domestic hot water load. The dedicated in series temperature maintenance tank is sized to meet the hot water circulation load. Multiple integrated HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Series Integrated HPWH

Narrative: This schematic is applicable for use with integrated HPWH equipment serving the primary heating load in combination with a dedicated in-series integrated HPWH to serve hot water circulation load. One or more integrated HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A dedicated integrated HPWH is configured in series with the primary HPWHs to treat the temperature maintenance load. The return water from the hot water circulation system is fed directly to the dedicated temperature maintenance tank. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 13: Multi-Pass Integrated HPWH System with Hot Water Circulation Returned to Series HPWH



Source: California Energy Commission

Piping Configuration: Cold water and return water from the hot water circulation system is supplied to the lower portion of the integrated HPWH equipment. Outgoing hot water is connected to the upper portion of the integrated HPWH equipment. When multiple integrated HPWHs are specified to serve the primary heating load, the HPWHs are configured in parallel to supply equal flow rates through all integrated HPWH units. The outgoing hot water from the integrated HPWH(s) is connected to the bottom of the temperature maintenance HPWH so that it is in series with the primary system. The hot water outlet of the temperature maintenance tank (swing tank) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

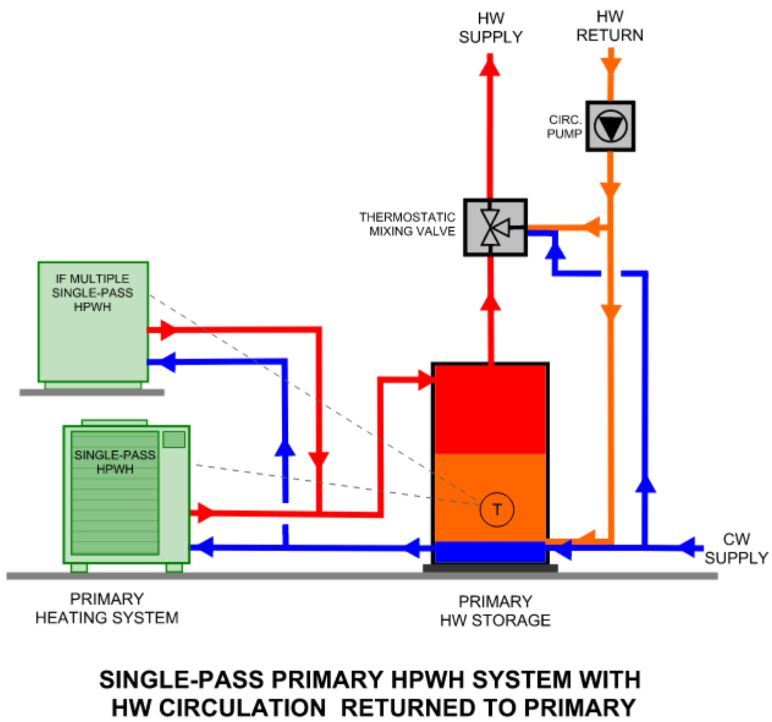
Control: The integrated HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use. The temperature maintenance integrated HPWH is controlled by the internal HPWH control system.

System Sizing: The integrated HPWH equipment is sized to meet the primary and temperature maintenance hot water domestic hot water load. The dedicated in-series integrated HPWH is sized to meet the hot water circulation load. Multiple integrated HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Single-Pass HPWH System with Hot Water Circulation Returned to Primary System

Narrative: This schematic is applicable for use with split system single-pass HPWHs. One or more split system single-pass HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. The return water from the hot water circulation system is fed back to the primary storage tank(s). A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 14: Single-Pass Primary HPWH System with Hot Water Circulation Returned to Primary



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the primary storage tank(s). The primary single-pass HPWHs pull water from the lower portion of the primary storage tank(s) and supply hot water to the top of the primary storage tank(s). When multiple split system single-pass HPWHs are specified to serve the primary heating load, the HPWHs are configured in parallel. The return water from the hot water circulation system is connected to the bottom of the primary storage tank(s). The hot water outlet of the primary storage tank(s) is connected to the hot supply side of the mixing valve. A cold water connection and hot water circulation connection are provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

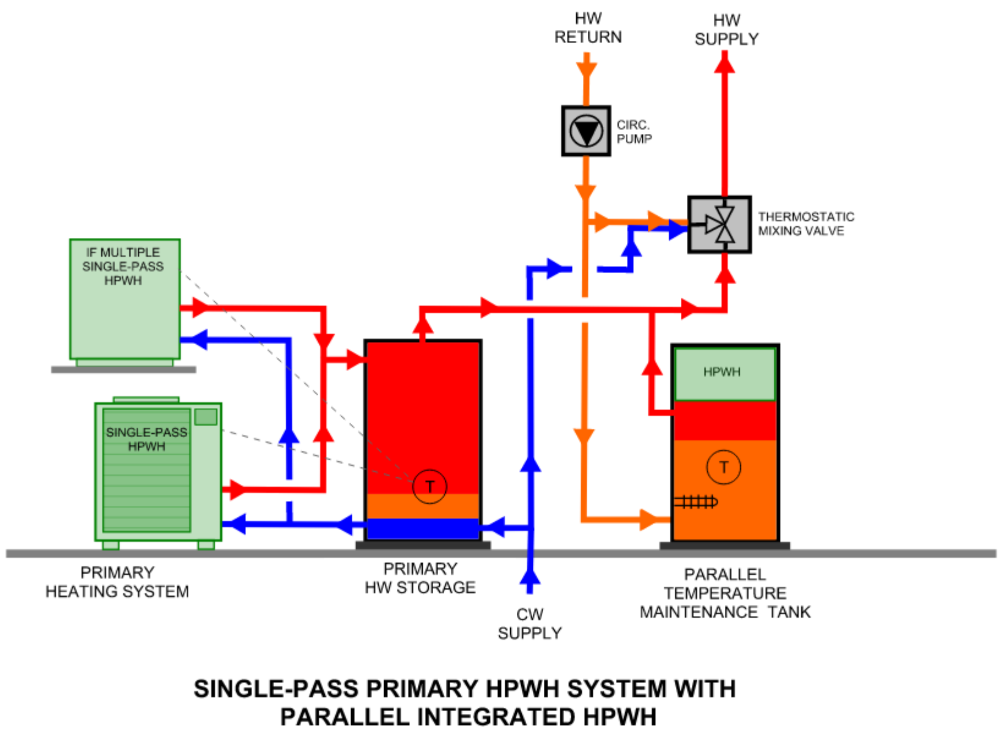
Control: The split-system single-pass HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use.

System Sizing: The split-system single-pass HPWH equipment is sized to meet the primary and temperature maintenance hot water domestic hot water load. Multiple split-system single-pass HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

Single-Pass Primary HPWH System with Parallel Integrated HPWH

Narrative: This schematic is applicable for use with single-pass HPWH in combination with a parallel integrated HPWH for temperature maintenance in the hot water circulation system. One or more heat pumps (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 15: Single-Pass Primary HPWH With Parallel Integrated HPWH



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the storage tank. Outgoing hot water is connected to the upper portion of the storage tank and connects to the hot supply side of the thermostatic mixing valve. The single-pass split-system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water to temperature, and supply it to the upper portion of the storage tank. When multiple storage tanks are specified, the storage tanks are configured in series with the top of the first tank connected to the bottom of the second tank. This top-to-bottom connection is repeated for all storage tanks in the series. The cold water is supplied to the lower portion of the first tank, and the outgoing hot water is supplied from the upper portion of the last storage tank in series. The outgoing hot water from the storage tank (or last storage tank in series) is connected to the hot supply side of the thermostatic mixing valve. An integrated HPWH is provided for temperature maintenance to keep the hot water circulation system at the set temperature. The return water from the hot water circulation system is connected to the lower portion of the integrated HPWH. The outlet of the integrated HPWH is connected in parallel with the hot outlet from the hot water storage tank. These two water paths combine before connecting to the hot-supply side of the thermostatic mixing valve. A cold water connection and the return water from the hot water circulation system are provided to the cold-supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

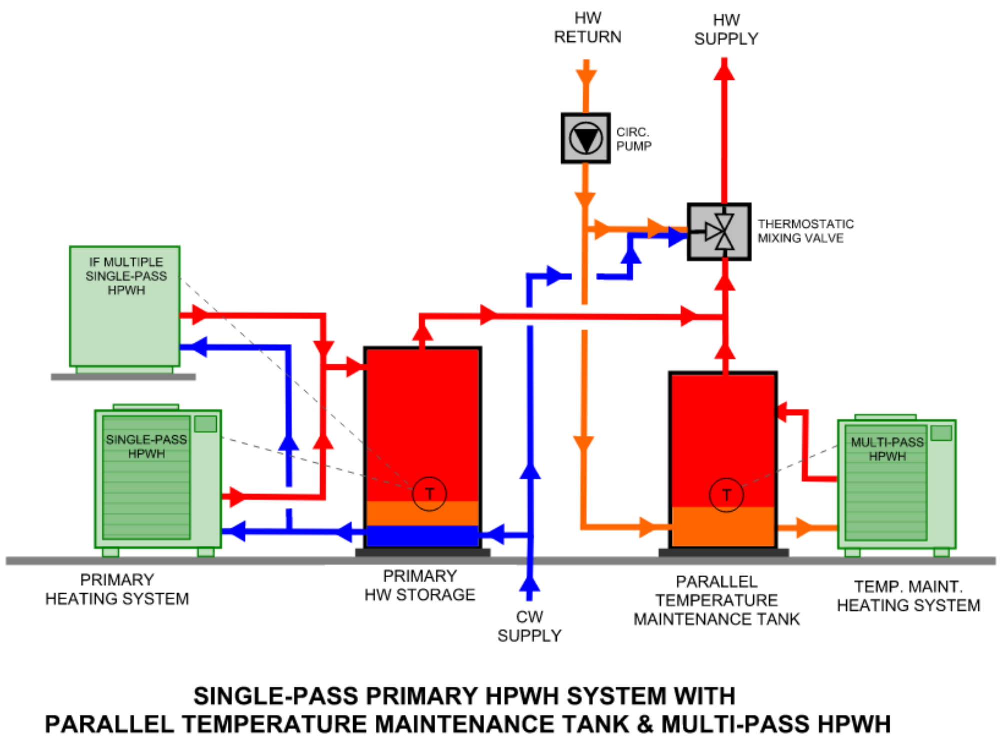
Control: The single-pass split-system HPWH(s) is controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage. The integrated HPWH that is part of the temperature maintenance system is controlled independently of the primary single-pass HPWH(s).

System Sizing: The HPWH equipment is sized to meet the primary domestic hot water load. Multiple HPWHs are specified when a single HPWH cannot meet the load. An integrated HPWH is sized to meet the temperature maintenance load associated with the hot water circulation system.

Single-Pass Primary HPWH System with Parallel Multi-Pass HPWH

Narrative: This schematic is applicable for use with single-pass HPWHs in combination with a parallel temperature maintenance system with multi-pass HPWH. One or more primary HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A dedicated temperature maintenance system is provided to serve the hot water circulation load and is configured in parallel with the primary heating system. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 16: Single-Pass Primary HPWH with Parallel Temperature Maintenance Tanke and Multi-Pass HPWH



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the primary storage tank(s). Outgoing hot water is connected to the upper portion of the storage tank and to the hot-supply side of the thermostatic mixing valve. The single-pass split-system HPWH(s) is connected to draw water from the lower portion of the tank, heat this water to temperature, and supply it to the upper portion of the storage tank. A dedicated storage tank and multi-pass HPWH are provided and serve the hot water circulation temperature maintenance load. This system is configured in parallel with the primary heating system. The return water from the hot water circulation system is connected to the lower portion of the temperature maintenance storage tank. A multi-pass HPWH is connected to the dedicated temperature maintenance storage tank to provide heat to the system. The outlet of the temperature maintenance storage tank is connected in parallel with the hot outlet from the hot water storage tank so that these two water paths combine before connecting to the hot-supply side of the thermostatic mixing valve. A cold water connection and the return water from the hot water circulation system are provided to the cold supply side of the mixing valve. The outgoing tempered side of the mixing valve is connected to the building hot water distribution piping system.

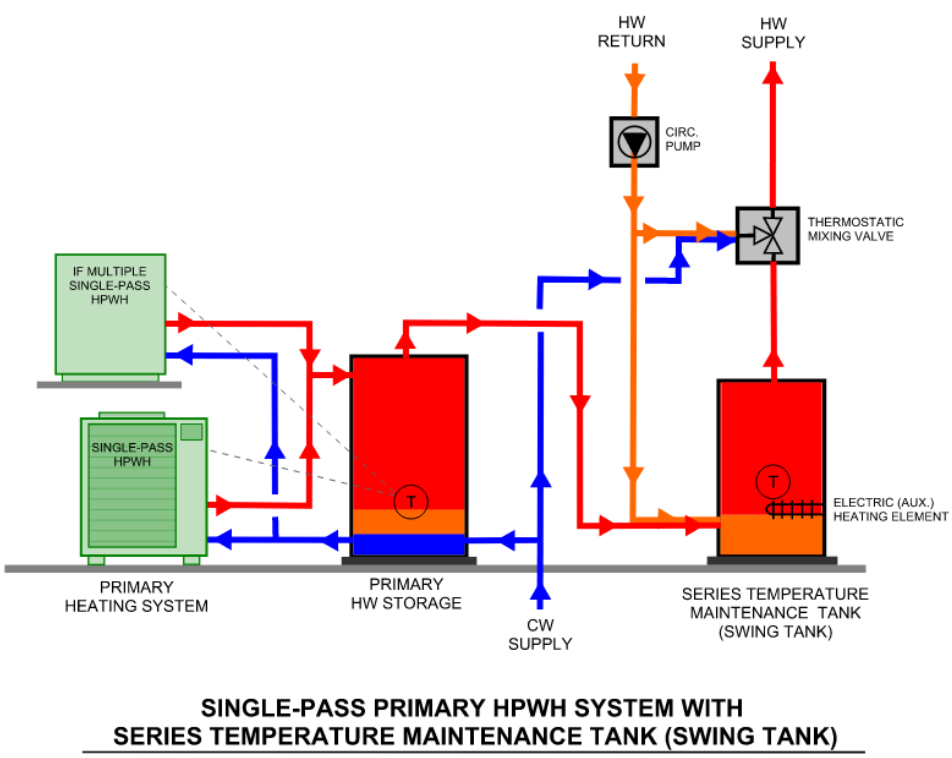
Control: The single-pass split-system HPWH(s) is controlled by a temperature sensor or multiple temperature sensors in the primary storage tank(s). Multiple parallel HPWHs are controlled in a single stage. The multi-pass HPWH that is part of the temperature maintenance system is controlled independently of the primary single-pass HPWH(s).

System Sizing: The HPWH is sized to meet the primary domestic hot water load. Multiple HPWHs are specified when a single HPWH cannot meet the load. The multi-pass HPWH is sized to meet the temperature maintenance load associated with the hot water circulation system.

Single-Pass Primary HPWH System with Series Temperature Maintenance Tank

Narrative: This configuration is used for the standard design system. This schematic is applicable for use with single-pass HPWH serving the primary heating load in combination with a dedicated in-series temperature maintenance tank (swing tank) to serve hot water circulation load. One or more single-pass HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. A dedicated temperature maintenance tank (swing tank) is configured in series with the primary HPWHs to treat the temperature maintenance load. The return water from the hot water circulation system is fed directly to the dedicated temperature maintenance tank. A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 17: Single-Pass Primary HPWH with Series Temperature Maintenance Tank (Swing Tank)



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the primary storage tank(s). Outgoing hot water is connected to the upper portion of the primary storage tank(s). When multiple single-pass HPWHs is specified to serve the primary heating load, the HPWHs are configured in parallel. The single-pass split-system HPWH(s) are connected to draw water from the lower portion of the tank, heat this water to temperature, and supply it to the upper portion of the storage tank. A dedicated temperature maintenance tank is provided. The outgoing hot water from the primary storage is connected to the bottom of the temperature maintenance tank (swing tank) so that it is in series with the primary system. The hot water outlet of the temperature maintenance tank (swing tank) is connected to the hot supply side of the mixing valve. A cold water connection is provided to the cold-supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

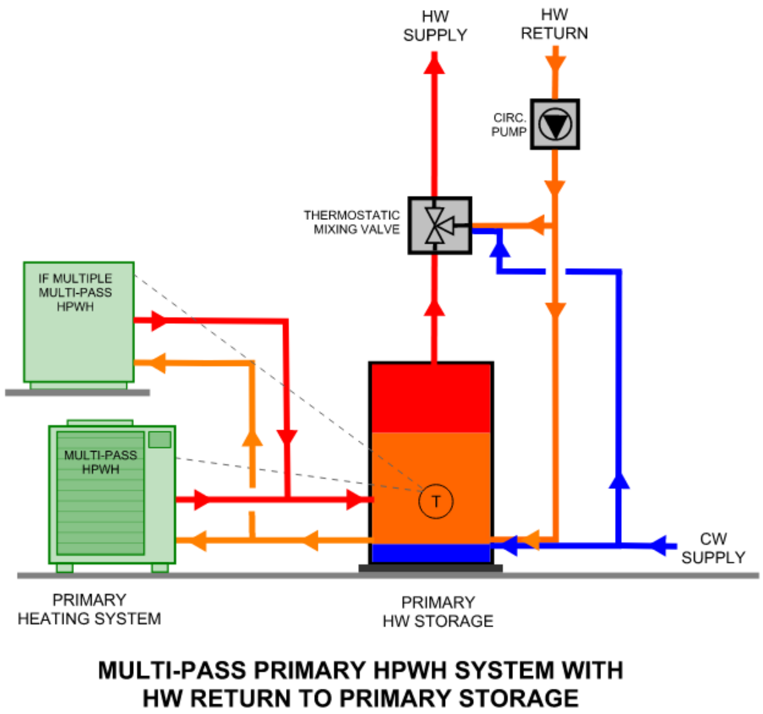
Control: The single-pass HPWH equipment is controlled by the internal equipment control system to prioritize compressor heating energy use and minimize auxiliary electric resistance heating energy use. The temperature maintenance tank includes an electric resistance heat element and is controlled by the internal electric water heater control system.

System Sizing: The single-pass HPWH equipment is sized to meet the primary and temperature maintenance hot water domestic hot water load. The dedicated in-series temperature maintenance tank is sized to meet the hot water circulation load. Multiple single-pass primary HPWHs are specified when a single HPWH cannot meet the load.

Multi-Pass HPWH System with Hot Water Circulation Returned to Primary System

Narrative: This schematic is applicable for use with split-system multi-pass HPWH equipment. One or more multi-pass HPWHs (compressors) may be specified. When multiple HPWHs are specified, they are piped in parallel. The return water from the hot water circulation system is fed back to the primary storage tank(s). A thermostatic mixing valve is provided to temper the hot water supplied to the building hot water distribution system.

Figure 18: Multi-Pass Primary HPWH System with Hot Water Return to Primary Storage



Source: California Energy Commission

Piping Configuration: Cold water is supplied to the lower portion of the primary storage tank(s). The primary multi-pass HPWHs pull water from the lower portion of the primary storage tank(s) and supply hot water to the middle portion of the primary storage tank(s). When multiple multi-pass HPWHs are specified to serve the primary and temperature maintenance heating loads, the HPWHs are configured in parallel. The return water from the hot water circulation system is connected to the bottom of the primary storage tank(s). The hot water outlet of the primary storage tank(s) is connected to the hot supply side of the mixing valve. A cold water connection and hot water circulation connection are provided to the cold supply side of the mixing valve. The tempered side of the mixing valve is connected to the building hot water distribution piping system.

Control: The split-system single-pass HPWH is controlled by the internal equipment control system to prioritize compressor heating energy use.

System Sizing: The split-system multi-pass HPWH is sized to meet the primary and temperature maintenance hot water domestic hot water load. Multiple split-system multi-pass HPWHs are specified when a single integrated HPWH equipment cannot meet the load.

APPENDIX C: PHOTOVOLTAICS

Photovoltaics

Compliance software shall calculate energy generated by photovoltaic (PV) systems on an hourly basis using the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM) algorithms upon which the PVWatts program is based (see Appendix F), or using a similar calculation method approved by the Energy Commission. PV systems with and without sub-array power electronics (i.e., microinverters and DC power optimizers) are further considered based on user inputs. Appendix C describes calculations and assumptions used in the California Building Energy Code Compliance (CBECC) and CBECC-Res compliance managers.

Power electronics are used to help minimize efficiency losses when the output of sub-array components (e.g., modules or cells) operate under different conditions. The largest driver of variation in conditions across a PV array is partial shading from nearby obstacles. A small fraction of shaded cells could lead to disproportionate reductions in PV power output. PVWatts, does not explicitly handle this effect. Literature describes a shading impact factor (SIF) which is the ratio of relative power output to fraction shaded:

$P_{sh} = P_{sys} \cdot (1\text{-}SIF \cdot f_{sh})$

Where P_{sh} is the power output of the shaded system, P_{sys} is the power output of the unshaded system, and f_{sh} is the fraction shaded.

A value of 1.0 implies that the power output declines proportionally to the fraction shaded. This is a theoretical minimum value of SIF in that it implies there are power electronics that are maintaining output consistent with the level of shading across the module. A value greater than 1.0 implies that shading has a disproportionate effect on system output.

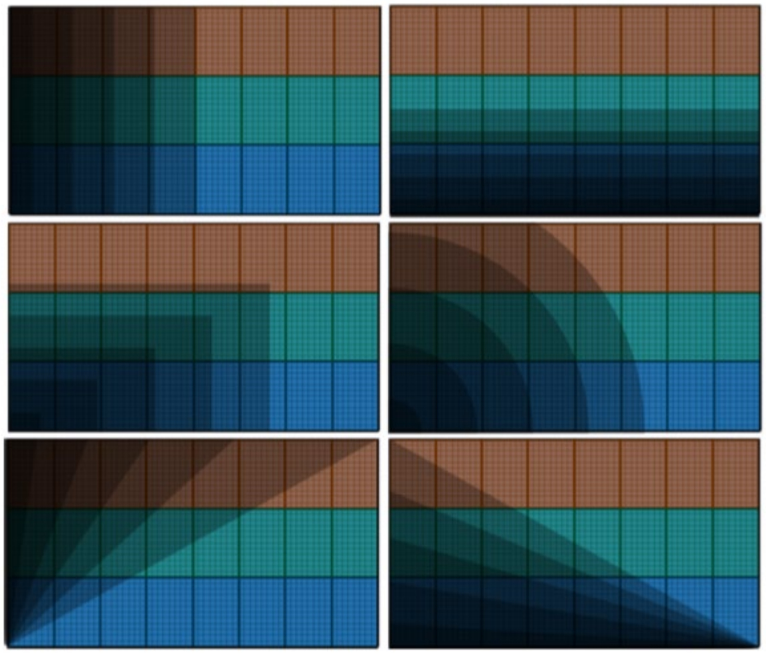
How the individual cells within an array are shaded can have a significant impact on SIF. This is illustrated in a study on a PV module without power electronics (see

Figure C-1).

In this study the same module was shaded in different fashions (see Figure C-2). For a given shade ratio, the actual output from the PV system can differ by 30 percent depending on which portions of the system are shaded (Note: the dotted lines in the first figure represent SIF values of 1.0 [y = 1 – 1.0*x] and 2.0 [y = 1 – 2.0*x] and serve as approximate bounds on the impact). Without cell-level fidelity in our shading model, it is impossible to know which specific cells are shaded at any given time. The compliance software will use a coarse approximation of SIF appropriate for panel and/or array level analysis.

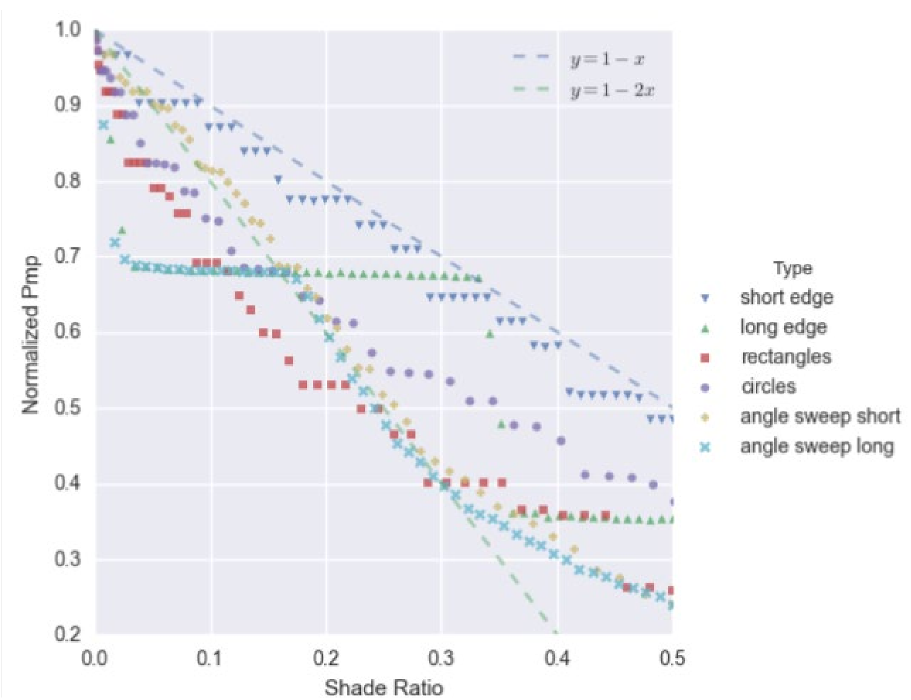
SIF should also change with higher levels of irradiance as shown in this study (see Table C-2). However, considering the coarseness of array-wide shading fraction (vs. cell-by-cell), accounting for this effect is not likely to provide a substantial increase in overall accuracy.

FIGURE C-1



Source: California Energy Commission

FIGURE C-2



Source: California Energy Commission

One problem with applying shading impact factors directly to the power output of the system is that there is a theoretical lower limit to PV production under shaded conditions: diffuse irradiance. Unless a cell is also blocked from diffuse solar (e.g., the shade is very close to the panel and blocking cells from the rest of the sky), all cells will receive a minimum level of incidence. To account for this, we propose introducing an alternative formulation using an "effective" plane-of-array incidence, where only the beam component is affected by shading.

$I_{poa,eff} = I_{poa,diff} + I_{poa,beam,eff}$

$I_{poa,beam,eff} = \max(I_{poa,beam}*(1\text{-}SIF*f_{sh}), 0.0)$

The compliance software shall use an SIF value of 2.0 for central inverters (CEC default) and a value of 1.2 for systems with power electronics (based on a 40 percent shade loss recovery as defined in this paper--see Table C-2. SIF for Total Inverter Efficiency).

System Loss Assumptions

In PVWatts, a single derating factor is used to cover a variety of system inefficiencies. The compliance software uses slightly different assumptions for this derating factor as described in the table below:

TABLE C-1. DERATING FACTOR

Loss Type	Value	Differences from PVWatts Default Assumptions
Soiling	0.02	N/A
Shading	0.0	Modeled explicitly
Snow	0.0	N/A
Mismatch	0.0	Mismatch from shading is characterized using SIF
Wiring	0.02	N/A
Connections	0.005	N/A
Light-induced degradation	0.015	N/A
Nameplate rating	0.01	N/A
Age	0.05	Estimated 0.5 percent degradation over 20 years based on these references: [1, 2, 3]
Availability	0.03	N/A
Total	0.14	N/A

Source: California Energy Commission

Inverter Efficiency

The software shall characterize the inverter efficiency corresponding to either a central inverter or microinverters depending on the type of power electronics used in the system.

Power Electronics

Options for power electronics are described below:

TABLE C-2. SIF FOR TOTAL INVERTER EFFICIENCY

Option	SIF	Total Inverter Efficiency
None	2.0	User input
Microinverters	1.2	User input
DC Power Optimizers	1.2	Optimizer efficiency * user input

Source: California Energy Commission

Optimizer efficiencies are assumed to be 0.99 (corresponding to suggestions in this document).

Space Function to PV/Battery Building Type Mapping

The software shall determine the size of the building PV and battery system based on the PV Capacity Factors and Battery Storage Capacity Factors from Energy Code Tables 140.10-A/170.2-U and 140.10-B/170.2-V. The PV Capacity Factors identify the capacity of a PV system based on the climate zone, building type, and conditioned floor area. The Battery Storage Capacity Factors identify the Energy Capacity or Power Capacity based on the building type and PV capacity. The default mapping of space function to PV capacity factor building type is in Appendix 5.4A. Default PV/Battery Building Type is editable so that users may adjust factors to match the proposed building type, or multiple building types when one or more are in the proposed building, according to definitions and requirements in the Energy Code.

Battery Storage

See Status of Modeling Batteries for California Residential Code Compliance, Appendix D.

APPENDIX D – STATUS OF MODELING BATTERIES FOR CALIFORNIA SINGLE-FAMILY AND MULTIFAMILY RESIDENTIAL CODE COMPLIANCE

D1 Modeling of Residential Battery/PV Systems for Self-Utilization Compliance Credit

Overview

The California Energy Commission added a self-utilization credit for residential battery systems to its residential building energy efficiency standards for 2019. Under these standards, a residential battery paired with an on-site photovoltaic (PV) system would receive fair credit toward the long-term system cost (LSC) energy. This document defines how the CBECC-Res compliance software will produce the battery credit for single-family residential buildings, and how compliance software will produce the battery calculations within the compliance framework for multifamily residential buildings.

Whereas most energy upgrades reduce energy use in a house or multifamily building, battery systems actually increase electricity consumption in exchange for some shaping of the load. A 14-kWh battery, with a 90% round-trip efficiency, that cycles 13 of those kWh 300 times a year, will consume 4.1 MWh of electricity and discharge 3.7 MWh of electricity per annum. But by charging when there is excess PV production and discharging when PV production is low and electricity is expensive, the battery both saves money for the residence and provides value to the electricity system overall. Thus, the single-family and multifamily self-utilization credit must account not for energy savings, but for savings in value-of-energy.

Distributed electric storage can provide value to the electricity system overall through load shaping and other behaviors. Bolstering demand during low periods helps to leave efficient power plants running full time and reduces ramping requirements. Reducing peak demand helps in a number of ways, including by allowing expensive peaker plants to remain idle more days of the year. In addition, having the batteries on-site can help reduce wear-and-tear on distribution systems.

D2 Long-term System Cost (LSC) and Source Energy

The 2025 Building Energy Efficiency Standards use LSC energy to account for the time value of energy for load and for self-generation credit. LSC is a composite measure of the actual cost of energy (for each of electricity, natural gas, and propane) to the utility, customers, and society at large. It has been crafted for evaluating energy efficiency savings based on when those savings manifest.

The LSC concept allows even-footing comparison of a set of time-series simulations of how different building designs use energy. Accordingly, it is the mechanism by which the CBECC-Res (for single-family residential) and compliance software for multifamily residential converts a residential battery's load shaping patterns into a self-utilization credit. If a building charges a battery from on-site PV during midday, the simulation foregoes a small LSC credit for power it would have fed to the grid. When the battery discharges in the evening, it can earn a much larger credit for reducing load when LSC is high. That net-LSC reduction counts toward reducing the single-family residential or the multifamily residential building's performance with respect to the compliance margin.

The 2025 Building Energy Efficiency Standards also useSource Energy factors to determine compliance for single-family residential and multifamily residential buildings.

D3 Calculating Compliance

For single-family residential buildings, CBECC-Res calculates compliance for a proposed design based on LSC energy, and Source Energy.

Compliance for a proposed design in CBECC-Res and compliance software for multifamily residential has three requirements:

1. The LSC, ignoring contributions from renewable generation and battery storage (except for the self-utilization credit described below), must be equal or lower than the LSC of the code prescriptive standard design (also ignoring contributions from renewable generation and battery storage). These values are called the Efficiency LSC for the respective proposed and standard designs. The intent of this requirement is to encourage designs that reduce loads in addition to generating energy.
2. The LSC of the final design (including contributions from renewable generation and battery storage) must be equal or lower than the LSC of the code prescriptive standard design (also including contributions from renewable generation and battery storage). These values are called the Total LSC for the respective proposed and standard designs.
3. The Source Energy of the proposed design must be equal or lower than the Source Energy of the standard design.

A minimum of six annual calculations are required to evaluate the compliance of a specific proposed design:

1. Proposed design the Efficiency LSC
2. Proposed design the Total LSC
3. Proposed design Source Energy
4. Standard design the Efficiency LSC
5. Standard design the Total LSC
6. Standard design Source Energy

The specific computations that produce these values are described in the Nonresidential and Multifamily Alternative Compliance Method (ACM) Reference Manual. The standard design is also described in the ACM.

Self-Utilization Credit

Initially implemented in the 2019 energy code, the self-utilization credit for a residential battery system allows proposed designs with PV systems and batteries (5 kWh or larger) to subtract additional LSC from the Efficiency LSC of the proposed design. The self-utilization credit is capped at a fraction of the PV-related LSC of the standard design. The cap varies by climate zone and is between 7% and 14% for a single-family residence and between 2% and 9% for a multi-family building.

The actual credit applied to the Efficiency LSC of the proposed design is the lesser of the battery related LSC in the final proposed design and the cap defined above. Effectively, the self-utilization credit allows the proposed the Efficiency LSC design to also get credit for a portion of the LSC savings that would otherwise be seen only in the final design.

D4 Compliance Software Requirements

Appendix JA12 provides the qualification requirements for energy storage systems.

Compliance software for multifamily buildings must consider usable capacity when determining the effect of energy storage on multifamily building performance. Usable capacity is the energy storage capacity in kWh that a manufacturer allows to be used for charging and discharging. For performance compliance, the usable capacity must be a minimum of 5 kWh.

Compliance software for multifamily buildings must model the time of use strategy and controls for separate energy storage systems as described in Appendix JA12. Software may also model the basic control strategies as described in Appendix JA12.

D5 CBECC-Res, CBECC and California Simulation Engine (CSE) Software Packages

Annual building loads used in the annual LSC calculation for single-family buildings in CBECC-Res and for multifamily buildings in CBECC are simulated using the underlying California Simulation Engine (CSE). CSE models the thermal and electrical interactions within a building. CBECC-Res and CBECC generates CSE input files based on the Title 24 rulesets. Separate CSE inputs files are created to simulate the standard design, and proposed design. For single-family buildings, CBECC-Res then processes the CSE simulation results to determine the Efficiency LSC, the Total LSC, and the Source Energy values as described in the previous section. Similarly for multifamily buildings, CBECC processes the CSE simulation results to determine the Efficiency LSC, the Total LSC, and the Source Energy values described in the previous section.

While the capability of CBECC-Res and CBECC are intentionally constrained by ruleset definitions, CSE has much greater flexibility to simulate a wide range of building components. CSE has the unique capability to define dynamic battery system control strategy using its built-in expression language. CSE predicts the building load and PV generation and operates the battery according to expressions pre-defined by CBECC-Res and CBECC rules.

D6 Battery Representation in CSE

In each simulated timestep, the control strategy sends a charge/discharge request to the battery module. The control strategies themselves are described in the next section. For now, it will suffice to say that the input to the battery module is a charge request (in kW) that can be either positive or negative.

```
charge_request > 0   // charge
charge_request < 0   // discharge
charge_request = 0   // do nothing
```

The battery has maximum charge and discharge rates (kW) with default values set based on the battery's size. CBECC-Res and CBECC define both defaults as the same fixed fraction (kW/kWh) of the battery's user-defined maximum capacity (kWh). The maximum capacity is based on the compliance cycling capacity in the case of single-family buildings, or the usable capacity in the case of multifamily buildings. These default values may be overridden with custom values by the user.

```
max_charge_power = 0.42 * max_capacity
max_discharge_power = 0.42 * max_capacity
```

And both a charge and discharge efficiency (fraction), which are user-defined:

```
η_charge
η_discharge
```

The user has the option to input a round-trip efficiency (fraction) as an alternative to inputting both the charge and discharge efficiencies. In this case, the charge and discharge efficiency would be equal to:

```
η_charge = sqrt(η_rte)
η_discharge = sqrt(η_rte)
```

At each timestep, there are also maximum charge and discharge limits (kW) defined by the state of charge on the battery. Charge and discharge power levels are measured at the battery's edge: before efficiency losses in the case of charging and after efficiency losses in the case of discharging. The battery's state-of-charge is metered between the two efficiency multipliers.

```
max_charge_available = (max_capacity - charge_level) /
                          η_charge * (timestep_minutes / 60)
max_discharge_available = charge_level * η_discharge *
                          (timestep_minutes / 60)
```

Altogether, that enables the module to determine the amount the battery should charge or discharge in the hour:

```
if charge_request > 0:
        charge_power = min(charge_request, max_charge_rate,
        max_charge_available)
else if charge_request < 0:
        charge_power = max(charge_request, max_discharge_rate,
        max_discharge_available)
else:
        charge_power = 0
```

At the conclusion of that timestep, the battery's charge level will have been updated:

```
if charge_power > 0:  // charging
        charge_level = charge_level + charge_power*η_charge
else if charge_power < 0  // discharging
        charge_level = charge_level + charge_power/η_discharge
else:
        charge_level = charge_level
```

D7 Battery Control Strategies in CSE

There are two battery control strategies enabled in CBECC-Res and CBECC: "Basic" and "Time of Use" (TOU). These strategies are responsible for the timestep-by-timestep charge requests that are sent to the CSE battery module.

Basic Strategy

The Basic strategy charges when a) production exceeds demand and b) the battery is not fully charged and discharges when a) demand exceeds production and b) the battery is not fully drained. That is, the battery both charges and discharges as soon as it can.

```
charge_request = -load_seen
```

By charging from any excess production and discharging as soon as it can to serve load, the basic strategy maximizes self-consumption of the on-site PV production. The other strategies account for the time-varying value of electricity (e.g., as measured by LSC) to varying degrees to increase the LSC-savings the battery provides.

If the battery system is standalone (no PV system), then basic control is not an available control option.

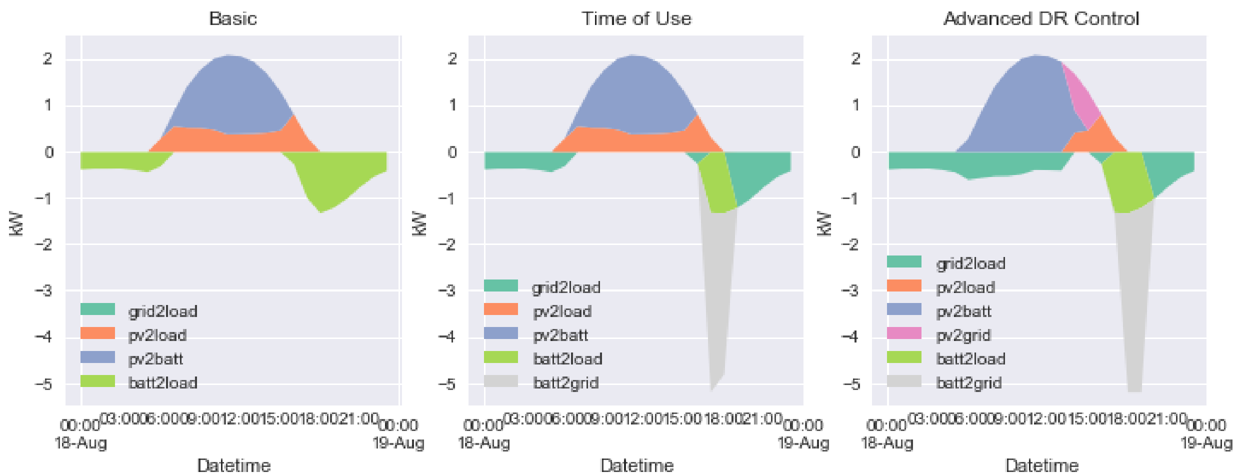


Figure 2: *Illustrations of the battery control strategies' different responses to a single day. Note that the TOU and Advanced strategies can discharge directly to the grid. Also notice that Advanced charges the battery from PV while serving loads from the grid.*

Time of Use Strategy

The TOU strategy attempts to preferentially discharge during high-value hours during a selected period of months. For a PV-tied system, the default duration for TOU months is July through September. For a standalone battery storage system, the default duration for TOU months is all year. Users can optionally input custom values for the first and last months to apply TOU control.

Charging rules are the same as the basic strategy for battery storage systems paired with a solar PV system. For standalone battery storage systems, the software provides a prescribed input to specify the hour of each day to start charging called "Charge Start Hour". The charging starts at midnight (hour 1) of each day.

Battery discharge follows the same approach for PV-tied and standalone batteries. The discharge period is statically defined (per climate zone) by the first hour of the expected TOU peak, which is a user-input within CBECC-Res and CBECC called "Discharge Start Hour." The default value for "Discharge Start Hour" is 19:00 for Climate Zones 2, 4, 8-15, and 20:00 for all other Climate Zones. The user has the option to change this value within CBECC-Res and CBECC if desired.

Consider a summer day in which the evening peak is defined to start at 20:00 but during which simulation load exceeds PV production during the 19:00 hour. While a simulation utilizing the Basic strategy would discharge to neutralize the net load during the 19:00 hour, a simulation on the TOU strategy would reserve the battery until 20:00 before commencing discharge. Because the LSC at 20:00 is likely to be higher than the LSC at 19:00, this strategy of reserving the battery for higher-value hours results in a lower (better) annual LSC.

A second difference: During the peak window, the battery is permitted to discharge at full power, even exceeding the site's net load. This is in contrast to the Basic strategy, which is limited to the net load.

```
if charge_start_hour <= this_hour < discharge_start_hour:
        charge_request = -min(load_seen, 0)   // only charge
else:
        charge_request = -1000   //  maximum discharge
```

Outside of selected months for the TOU strategy, control reverts to the Basic strategy.

Battery Parameters Included in CBECC-Res/CBECC/CSE

CBECC-Res and CBECC allow the modeler to adjust several battery parameters (Figure 4):

- Compliance cycling capacity/usable capacity(kWh): the CBECC-Res and CBECC software enforce a 5kW minimum size for the battery to qualify for the Self Utilization Credit.
- A checkbox to indicate if a standalone battery (no PV system) is modeled.
- Control strategy, chosen from the three options described in the Battery Control Strategies section of this appendix.
    - Note that "Basic" control is not an available control option for standalone battery systems

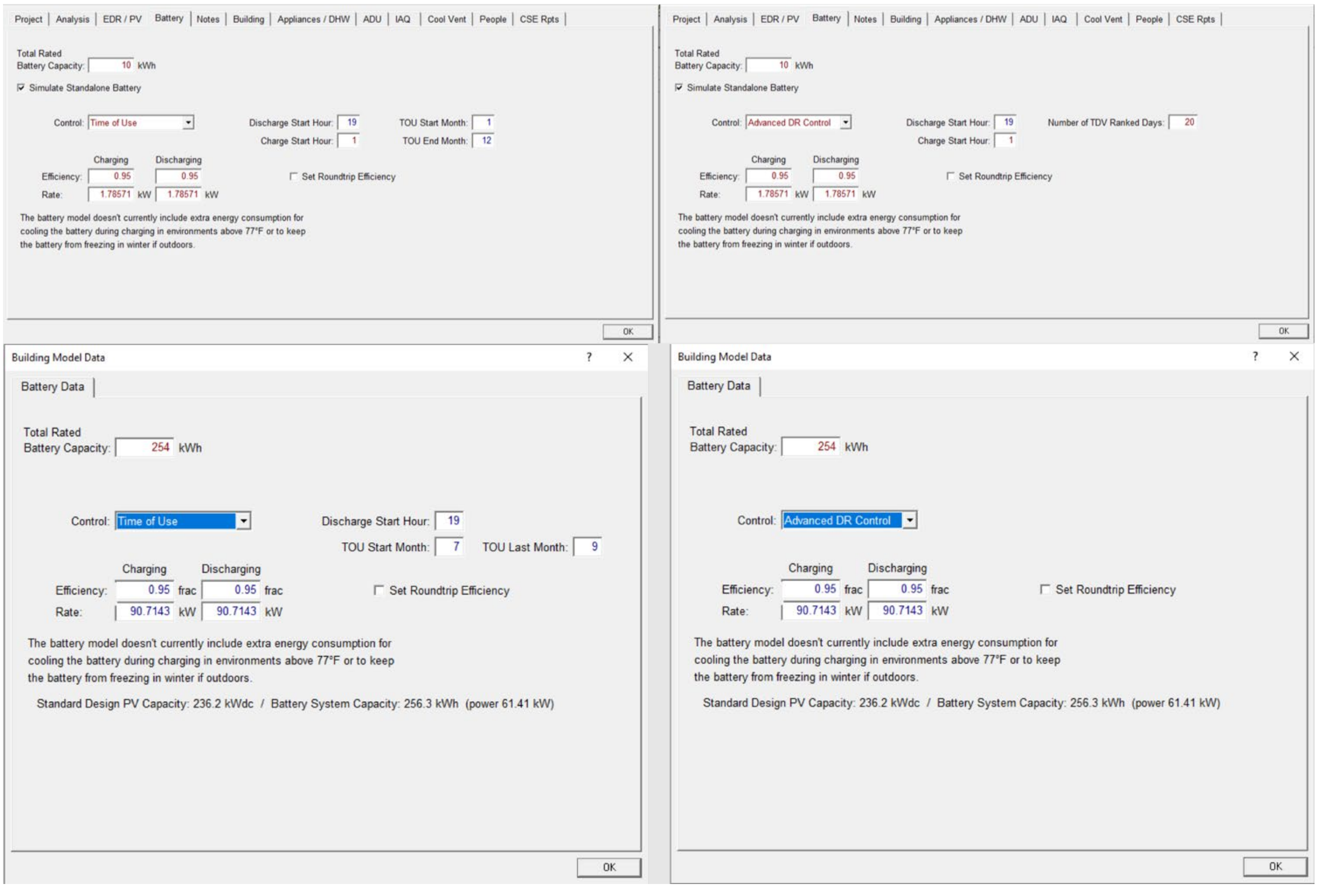


Figure 4: *The CBECC-Res (top) and CBECC (bottom) battery dialog box allows the modeler to set battery capacity, control strategy, charge/discharge efficiencies, and other control parameters related to charging and discharging hours and TOU months. Example images are shown for the TOU and Advanced DR Control options.*
(Source: screenshot of CBECC-Res and CBECC software user interface.)

- Charging and discharging efficiency (fraction): CSE allows charging and discharging efficiencies to be defined independently. The CBECC-Res and CBECC default is 0.95 for each, resulting in a default round-trip efficiency of 0.9025.
  - A single input for round-trip efficiency may be input by selecting the checkbox "Set Roundtrip Efficiency" (as shown in Figure 4). When checked, the inputs for charge and discharge efficiency are hidden and only the round-trip efficiency input is shown. Round-trip efficiency inputs less than 80% will result in no battery included in the simulation.
- Charge start hour may be input for standalone battery systems. Discharge start hour may be input for standalone and PV-tied battery systems. Allowable inputs are integers between 1 and 24 (inclusive).

- TOU period start and end months may be input. Allowable inputs are integers between 1 and 12 (inclusive).

CBECC-Res and CBECC also makes a set of assumptions to set CSE battery parameters. These are parameters that can be set in the lower-level CSE but that CBECC-Res and CBECC define itself.

- CBECC-Res and CBECC assume that the input battery capacity is the capacity of a brand new system. To account for aging across the battery's life cycle, the software derates the effective battery compliance cycling capacity for single family buildings, or the usable capacity for multifamily buildings to 85% of the input battery capacity. A nominal 10 kWh battery gets 8.5 kWh of usable capacity in the simulation.
- The 85%-of-input-capacity figure interrelates with the fact that battery systems often have different published values for total and usable capacity. The battery management system prevents complete discharges, so the usable capacity is typically single-digit percentages lower than the total capacity (e.g., the Powerwall 2 has 14 kWh total and 13.5 kWh available energy). CBECC-Res and CBECC should clarify whether the input capacity should be total or useful, and the degradation derate figure should be consistent with the input CBECC-Res and CBECC expect.
- CBECC-Res and CBECC derive the CSE parameters Maximum charge rate and Maximum discharge rate (kW/hr) from the battery capacity. They are each defined to be battery capacity * 0.42. That is, the battery is sized to have 2.38 hours of storage at full discharge. (1/0.42 = 2.38). That ratio is likely derived from the 14 kWh capacity and 5 kW discharge power of the Powerwall 2: 14 * 0.85 / 5 = 2.38.
- The battery is assumed to start the simulation fully discharged. It is not required to be fully charged at the conclusion of the simulation.
- Battery-PV installations come in a range of electrical configurations, sometimes with independent inverters for each component (AC-coupled), sometimes sharing an inverter (DC-coupled). CSE assumes an AC-battery-module electrical configuration as shown in Figure 5. The modeling implication of that configuration is that the user-input battery charge and discharge efficiencies should include the losses associated with the battery module's onboard inverter. In CSE, the PV system always has a dedicated PV inverter.

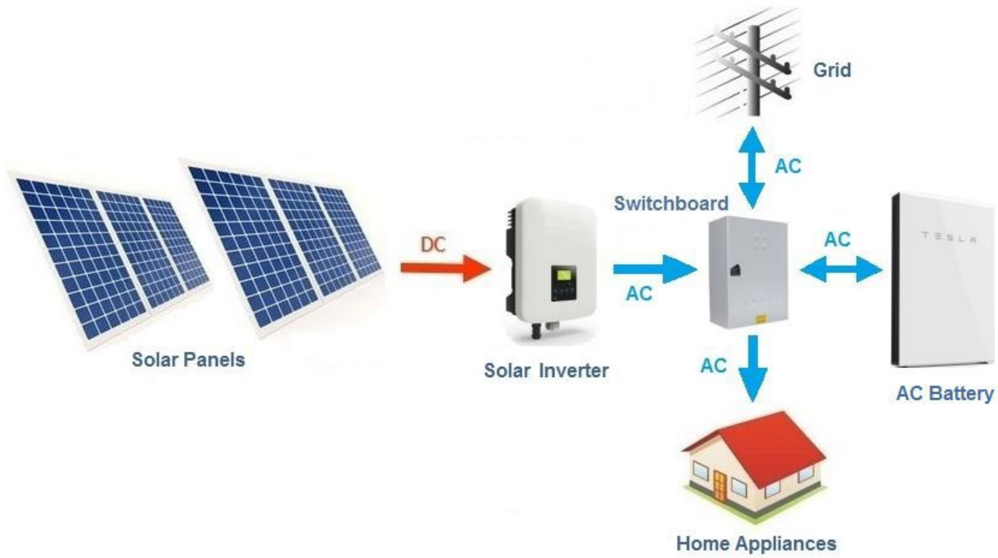


Figure 5: General diagram of an AC battery module layout of a residential PV-battery system. (Source https://www.cleanenergyreviews.info/blog/ac-coupling-vs-dc-coupling-solar-battery-storage.)

Simulated battery performance is static in the current CSE implementation. In particular, charge and discharge efficiencies do not vary with either charge rate or temperature. In real-world battery systems, efficiency falls from the benchmark a) with age, b) under rapid charging/discharging, and c) when temperatures are outside an ideal range (e.g., 25 °C/77 °F).

A real-world battery's usable capacity is also subject to age and external conditions. Low temperatures, especially, reduce a battery's in-the-moment usable capacity. CSE neglects those effects as well. The long-term dynamics of how batteries age warrants its own section, below.

The existence of a battery in the CBECC-Res and CBECC models also relaxes size limits on PV systems. Without onsite storage, the PV system is limited by the interconnection rule: solar generation must not exceed the building's electricity consumption over the course of a year. Title 24, Part 6 allows a building with a battery larger than 5 kWh to have a PV system that produces up to 1.6 times the building's annual electricity consumption. The CBECC-Res and CBECC software implement this change.

APPENDIX E – PLUG LOADS AND LIGHTING MODELING

1.1 Appliances, Miscellaneous Energy Use and Internal Gains

Full details of the assumptions for lighting and appliance loads are found in the Codes and Standards Enhancement Initiative (CASE) Plug Loads and Lighting Modeling (Rubin 2016, see Appendix D).

1.1.1 Background

Rulesets for all plug loads (including appliances and miscellaneous electric loads (MELs)) and lighting loads were updated in 2016. The CASE report describes the methodology, data sources, and assumptions used to develop the rulesets. The updated methodology replaces the rulesets from the 2019 *Residential Alternative Calculation Method (ACM) Reference Manual* (ACM Reference Manual), which in turn referenced the 2008 California Home Energy Rating System (HERS) Technical Manual.

The rulesets were modified to reflect efficiency levels assuming 2017 federal code baseline or 2017 projected market average performance, depending on whether or not a product is regulated by federal energy efficiency standards. Miscellaneous loads were disaggregated so that the three largest loads in this group—televisions, set-top boxes, and computers and monitors—are modeled individually. The remaining miscellaneous loads are modeled in aggregate. Garage lighting is also disaggregated from interior lighting. Assumptions about how energy use scales with building size were updated for all plug load and lighting end uses.

Updated load profiles were proposed for the majority of the modeled plug load and lighting end uses. The proposed updates include revisions to both the hourly schedules and seasonal multipliers. The updated load profiles are based on the water heating models described in section 2.9 of the ACM Reference Manual for the applicable end uses and otherwise on recent submetering studies.

1.1.2 Approach

Rulesets for all modeled end uses reflect the estimated energy consumption of those devices in new homes built during the 2025 Title 24 Code Cycle. The plug load rulesets estimate annual energy consumption (AEC) as a function of number of bedrooms (BR/Unit) and the lighting rulesets estimate AEC as a function of conditioned floor area (CFA/Unit). The relationship between AEC and BR/Unit for dishwashers, clothes washers, and clothes dryers was based on the usage assumptions in the water heating model. The relationship between all other plug load AEC and BR/Unit was generally derived from the 2009 Residential Appliance Saturation Survey (RASS), through a statistical and engineering analysis that applied modern efficiency assumptions to estimate what the AEC of plug loads within homes included in the 2009 RASS would be if they were built during the 2016 Title 24 code cycle. The relationship between lighting AEC and CFA/Unit was derived using a similar analysis completed on the RASS data but using data from the 2012 California Lighting and Appliance Saturation Survey.

With additional user inputs, the default AEC equations for primary refrigerators, clothes washers, and clothes dryers can be modified to reflect the efficiency of the devices that are actually installed in the building. That is, the modeled energy use can be adjusted downward if more efficient devices are installed (the software tool can also adjust energy use upward if devices are less efficient).

Updated load profiles are derived from the following data sources:

- **Dishwashers, clothes washers, and clothes dryers:** updated to be consistent with the usage patterns assumed by water heating models described in the ACM Reference Manual.
- **Ovens, cooktops, and televisions:** based on data from the Phased Deep Retrofit (PDR) study conducted by the Florida Solar Energy Center (FSEC), which submetered 60 Florida homes in 2012.
- **Set-top boxes, computers, and monitors:** based on the Northwest Energy Efficiency Alliance (NEEA) Residential Building Stock Assessment (RBSA), released in 2014. This study monitored 100 homes in the Pacific Northwest over the course of one year, submetering major end uses at 15 minute intervals.
- **Exterior lighting:** the proposed hourly schedule for exterior lighting is derived from the NEEA RBSA light logging data; the proposed exterior lighting seasonal multipliers are no longer constant, but instead equivalent to the interior and garage seasonal multipliers.

Load profiles for interior lighting, garage lighting, and residual MELs were not updated in 2016. The current hourly schedules for interior lighting are based on the 1999 Heschong Mahone Group (HMG) study “Lighting Efficiency Technology Report: California Baseline.” The current hourly schedule for residual MELs is derived from the 2008 Building America House Simulation Protocol, which in turn relied on data from a 1989 Pacific Northwest submetering study conducted by the End-Use Load and Consumer Assessment Program (ELCAP).

Refrigerators and freezers use PDR data to adjust estimated energy use on an hourly basis depending on the modeled indoor temperature (using the Title 24 compliance software) in the space where the refrigerator is installed.

1.1.3 Problems

The plug load and lighting rulesets have some limitations. The rulesets generally do not account for differences in energy use patterns between single-family and multi-family housing. For example, they do not account for the energy use of laundry equipment in multi-family residences that is installed in common areas—only laundry equipment in the dwelling units.

The plug load and lighting rulesets should not be used for estimating energy use for existing homes.

1.1.4 Inputs

AEC Inputs and Algorithms

Table 1 summarizes the user inputs that determine the plug load and lighting annual energy consumption (AEC) estimates. The variable 'BR/Unit' refers to the number of bedrooms in a single-family home or the number of bedrooms in each dwelling unit of a multi-family building. Similarly, 'CFA/Unit' refers to the conditioned floor area per dwelling unit. AEC equations are to be applied to each dwelling unit within a multi-family building, not the building as a whole. Users also specify the zone where certain major appliances are located; however, this affects the modeled internal gains from equipment and lighting, not their estimated energy use of the plug load or lighting load and is therefore not included in the table below.

Table 1: User Inputs Affecting Estimated Plug Load and Lighting Energy Use

End Use	User Inputs that Determine Estimated Energy Use	Notes
Primary Refrigerator/ Freezer	- BR/Unit - Optional: rated annual kWh usage from the Energy Guide label of the installed device	- Default kWh can be overridden with the rated annual kWh usage input on the Energy Guide label; however, there is a maximum allowable kWh credit dependent on BR/Unit. - Energy use adjusted on an hourly basis depending on the indoor temperature in the kitchen simulated in the software.
Non-Primary Refrigerators and Separate Freezers	- BR/Unit - Single-family or multi-family housing	- Assumed to be installed in the garage in new, single-family homes. - Assumed to be absent in multi-family dwelling units.
Dishwasher	- BR/Unit - Presence of device - Single-family or multi-family	- Ruleset estimates machine energy use only. - Energy use is only included if user indicates the device will be present. - Assumed different usage patterns in single family and multi-family when developing algorithms.
Clothes Washer	- BR/Unit - Presence of device - Single-family or multi-family - Optional: whether installed device will comply with the 2015 federal efficiency standards (credit for installing new or nearly-new device)	- Ruleset estimates machine energy use only. - Energy use is only included if user indicates the device will be present. - Assumed different usage patterns in single family and multi-family when developing algorithms. - Default energy use can be reduced if the user specifies the device will meets the 2015 federal standard, which can be determined by looking up the model on the California Appliance Efficiency Database.

End Use	User Inputs that Determine Estimated Energy Use	Notes
Clothes Dryer	- Bedrooms per unit - Presence of device - Fuel type (natural gas, propane, or electric) - Single-family or multi-family - Optional: percent remaining moisture content (RMC) of the clothes washer	- Energy use is only included if user indicates the device will be present. - User can select fuel type. If user indicates natural gas is available at the site (see Section 2.2.10 of RACM), then the default fuel type is natural gas. If user indicates that natural gas is not available at the site then the default fuel type is electric. User cannot select natural gas as the fuel type if natural gas is not available at the site. - Default energy use can be reduced if the user specifies that the installed clothes washer has a rated RMC of less than 50 percent.
Oven	- Bedrooms per unit - Presence of device - Fuel type (natural gas, propane, or electric)	- Energy use is only included if user indicates the device will be present. - User can select fuel type, but default assumption is natural gas if user indicates that natural gas is available on-site and electric if user indicates natural gas is not available on-site
Cooktop	N/A	N/A
Televisions, Set-Top Boxes, Computers and Monitors, Residual MELs	- Bedrooms per unit	N/A
Interior Lighting, Exterior Lighting	- CFA/Unit	N/A
Garage Lighting	- CFA/Unit - Presence of garage	- Energy use is only included if user indicates there is a garage present. - Garage lighting is assigned to multi-family buildings if there is at least once garage present. - Carport lighting is covered under the exterior lighting ruleset.

Source: California Energy Commission

Table 2 summarizes the proposed AEC algorithms for plug load and lighting. These linear equations take the following general form where the homes size metric is bedrooms per unit (BR/Unit) for plug loads and CFA/Unit for lighting:

$$y = mx + b$$

Where: y = Estimated AEC measured in kWh/yr or therms/yr

m = how AEC changes with home size

x = home size as measured in BR/Unit for plug loads or CFA/Unit for lighting

b = minimum energy use (energy use at y-intercept)

BR-based equations are capped at 7 bedrooms, meaning that units with eight or more bedrooms have the same estimated AEC as a 7-bedroom unit. CFA-based equations are capped at 4,150 square feet. For those end uses that list 'presence of device' as a user input in Table 2, the AEC equation is only applied if the device is present. Similarly, for the AEC equations for end uses that can be gas or electric are only applied according to the user-specified fuel type. Gas algorithms apply to devices that use natural gas or propane.

Table 2: Algorithms for Plug Load and Lighting Annual Energy Use

End Use	Standard Design Fuel Type	kWh or therms	Intercept	Slope	Per-Unit BR or CFA
Primary Refrigerator/Freezer	Electricity	kWh	454	37.0	BR
Non-Primary Refrigerators and Separate Freezers (Single-Family only)	Electricity	kWh	0	71.0	BR
Oven	Electricity	kWh	138	16	BR
Oven	Gas	therms	6.0	0.95	BR
Oven	Gas	kWh	41	4.79	BR
Cooktop	Electricity	kWh	84	5.68	BR
Cooktop	Gas	therms	5.0	0.30	BR
Cooktop	Gas	kWh	0	0	BR
Televisions	Electricity	kWh	265	31.8	BR
Set-Top Boxes	Electricity	kWh	76	59.4	BR
Computers and Monitors	Electricity	kWh	79	55.4	BR
Residual MELs	Electricity	kWh	672	235	BR
Interior Lighting	Electricity	kWh	100	0.1775	CFA
Exterior Lighting	Electricity	kWh	8.0	0.0532	CFA
Garage Lighting	Electricity	kWh	20	0.0063	CFA

Source: California Energy Commission

Table 3 and Table 4 summarize the AEC algorithms for dishwashers, clothes washers and clothes dryers. These rulesets only include machine energy use from dishwashers and clothes washers. Energy use for water heating is accounted for in the water heating model.

Table 3: Single-Family Residence Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRper Unit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryers (kWh/yr)	Gas Dryer Natural Gas Use (therms/yr)	Gas Dryer Electricity Use (kWh/yr)
0	83	84	634	22	32
1	83	84	634	22	32
2	91	85	636	22	32
3	100	99	748	26	37
4	99	101	758	27	38
5+	119	227	877	31	44

Source: California Energy Commission

Table 4: Multi-Family Dwelling Unit Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRper Unit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryers (kWh/yr)	Gas Dryer Natural Gas Use (therms/yr)	Gas Dryer Electricity Use (kWh/yr)
0	56	66	496	17	25
1	68	70	527	19	26
2	96	99	745	26	37
3	94	97	733	26	37
4	121	118	885	31	44
5+	114	107	805	28	40

Source: California Energy Commission

AEC Algorithms for High-Efficiency Appliances

As indicated in Table 5, if allowed in the software, users could override the default AEC rulesets for the primary refrigerator, clothes washer and clothes dryer if the software user has additional information about the device that will be installed.

For the primary refrigerator, the default AEC ruleset could be replaced with the rated AEC listed on the refrigerator's Energy Guide label. If using this option, the user will input AEC measured in kWh per year, and that value will replace the AEC value for the primary refrigerator calculated using the equation below. The default AEC of the primary refrigerator cannot be adjusted below a certain value, which is dependent on BR/Unit as described in the following equation:

$$MinPrimaryRefrigAEC\frac{kWh}{yr} = \left(8.4\frac{kWh}{BRperUnit\text{-}yr} \times BRperUnit\right) + 291\frac{kWh}{yr}$$

Users could reduce the estimated primary refrigerator AEC to this value, but no lower.

Table 5: Minimum primary refrigerator AEC that builders may claim by BR/Unit

BR/Unit	Default Primary Refrigerator AEC (kWh/yr)	Minimum Allowable Primary Refrigerator AEC (kWh/yr)
0	470	291
1	496	299
2	523	308
3	550	316
4	577	325
5	603	333
6	630	341
7+	657	350

Source: California Energy Commission

For clothes washers, if allowed in the software, the user could specify that the installed clothes washer meets the 2015 federal standards (as documented on the CEC Appliance Efficiency Database). This effectively provides credit if the clothes washer is new or nearly new. Table 6 presents the AEC values used if the washer is compliant with the 2015 federal standards.

Table 6: Minimum allowable high-efficiency AEC for clothes washers

BR/Unit	Single Family Default AEC (kWh/yr)	Single Family High-Efficiency Clothes Washer AEC[1] (kWh/yr)	Multifamily Default AEC (kWh/yr)	Multifamily High-Efficiency Clothes Washer AEC[1] (kWh/yr)
0	84	68	66	53
1	84	68	70	57
2	85	68	99	80
3	100	80	98	79
4	101	81	118	95
5+	117	94	107	86

[1]Applicable to clothes washers that meet the 2015 federal efficiency standards

Source: California Energy Commission

For clothes dryers, if allowed in the software, the user could specify the percent remaining moisture content (RMC) of the installed clothes washer (as documented on the CEC Appliance Efficiency Database) to override the default clothes dryer AEC ruleset. The RMC-adjusted clothes dryer AEC should be calculated using the equations provided below. For natural gas dryers the RMC-adjusted AEC modifies natural gas use but does not impact electricity use.

Electric Dryer: RMC-adjusted AEC (kWh/yr)

$$RMC\text{-}adjusted\ AEC\ \frac{kWh}{yr} = 12.67\,\frac{kWh}{yr} + \left[\left(3.80\,\frac{kWh}{cycle}\left(RMC_{User,Input}\right) + 0.25\ \frac{kWh}{cycle}\right) \times \frac{cycles}{yr}\right]$$

Gas Dryer: RMC-adjusted AEC (therms/yr)

$$RMC\text{-}adjusted\ AEC\ \frac{therms}{yr} = \left[0.136\,\frac{therms}{cycle}\left(RMC_{User,Input}\right) + 0.00853\ \frac{therms}{cycle}\right] \times \frac{cycles}{yr}$$

Table 7: Annual clothes dryer cycles estimated based on BR/Unit

BR/Unit	Clothes Dryer Cycles Single-Family	Clothes Dryer Cycles Multi-Family
0	290	227
1	290	241
2	291	341
3	342	335
4	346	405
5+	401	368

Source: California Energy Commission

Load Profiles

Dishwashers and clothes washers loads are specified in the water heating load profiles. Clothes dryers have the same usage assumptions as clothes washers, but shifted one hour later.

The estimated energy use for refrigerators is adjusted for each hour of the year depending on the simulated indoor temperature in the thermal zone where the refrigerator or freezer is installed (user input). Multi-family housing is assuccccmed to have no energy use for non-primary refrigerators or separate freezers.

The following tables summarize the hourly load profiles and seasonal multipliers for the remaining plug load and lighting end uses.

Table 8: Hourly Multiplier – Weekdays

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
1	0.005	0.035	0.040	0.036	0.037	0.023	0.046
2	0.004	0.026	0.040	0.033	0.035	0.019	0.046
3	0.004	0.023	0.040	0.032	0.034	0.015	0.046
4	0.004	0.022	0.040	0.032	0.034	0.017	0.046
5	0.004	0.021	0.040	0.031	0.032	0.021	0.046
6	0.014	0.021	0.040	0.032	0.036	0.031	0.037
7	0.019	0.025	0.040	0.034	0.042	0.042	0.035
8	0.025	0.032	0.041	0.036	0.044	0.041	0.034
9	0.026	0.038	0.040	0.039	0.037	0.034	0.033
10	0.022	0.040	0.040	0.043	0.032	0.029	0.028
11	0.021	0.038	0.040	0.045	0.033	0.027	0.022
12	0.029	0.038	0.040	0.045	0.033	0.025	0.015
13	0.035	0.041	0.040	0.046	0.032	0.021	0.012
14	0.032	0.042	0.040	0.046	0.033	0.021	0.011
15	0.034	0.042	0.041	0.046	0.035	0.021	0.011
16	0.052	0.041	0.041	0.047	0.037	0.026	0.012
17	0.115	0.044	0.042	0.048	0.044	0.031	0.019
18	0.193	0.049	0.043	0.049	0.053	0.044	0.037
19	0.180	0.056	0.044	0.049	0.058	0.084	0.049
20	0.098	0.064	0.045	0.049	0.060	0.117	0.065
21	0.042	0.070	0.046	0.049	0.062	0.113	0.091
22	0.020	0.074	0.047	0.048	0.060	0.096	0.105
23	0.012	0.067	0.045	0.044	0.052	0.063	0.091
24	0.010	0.051	0.045	0.041	0.045	0.039	0.063

Source: California Energy Commission

Table 8: Hourly Multiplier – Weekends

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
1	0.005	.035	0.041	0.036	0.037	0.023	0.046
2	0.004	0.027	0.041	0.034	0.035	0.019	0.046
3	0.003	0.022	0.040	0.033	0.034	0.015	0.045
4	0.003	0.021	0.041	0.033	0.034	0.017	0.045
5	0.003	0.020	0.040	0.032	0.032	0.021	0.046
6	0.005	0.020	0.040	0.033	0.036	0.031	0.045

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
7	0.010	0.022	0.040	0.033	0.042	0.042	0.044
8	0.027	0.029	0.040	0.035	0.044	0.041	0.041
9	0.048	0.037	0.041	0.038	0.037	0.034	0.036
10	0.048	0.043	0.042	0.042	0.032	0.029	0.030
11	0.046	0.042	0.042	0.044	0.033	0.027	0.024
12	0.055	0.039	0.041	0.045	0.033	0.025	0.016
13	0.063	0.040	0.041	0.046	0.032	0.021	0.012
14	0.059	0.042	0.041	0.047	0.033	0.021	0.011
15	0.062	0.045	0.041	0.047	0.035	0.021	0.011
16	0.068	0.048	0.042	0.048	0.037	0.026	0.012
17	0.091	0.051	0.042	0.049	0.044	0.031	0.019
18	0.139	0.052	0.043	0.049	0.053	0.044	0.038
19	0.129	0.056	0.044	0.048	0.058	0.084	0.048
20	0.072	0.061	0.044	0.048	0.060	0.117	0.060
21	0.032	0.065	0.045	0.048	0.062	0.113	0.083
22	0.014	0.069	0.045	0.047	0.060	0.096	0.098
23	0.009	0.064	0.044	0.044	0.052	0.063	0.085
24	0.005	0.050	0.039	0.041	0.045	0.039	0.059

Source: California Energy Commission

Table 9: Seasonal Multipliers

Month	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs and Lighting
Jan	1.094	1.032	1.02	0.98	1.19
Feb	1.065	0.991	0.84	0.87	1.11
Mar	1.074	0.986	0.92	0.89	1.02
Apr	0.889	0.990	0.98	1.11	0.93
May	0.891	0.971	0.91	1.14	0.84
Jun	0.935	0.971	0.94	0.99	0.80
Jul	0.993	1.002	1.05	1.05	0.82
Aug	0.920	1.013	1.06	1.01	0.88
Sep	0.923	1.008	1.06	0.96	0.98
Oct	0.920	1.008	1.14	0.97	1.07
Nov	1.128	1.020	1.03	0.99	1.16
Dec	1.168	1.008	1.05	1.04	1.20

Source: California Energy Commission

APPENDIX F – TECHNICAL REFERENCES

2006 International Energy Conservation Code, International Code Council. Publications at 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795. 888-422-7233. www.iccsafe.org.

2015 International Energy Conservation Code, International Code Council. Publications at 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795. 888-422-7233. www.iccsafe.org.

ANSI/RESNET/ICC 301-2014 Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index, International Code Council. Publications at 4051 West Flossmoor Road, Country Club Hills, IL 60478-5795. 888-422-7233. www.iccsafe.org.

Rubin - Codes and States Enhancement Initiative (CASE) Plug Loads and Lighting Modeling. Eric Rubin, Daniel Young, Maxmilian Hietpas, Arshak Zakarian, Phi Nguyen (Energy Solutions), June 2016

Dobos - PVWatts Version 5 Manual, National Renewable Energy Laboratory (NREL), Aron P. Dobos, September 2014

Ecotope - A Guide to HPWHsim, Ecotope, April 15, 2016

Ecotope - Heat Pump Water Heater Model Validation Study, Ecotope Inc., Northwest Energy Efficiency Alliance, Report #E15-306, March 2, 2015

Ecotope - HPWHsim Project Report, Ecotope, April 14, 2016

Fuentes - A Simplified Thermal Model for Flat Plate Photovoltaic Arrays, Martin K. Fuentes

Lutz – Calculation to Determine Hourly Energy Consumption of Tankless (Instantaneous) Water Heaters, Jim Lutz, April 2, 2019

Kruis – Development of Realistic Water Draw Profiles for California Residential Water Heating Energy Estimation, Neal Kruis, PhD - Big Ladder Software, Bruce Wilcox, PE, Jim Lutz - Hot Water Research, Chip Barnaby – Revised (March 2019)

Gilman - Errata for SAM Photovoltaic Model Technical Reference, National Renewable Energy Laboratory (NREL), P. Gilman, December 2015

Gilman - SAM Photovoltaic Model Technical Reference, National Renewable Energy Laboratory (NREL), P. Gilman, December 2015

Documents are available at the Reference Documents Page for the CBECC Modeling Software (http://www.bwilcox.com/BEES/reference.html).

APPENDIX G - ALGORITHMS

TABLE OF CONTENTS

FIGURES

APPENDIX FIGURES

TABLES

1 California Simulation Engine (CSE)

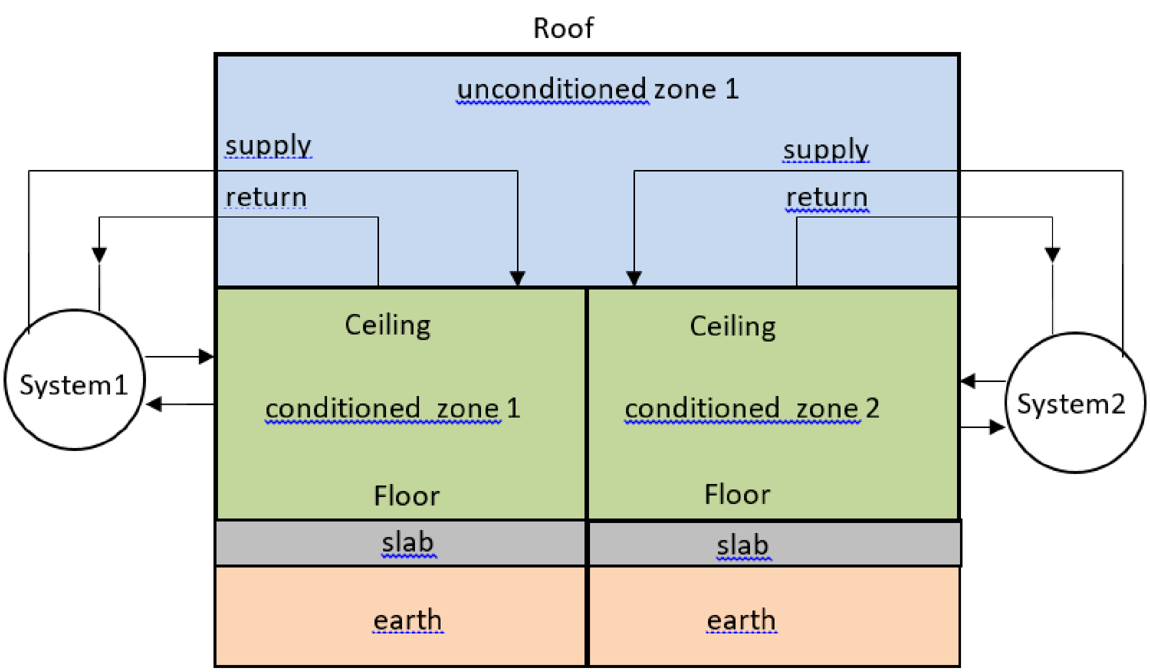
1.1 Overview

The building modeled can have multiple conditioned and unconditioned zones. Each conditioned zone has an air handler associated with it, and each air handler can have supply and/or return ducts in an unconditioned zone (nominally the attic), and in the conditioned zone itself. Air handlers can operate independently in either a heating, cooling, or off mode. See Figure 1.

Every time step (nominally two minutes), the zone model updates the heat transfers to and from the zones and the zone mass temperatures. Each zone's conditions are updated in succession and independently, based on the conditions in the adjacent zones in the last time step.

The conditioned zone thermostat algorithms determine whether an air handler should be in a heating or cooling mode, or floating, and if heating or cooling, the magnitude of the load that must be met by the air handler to keep the conditioned zone at its current setpoint. If the setpoints cannot be satisfied, the conditioned zone floats with heating, cooling, or ventilation, at full capacity. In the off mode case the zones are modeled during the time step without duct or air handler effects.

Figure 1: Schematic of Zones and Air Handler Systems



Although shown partly outside of the envelope, all ducts are assumed to be in either the conditioned or unconditioned zones only.

The duct system model determines duct losses, their effect on the conditions of the unconditioned and conditioned zones, and their effect on the heating or cooling delivery of the air handler system.

The duct system model allows unequal return and supply duct areas, with optional insulation thicknesses. The ducts can have unequal supply and return leakages, and the influence of unbalanced duct leakage on the unconditioned and conditioned zones infiltration and ventilation is taken into account. Every time step it updates the air handler and duct system heat transfers, and HVAC energy inputs, outputs, and efficiency.

For each window, the ASHWAT window algorithm calculates the window instantaneous shortwave, longwave, and convective heat transfers to the zones.

The AIRNET infiltration and ventilation algorithm calculates the instantaneous air flow throughout the building based on the air temperatures in the zones, and on the outside wind and air temperature. AIRNET also handles fan induced flows.

In the update processes, a zones mass-node temperatures are updated using a forward-difference (Euler) finite difference solution, whereby the temperatures are updated using the driving conditions from the last time step. For accuracy, this forward-difference approach necessitates a small time-step.

The small time-step facilitates the *no-iterations* approach we have used to model many of the interactions between the zones and allows the zones to be updated independently.

For example, when the zone energy balance is performed for the conditioned zone, if ventilation is called for, the ventilation capacity, which depends on the zone temperatures (as well as maximum possible ventilation openings and fan flows), is determined from the instantaneous balance done by AIRNET. To avoid iteration, the ventilation flows, and the accompanying heat transfers are based on the most recently available zone temperatures.

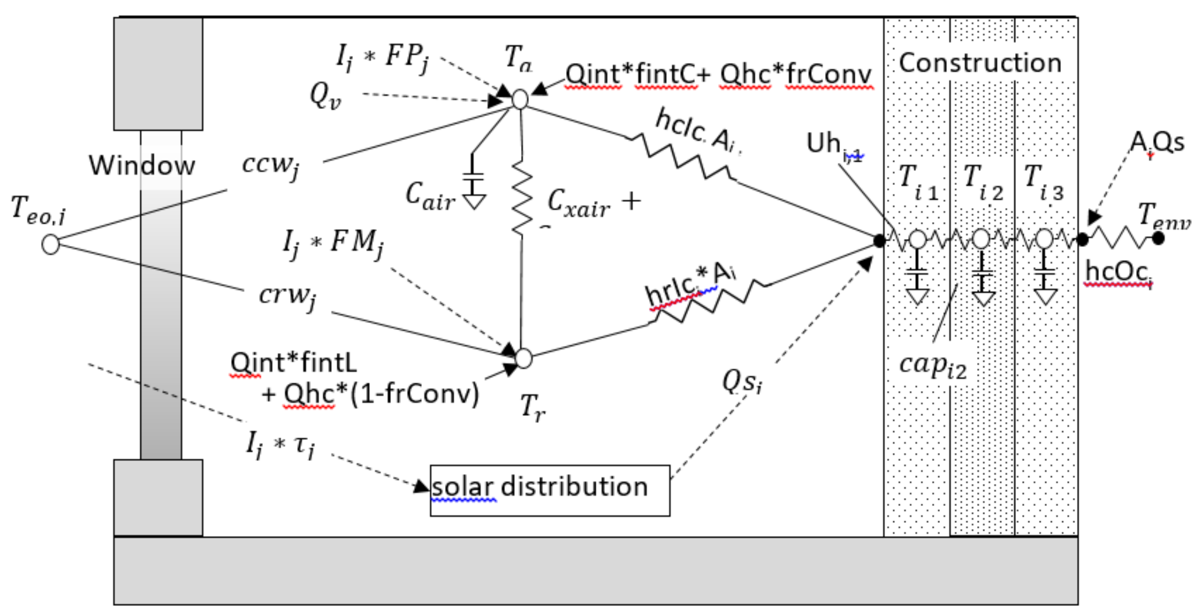
To avoid iteration, a similar use of the last time-step data is necessary is dealing with inter-zone wall heat transfer. For example, heat transfer through the ceiling depends on the conditions in both zones, but these conditions are not known simultaneously. Thus, ceiling masses are treated as belonging to the attic zone and updated at the same time as other attic masses, partly based on the heat transfer from the conditioned zone to the ceiling from the last time step. In turn, when the conditioned zone is updated it determines the ceiling heat transfer based on the ceiling temperature determined two-minutes ago when the attic balance was done.

Similarly, when the conditioned zone energy balance is performed, if for example heating is called for, then the output capacity of the heating system needs to be known, which requires knowing the duct system efficiency. But the efficiency is only known after the air handler simulation is run. To avoid iteration between the conditioned zone and attic zones, the most recent duct efficiency is used to determine the capacity in the conditioned zones thermostat calculations. When the attic simulation is next performed, if the conditioned zone was last running at capacity, and if the efficiency now calculated turns out to be higher than was assumed by the thermostat calculations, then the load will have exceeded the limiting capacity by a small amount depending on the assumed vs. actual efficiency. In cases like this, to avoid iteration, the limiting capacity is allowed to exceed the actual limit by a small amount, so that the correct energy demand is determined for the conditioned zone load allowed.

1.1.1 Schematic of Zone Thermal Network

Figure 2 shows a schematic of the zone model network. It models a single zone whose envelope consists of any number of walls, ceilings, floors, slabs, and windows, and can be adjacent to other conditioned or unconditioned zones. The envelope constructions can be made of any number of layers of different materials of arbitrary thermal conductivity and heat capacity. Each layer is modeled with one or more "T" networks in series. Each T has the layer heat capacitance, cap_{ij}, centered between by two thermal conductances, where the first subscript corresponds to the wall construction number and the second to the layer number. Framed constructions are treated as two separate surface areas, the surface area of the part between framing, and the surface area of the part containing the framing itself; the heat flow is assumed to follow independent and parallel paths through these two surfaces.

Figure 2: Schematic of Simulation Network



The room air, represented by the mass node Ta, is assumed to be well-mixed and have heat capacitance C_{air} (Btu/F). The air is shown in Figure 2 to interact with all of the building interior construction surfaces via convection coefficients $hcIc_i$ for surface i. The overall conductance through the window between T_a and an effective outdoor temperature T_{eo} is ccw_j for window surface j. The conductances ccw_j and the corresponding radiant value crw_j are outputs of the ASHWAT windows algorithm applied to window j each time step.

A mean radiant temperature node, T_r, acts as a clearinghouse for radiant exchange between surfaces. With conductances similar to those of the air node: $hrIc_i$ and crw_j.

Depending on the size of the zone and the humidity of the air, the air is assumed to absorb a fraction of the long-wave radiation and is represented by the conductance C_{Xair}.

The internal gains, $Qint$, can be specified in the input as partly convective (fraction $fintC$), partly long wave ($fintLW$), and partly shortwave (fintSW). The heating or cooling heat transfers are shown as Qhc (+ for heating, - for cooling). If Qhc is heating, a fraction ($frConv$) can be convective with the rest long-wave. The convective parts of $Qint$ and Qhc are shown as added to the air node. The long wave fraction of Qint and Qhc are shown added to the $\mathrm{T_r}$ node.

Additional outputs of the ASHWAT algorithm are FP_j the fraction of insolation I_j incident on window j that ultimately arrives at the air node via convection, and FM_j, the fraction that arrives at the radiant node as long-wave radiation.

The term Qs_i is the the total solar radiation absorbed by each construction surface i, as determined by the solar distribution algorithm. The short wave part of the internal gains, $\mathrm{Qint} * \mathrm{fintSW}$, is distributed diffusely, with the same diffuse targeting as the diffusely distributed solar gains.

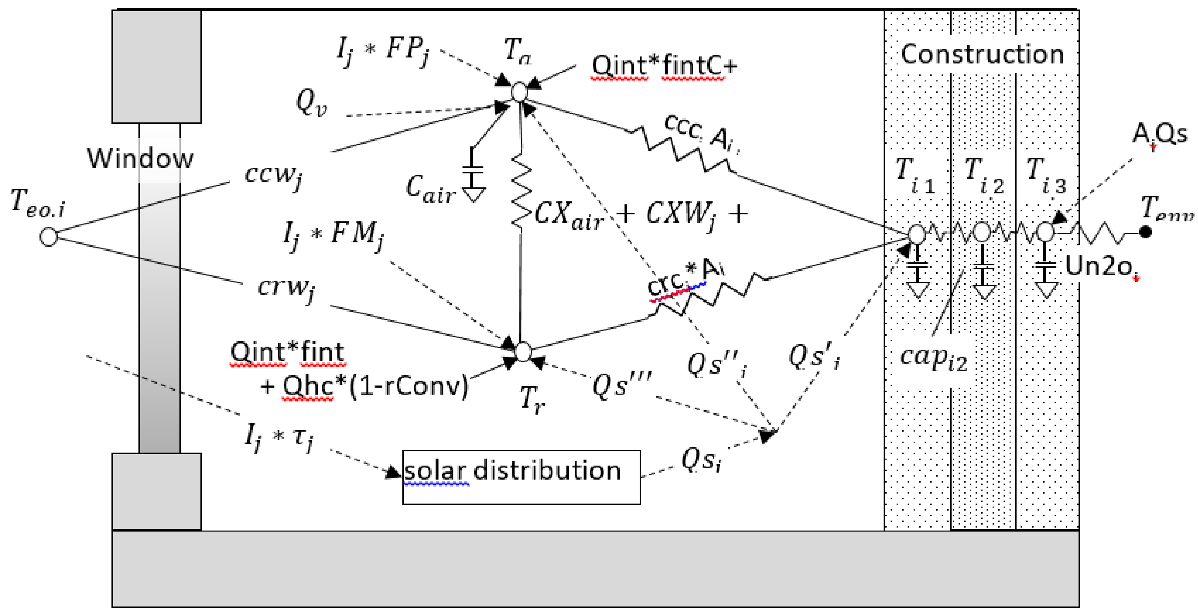
Solar gains absorbed at the outside surface of constructions are represented by Qs_o in Figure 2.

The slab is connected to the Ta and Tr in a similar fashion as the wall surfaces, although the slab/earth layering procedure is different than for walls.

1.1.2 Schematic of Reduced Thermal Network

Before a zone energy balance is formulated it is convenient to dissolve all the massless nodes from the network of Figure 2 (represented by the black dots), except for the mean radiant temperature node Tr. Figure 3 shows the resulting reduced network. A massless node is eliminated by first removing the short-wave gains from the node by using the current splitting principle (based on superposition), to put their equivalent gains directly onto adjacent mass nodes and other nodes that have fixed temperatures during a time step. Then the massless node can be dissolved by using Y-Δ transformations of the circuit.

Figure 3: Network after Dissolving Massless Nodes



For example, to eliminate the massless surface node of layered mass in Figure 2, the gain Qs_i absorbed by the surface node is split into three parts: Qs_i' to the $T_{i,1}$ node, Qs_i'' to the Ta node and Qs_i''' to the Tr node. For example, by current splitting,

$$Qs_i' = Qs_i \frac{Uh_{i,1}}{hcIc_i + hrIc_i + Uh_{i,1}}$$

Equation 1

A Y-Δ transformation of the remaining Y circuit gives the ccc_i and crc_i conductances, as well as an additional cross conductance CXC_i that is added to CXair. For example,

$$ccc_i = \frac{hcIc_i * Uh_{i,1}}{hcIc_i + hrIc_i + Uh_{i,1}}$$

Equation 2

1.1.3 Zone Balance Calculation Sequence

The temperatures in the zone are determined using a thermal balance method. The following procedure is followed each time step.

At the start of the simulation, say time t, assume all temps $Ta(t), Tr(t), T_{i,1}(t), T_{i,2}(t)$, etc. are known along with all the solar gains, internal gains, etc.

(1) First, the layered mass temperatures are updated using the explicit Euler routine (see Section 1.2), giving $T_{i,1}(t + dt), T_{i,2}(t + dt)$, etc. The Euler method determines each of these mass temperatures assuming that all the boundary conditions (temperatures and heat sources) that cause the change in the mass temperatures,

are conditions at time t. Thus the mass node temperatures can be in any order, independently of each other.

(2) Next, a steady-state instantaneous energy balance at the Ta and Tr nodes is made at time t+ dt. This balance involves the mass temperatures determined for time t + dt in Step-1, as well other heating or cooling sources at time t+ dt. The balance in this step involves querying the HVAC control algorithm which allows heating, cooling and ventilation (forced or natural) in response to scheduled setpoints. The idealized control system is assumed to keep the zone at exactly the scheduled setpoint unless Ta is in the deadband or if the HVAC capacity is exceeded, whereupon the system runs at maximum capacity, and Ta floats above or below the relevant setpoint. While the heating, cooling and forced ventilation system capacities are scheduled inputs, the natural ventilation capacity is dependent on the current zone and environment conditions.

Thus, the energy balance at the Ta and Tr nodes returns either the heating, the cooling or the ventilation required to meet the setpoint, or else returns the floating Ta that results at the capacity limits or when Ta is in the deadband.

At this stage the conditions have been predicted for the end of the time step, and steps 1 and 2 and repeated. The various boundary conditions and temperature or air flow sensitive coefficients can be recalculated as necessary each time step at the beginning of step (1), giving complete flexibility to handle temperature sensitive heat transfer and control changes at a time step level.

Note that step (2) treats the energy balance on Ta as a steady state balance, despite the fact that air mass makes it a transient problem. However, as shown in Section 1.3.1, if the air mass temperature is updated using an implicit-difference method, the effect of the air mass can be duplicated by employing a resistance, *Δt/Cair*, between the Ta node and a fictitious node set at the beginning of the time-step air temperature TaL = Ta(t), and shown as such in Figure 3.

The overall CSE Calculation Sequence is summarized below:

Hour

Determine and distribute internal gains.

Sub-hour

Determine solar gain on surfaces.

Determine surface heat transfer coefficients.

Update mass layer temperatures.

Find AirNet mass flows for non-venting situation (building leakage + last step HVAC air flows).

Find floating air temp in all zones / determine if vent possibly useful for any zone.

If vent useful

- Find AirNet mass flows for full venting
- Find largest vent fraction that does not sub-cool any zone; this fraction is then used for all zones.
- If largest vent fraction > 0, update all floating zone temperatures assuming that vent fraction

Determine HVAC requirements for all zones by comparing floating temp to setpoints (if any)

- System heating / cooling mode is determined by need of 1st zone that requires conditioning
- For each zone, system indicates state (t and w) of air that could be delivered at register (includes duct loss effects). Zone then requests air flow rate required to hold set-point temperature

Determine HVAC air flow to zones (may be less than requested); determine zone final zone air temperatures.

Determine system run fraction and thus fuel requirements.

Determine zone humidity ratio for each zone.

Calculate comfort metrics for each zone.

1.2 Updating Layered Mass Temperatures

The heat transfer through the layered constructions is assumed to be one dimensional. The heat conduction equation ($\frac{\partial^2 T^2}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$) is solved by using finite differences (Δt and Δx) to approximate the differential increments in time and distance; ɑ is the thermal diffusivity. The smaller the finite increments, the more accurate the solution. The homogeneous layers are divided into lumps Δx thick, and the lumps are represented by the two-conductance/one-capacitance "T" circuits shown for each layer in Figure 2. Frequently the actual layer thicknesses as sufficiently thin that Δx can be taken as the layer thickness. However, at times the actual layer of homogeneous material must be divided into smaller thicknesses. See Section 1.4–Discretization Errors for the criterion used to determine Δx and Δt.

The temperatures of the mass nodes are updated every time step using the Euler explicit numerical integration method (see Press et al), whereby the change in temperature of the mass during the time step is based only on the boundary conditions at the beginning of the time step. The boundary conditions are the temperatures of the surrounding nodes and other heat flow sources.

To update $T_{i,1}$ in Figure 3, for example, if the rate of heat transfer into $T_{i,1}$ is equated to its rate of change in internal energy, resulting in the differential equation for mass temperature $T_{i,1}$:

$$\frac{dT_{i,1}}{dt} = \frac{Tss_{i,1} - T_{i,1}}{\tau}$$ Equation 3

where $T_{i,1}$ is the surface layer mass temperature, and $Tss_{i,1}$ is the temperature $T_{i,1}$ would have if steady state were reached:

$$Tss_{i,1} = \frac{ccc_{i,1}Ta + crc_{i,1}Tr + Ubn_{i,1}T_{i,2} + Qs_i'}{ccc_{i,1} + crc_{i,1} + Ubn_{i,1}}$$

Equation 4

Qs_i' is given by Equation 1, $ccc_{i,1}$ by Equation 2, $T_{i,2}$ is the temperature of mass node 2, and τ is the time constant of mass node 1 given by:

$$\tau = \frac{cap_{i,1}}{ccc_{i,1} + crc_{i,1} + Ubn_{i,1}}$$

Equation 5

The heat capacity of layer-1 is $cap_{i,1}$ (Btu/ft^2-F). $Ubn_{i,1}$ is the conductance between nodes 1 and 2, given by:

$$Ubn_{i,1} = \frac{1}{\frac{1}{Uh_{i,1}} + \frac{1}{Uh_{i,2}}}$$

Equation 6

To integrate of Equation 3 over a time step, the Euler procedure assumes that the right hand side of the equation remains constant over the time step at its value at the beginning of the time step. In this case the mass temperature at the end of the time step becomes:

$$T(i,1)(t + \Delta t) = T(i,1)(t)\left(1 - \frac{\Delta t}{\tau}\right) + T_{ss}\left(\frac{\Delta t}{\tau}\right)$$ *Equation 7*

If the capacitance of any layer is zero (a convecting air layer for example) its updated temperature is set equal to Tss. That is, the temperature at the central node is determined by a steady state energy balance.

All of the mass nodes are updated in an analogous fashion each time step. The order in which the masses are updated is irrelevant because they are updated based only on the values of variables at the beginning of the time step, not on the values that may have been updated since.

1.3 Zone Energy Balance

1.3.1 Implicit Update of Air Temperature

Similar to the energy balance on the construction mass nodes, an energy balance on the air node gives the differential equation:

$$\frac{dT_a}{dt} + \frac{T_a}{\tau_a} = \frac{Tss}{\tau_a}$$

Equation 8

where Tss, the asymptotic steady state temperature of Ta, includes all the sources connected to Ta. For simplicity, if the zone only contained the one construction (*i* = 1) and one window (*j*=1), like in Figure 3, then from a steady state energy balance Tss is given by:

$$T_{SS} = \left[T_{out}\left(U_{inf} + U_v\right) + ccw_1 Awin_1 T_{out} + ccc_1 Acon_1 T_{1,1} + Acon_1 Qs_1^{"} + Awin_1 Qsw_1^{"} + Qint * fintC + Qhc * frConv + CX * Tr\right]/Usum$$

Equation 9

where

$$CX = CXair + CXW_1 + CXC_1$$

Equation 10

$$Usum = U_{inf} + U_v + ccw_1 Awin_1 + ccc_1 Acon_1 + CX$$

Equation 11

and the air time constant is:

$$\tau_a = \frac{Cair}{Usum}$$

Equation 12

Equation 8 is solved using an full implicit (or backward time) difference, similar to the Euler explicit method except here the right hand side of the equation remains constant over the time step at its value at the end of the time step, not its value at the beginning as in the Euler method. Thus, Equation 8 then becomes:

$$T_a(t + \Delta t) = \frac{\frac{T_a(t)\tau_a}{\Delta T} + Tss(t + \Delta t)}{\frac{\tau_a}{\Delta t} + 1}$$

Equation 13

Where the times *t* and *t+Δt* in parenthesis indicate the terms are evaluated at the beginning and end of the time step, respectively. Substituting Equation 12 for τ_a, Equation 13 can be put in the convenient form:

$$T_a(t + \Delta t) = \frac{\frac{T_a(t)Cair}{\Delta T} + Usum * Tss(t + \Delta t)}{\frac{Cair}{\Delta t} + Usum}$$

Equation 14

As this equation shows, with the implicit difference the effect of the air mass can be thought of as a resistance, *Δt/Cair*, between the Ta node and a fictitious node set at the air temperature at the value it was at the beginning of the time step, $TaL = Ta(t)$.

This alternative is known as an 'associated discrete circuit'. Leaving out the explicit time references, Equation 14 can be written:

$$Ta = \frac{\frac{TaL * Cair}{\Delta T} + Usum * Tss}{\frac{Cair}{\Delta t} + Usum}$$

Equation 15

where Ta and Tss are evaluated at the end of the time step, and TaL stands for $T_a(t)$ at the beginning of the time step. Note that Equation 15 still contains the variable Tr (hidden in Tss) which is unknown. Tr can be eliminated by making an energy balance on the Tr node and substituting the expression for Tr into Equation 15. This is done for the complete set of equations that follow.

1.3.2 Zone Balance Equations

The complete set of zone energy balance equations for multiple windows and constructions are given below. Terms containing Qv and Qhc are kept separate so that the resulting equations can be solved for Qv or Qhc when Ta is fixed at a setpoint.

1.3.2.1 Air Node Balance

The energy balance equation on the Ta node, comparable to Equation 15 above is:

$$Ta = \frac{Qv + Qhc \cdot frConv + Nair + CX \cdot Tr}{Dair + CX}$$

Equation 16

The Equation 16 form, using $\mathrm{Q_v}$, is used when heat is transferred to a conditioned zone with ventilation or infiltration air. When heat is transferred to an unconditioned zone due to ventilation or infiltration, $\mathrm{Q_v}$ is replaced by the essentially equivalent form given by Equation 17, wherein $\mathrm{Q_v}$ is replaced by $\mathrm{Q_v = mC_p\Delta T}$ such that $\mathrm{mdot * c_p * T}$ is added to the numerator and $\mathrm{mdot * c_p}$ is added to the denominator. This was implemented to eliminate oscillations in Ta.

$$Ta = \frac{ST + Qhc \cdot frConv + Nair + CX \cdot Tr}{SB + Dair + CX}$$

Equation 17

where,

$$ST = \sum mdot * c_p * T$$

Equation 18

where T is the temperature of the air in the zone supplying the infiltration or ventilation air.

$$SB = \sum mdot * c_p$$

Equation 19

$$CX = CXair + \sum^{con} Acon_i * cxc_i + \sum^{win} Awin_i * cxw_i$$

Equation 20

with the sum's for all constructions and all windows respectively.

$$\begin{aligned} Nair = TaL\left(\frac{Cair}{dt}\right) + Qint * fintC \\ + \sum^{con} Acon_i * \left(ccc_i * T_{i1} + \frac{Q_{si} * hcIc_i}{hcIc_i + hrIc_i + Uh_{i1}}\right) \\ + \sum^{win} \left[Awin_i\left(ccw_i * Teo_i + I_j * FP_j\right)\right] \end{aligned}$$

Equation 21

$$Dair = \frac{Cair}{dt} + \sum^{con} Acon_i * ccc_i + \sum^{win} Awin_i * ccw_i$$

Equation 22

Qv is the heat transfer to the air node due to infiltration and forced or natural ventilation.

1.3.2.2 Radiant Node Balance

An energy balance on the Tr node gives Equation 23.

$$Tr = \frac{Qhc \cdot (1 - frConv) + N_{rad} + CX \cdot Ta}{Drad + CX}$$

Equation 23

where,

$$\begin{aligned} Nrad = Qint * fintLW + \sum^{con} Acon_i\left(crc_i * T_{i1} + Qsi_i * \frac{hrIc_i}{hcIc_i + hrIc_i + Uh_{i1}}\right) \\ + \sum^{win} Awin_i\left(crw_i * Teo_i + I_j * FM_j\right) \end{aligned}$$

Equation 24

$$Drad = \sum^{con} Acon_i * crc_i + \sum^{win} Awin_i * crw_i$$ Equation 25

1.3.2.3 Simultaneous Solution of Ta and Tr Equations

Equation 16 and Equation 23 can be solved simultaneously to eliminate Tr and give Ta explicitly:

$$Ta = \frac{(Qv + Qhc \cdot frConv + Nair)(Drad + CX) + CX(Nrad + Qhc(1 - frConv)}{(Dair + Drad)CX + Dair \cdot Drad}$$

Equation 26

Similar to Equation 16 and Equation 17), the alternate form of Equation 26 is given by Equation 27.

$$Ta = \frac{(ST + Qhc \cdot frConv + Nair)(Drad + CX) + \ CX(Nrad + Qhc(1 - frConv)}{(SB + Dair + Drad)CX + (SB + Dair)\mathrm{D}rad}$$

Equation 27

Substituting Ta from Equation 26 into Equation 23 gives Tr.

1.3.2.4 Qhc and Qv Equations

When *Ta* is at either the heating or cooling setpoints, Equation 26 is solved to determine the required *Qhc*. In this case *Qv* is set *to QvInf.*

$$Qhc = \frac{Ta\big(Dair * Drad + CX(Dair + Drad)\big) - \ (Nair + Qv)(Drad + CX) - Nrad * CX)}{frConv * Drad + CX}$$

Equation 28

Similarly, when Ta is at the ventilation setpoint, Equation 26 can be solved for Qv to give:

$$Qv \ = \frac{\big(Dair * Drad + CX(Dair + Drad)\big)Ta - CX\big(Nrad + Qhc(1 - frConv)\big)}{Drad + CX} - (Qhc * frConv + Nair)$$

Equation 29

With *Qhc* = 0 this becomes:

$$\mathrm{Qv} \ = \frac{\big(Dair * Drad + CX(Dair + Drad)\big)Ta - Nair(Drad + CX) - CX * Nrad}{Drad + CX}$$

Equation 30

The zone balance is essentially an instantaneous balance, so all the temp inputs are simultaneous values from the end of the time step (with the exception of TaL; see Section 1.3.1). Although the balance is with contemporary temperatures, many of the heat flows in $Nair$ etc., are based on last time step conditions.

1.3.3 Thermostat Logic

At the end of each time step the program finds the floating temperature of the zone without HVAC ($Qhc = 0$) and with venting $\mathrm{Qv} = \mathrm{QvInf}$. This floating temperature found from Equation 26 is defined as TS1. Next, the venting capacity is determined (see Section 1.9.3.10, Heat Flow), and Equation 26 is solved for Ta at the full venting capacity. This Ta is defined as TS2.

TS1 will satisfy one of the four cases:

- TS1>TC

- TC > TS1 > TD
- TD > TS1 > TH
- TH > TS1

Similarly, TS2 will satisfy one of the four cases:

- TS2 > TC,
- TC > TS2 > TD
- TD > TS2 > TH
- TH > TS2

where TC, TD, and TH are the scheduled cooling, ventilation, and heating setpoints, with TC > TD > TH.

Based on the cases that TS1 and TS2 satisfy, nested logic statements determine the appropriate value of heating, cooling, venting, or floating .

For example, if TS1 and TS2 are both > TC, then Q_v is set *QvInf* and Ta is set to TC, and Equation 28 is solved for the required cooling, Qhc. If Qhc is smaller than the cooling capacity at this time step then Qhc is taken as the current cooling rate and the zone balance is finished and the routine is exited. If Qhc is larger than the cooling capacity then Qhc is set to the cooling capacity, and Equation 26 is solved for Ta, floating above TC due to the limited cooling capacity. If Ta < TS2 then Ta and Qhc are correct and the zone balance routine is exited. If this Ta > TS2 then Ta is set equal to TS2, Qhc is set to zero, and Equation 29 is solved for the ventilation rate *Qv*, and the Zone Balance routine is complete.

Similar logic applies to all other logically possible combinations of the TS1 and TS2 cases above.

1.3.4 Limiting Capacities

The limiting capacity of the heating and cooling system is determined each time step by multiplying the scheduled nominal air handler input energy capacity by the duct system efficiency. To avoid iteration between the conditioned zone and unconditioned zone simulations, the duct system efficiency is taken from the last time-step's unconditioned zone simulation, or unity if the system mode (heating, cooling, venting, or floating) has changed.

1.4 Discretization Errors

The temperatures predicted by Equation 7, which updates the layered mass temperatures, is subject to errors due to the finite lump size chosen to represent real wall homogeneous layers. It is also subject to errors due to the finite time step Δt. Similarly Equation 14 for updating the air mass temperature is subject to error due to the finite time step chosen.

Discretization errors can be made negligible by reducing the layer thicknesses and time step to very small values. However for practical run time minimization purposes it is useful to have large Δt and Δx layers, insofar as accuracy allows. The range of choices of Δt and Δx is narrowed if accurate results are only required for a limited range of frequencies of the driving boundary conditions. Only extremely thin lumped layers have the correct frequency response at high frequencies. To model environmental influences, 3 cycles/day (8-hr period sinusoid) is likely the highest frequency necessary to consider when determining the frequency response of buildings (Goldstein, Anderson and Subbarao). Higher frequencies may be desirable for accurately modeling things like control step changes. During the program development, accuracy was measured by analyzing the frequency response at 3 cycles/day.

The exact frequency response of a layered wall can be obtained using the matrix method (Section 3.7 of Carslaw & Jaeger) which gives the inside driving point admittance (from the inside air node), the outside driving point admittance, and the transfer admittance, for any frequency. The magnitude of the inside driving point admittance is the principle parameter used to assess algorithm accuracy.

At the frequency chosen, 3 cycles/day say, the exact driving point admittance of the real wall (with homogeneous layers) can be obtained from the matrix method. Similarly the exact driving point admittance of the lumped wall which the user has chosen to represent the real wall, can also be determined by the matrix method. Comparing these two results shows the accuracy of the lumping assumptions, independent of time step considerations.

The time discretization error associated with Equation 7 at the frequency chosen can be assessed by comparing the driving point admittance predicted by the CSE code, when the air node is driven with a sinusoidal temperature at the chosen frequency, to the theoretical admittance of the lumped wall. Note that this procedure measures the global discretization error, larger potentially than the per time-step error.

Using this procedure for typical lightweight residential construction, we have confirmed that the errors in the temperature predictions made by the CSE finite difference algorithms indeed tend toward zero as Δt and Δx are reduced toward zero.

1.4.1 Layer Thickness of a Homogeneous Material

The lumped layer thickness, Δx, should be is chosen thin enough that the single temperature of the lumped layer is a good measure of the average temperature over a width Δx of the sinusoidal temperature distribution in the material. That is, the temperature of the sinusoidal wave should not vary much over the layer width. This criterion is similar to that used by Chirlian (1973) to determine the appropriate lump sizes in electrical circuits.

The wave length of the temperature distribution in a particular material is given by

$$\lambda = 2\pi d_p$$

Equation 31

where d_p , the penetration depth, an intrinsic characteristic of the material, is given by

$$d_p = \sqrt{2\alpha/\omega}$$

Equation 32

where the angular frequency $\omega = \frac{2\pi}{period}$, α is the thermal diffusivity of the layer material, and ω is the highest angular frequency of the environmental boundary conditions for which good frequency response is desired. As a general guideline it is suggested that the lumped layer thicknesses, Δx, be chosen to be thinner than the penetration depth for the layer. That is, select

$$\Delta x \lesssim d_p$$

Equation 33

Substituting Equation 32 into Equation 33 shows that the rule of Equation 33 limits the lump size Δx to about 16% of the wavelength:

$$\Delta x \lesssim dp = \lambda/_{2\pi} = 0.16\lambda$$

Equation 34

The Equation 33 rule is more important for the modeling of layers on the inner side of the wall, where the layers are subjected to the higher frequency harmonics of inside driving conditions. Deeper into the wall the high frequency harmonics begin to be damped (by about a factor of $e^{-\frac{\Delta x}{d_p}}$), so accurate modeling is of less significance.

1.4.2 Choosing the Time Step

The time step used in the code is input by the user. For high accuracy Equation 7 and Equation 14 should be applied using a time step that is a small fraction of the smallest time constant of any layer.

$$\Delta t \ll \tau$$

Equation 35

Thin layers of a material have a smaller time constant τ than thick layers. The time constant of a layer scales as $\sim \beta^2$, where β is the a layers dimensionless thickness defined as $\beta = \frac{\Delta x}{d_p}$. Thus, if a layers dimensionless thickness is reduced by a factor of two, the time constant is reduced by a factor of four. Therefore the time to run an annual simulation can increase rapidly for small β's. Small tau layers have cv increased such that tau = dt.

Note that the Euler mass layer update algorithm of Equation 7 becomes unstable when $\Delta t > \tau$. The predicted temperatures will oscillate with increasing amplitude each time step. The code outputs warnings whenever a mass node update is performed for which $\Delta t > \tau$.

Like the explicit Euler method, the implicit differencing used at the air node is most accurate for small time steps relative to the air's time constant (Equation 12). The implicit difference method is never unstable, and time steps larger than the air time constant give useful, if somewhat inaccurate predictions. The air balance could have been solved using an Euler difference, but since the air time constant is likely the smallest in the zone, it would dictate smaller time steps than is afforded using the implicit method

1.5 Surface Heat Transfer Coefficients

The radiation coefficients for surfaces inside the conditioned zone are given in Section 1.6.1 where the long-wave radiant network model is discussed.

1.5.1 Local Wind Velocity Terrain and Height Correction

The wind velocity as a function of height at the house site is obtained from the meteorological station wind measurement by making adjustments for terrain and height differences between the meteorological station and the house site.

1.5.1.1 Sherman-Grimsrud method

This method uses *Equation 36* which determines the wind velocity $V(z)$, in ft/sec, at any height z (ft) based on the wind velocity, V_{met} in ft/sec, measured at a location with a Class II terrain (see Table 1) and at a height of 10-meters (32.8 ft):

$$V(z) = SC * V_{met} * \alpha * \left(\frac{z}{32.8}\right)^{\gamma} \qquad \textit{Equation 36}$$

where,

α and γ are obtained from Table 1 for the terrain class at the building location.

SC = shielding coefficient from Table 2 for the building location.

$V(z)$ = wind velocity at height z at the building location (ft/sec).

V_{met} = wind velocity (ft/sec) measured at 10-meters height in a Class II location.

The terrain factor of Table 1 is a general factor describing the influence of the surroundings on a scale on the order of several miles. The shielding factor of Table 2 is a local factor describing the influence of the surroundings on a scale of a few hundred yards.

Table 1: Parameters for Standard Terrain Classifications

Class	**ϒ**	**A**	**Description**
I	0.10	1.30	Ocean or other body of water with at least 5 km of unrestricted expanse
II	0.15	1.00	Flat terrain with some isolated obstacles (buildings or trees well separated)

Class	ϒ	A	Description
III	0.20	0.85	Rural areas with low buildings, trees, etc.
IV	0.25	0.67	Urban, industrial, or forest areas
V	0.35	0.47	Center of large city

Source: NORESCO for California Energy Commission

Table 2: Local Shielding Parameters

Class	C'	SC	Description
I	0.324	1.000	No obstructions or local shielding
II	0.285	0.880	Light local shielding and few obstructions
III	0.240	0.741	Moderate local shielding, some obstructions within two house heights
IV	0.185	0.571	Heavy shielding, obstructions around most of the perimeter
V	0.102	0.315	Very heavy shielding, large obstructions surrounding the perimeter within two house heights

Source: NORESCO for California Energy Commission

1.5.1.2 Implementation

If it is assumed that the default value of the terrain classification at the building location is Class IV terrain of Table 1, and the default local shielding coefficient is SC= 0.571 of Class IV of Table 2, then the wind velocity at the building site at height z is given by:

$$V(z) = SC * V_{met} * \alpha * \left(\frac{ze}{32.8}\right)^{\gamma} = 0.571 * V_{met} * 0.67 * \left(\frac{z}{32.8}\right)^{0.25}$$

or,

$$V(z) = 0.16 * z^{0.25} * V_{met}$$

For example, for 1, 2, and 3 story buildings, of 9.8 ft (3-m), 19.7 ft (6-m), and 29.5 ft (9-m), respectively, then the local eave height wind velocities are:

V(9.8) $= 0.16 * 9.8^{0.25} * V_{met}$ = 0.28 V_{met} for a 1-story building.

V(19.7) = 0.34 V_{met} for a 2-story building.

V(29.5) = 0.38 V_{met} for a 3-story building.

(References: Sherman & Grimsrud (1980), Deru & Burns (2003), Burch & Casey (2009), European Convention for Constructional Steelwork (1978).)

1.5.2 Convection Coefficient for Inside and Outside Surfaces of Zones

The schematic buildings in Figure 4 and Figure 5 show all of the possible interior heat transfer situations for which the convection heat transfer coefficients are determined. The figures symbolically show the nature of the heat transfer boundary layer, and the heat flow direction. The symbols used are explained at the end of this document. Similar schematics have not been done for the outside surfaces.

The equations are developed that give the heat transfer coefficient for each of the Figure 4 and Figure 5 situations, and for the building outside surfaces. The heat transfer coefficients depend on the surface tilt angle θ ($0 \leq \theta \leq 90$), the surface and air temperatures, and on whether the heat flow of the surface has an upward or downward facing component.

The results, which apply to both the UZ and CZ zones, can be summarized as follows:

1.5.2.1 Inside surfaces

For floors, and either vertical walls, or walls pulled-in-at-the-bottom:

If Tair > Tsurf use Equation 53. (heat flow down)

If Tair < Tsurf use Equation 52. (heat flow up)

For ceilings (horiz or tilted), and walls pulled-in-at-the-top:

If Tair > Tsurf use Equation 52. (heat flow up)

If Tair < Tsurf use *Equation 53*. (heat flow down)

1.5.2.2 Outside surfaces

For all vertical walls, and walls with moderate tilts use *Equation 54*.

For horizontal or tilted roof, use Equation 57.

Figure 4: Heat Flow Down Situations

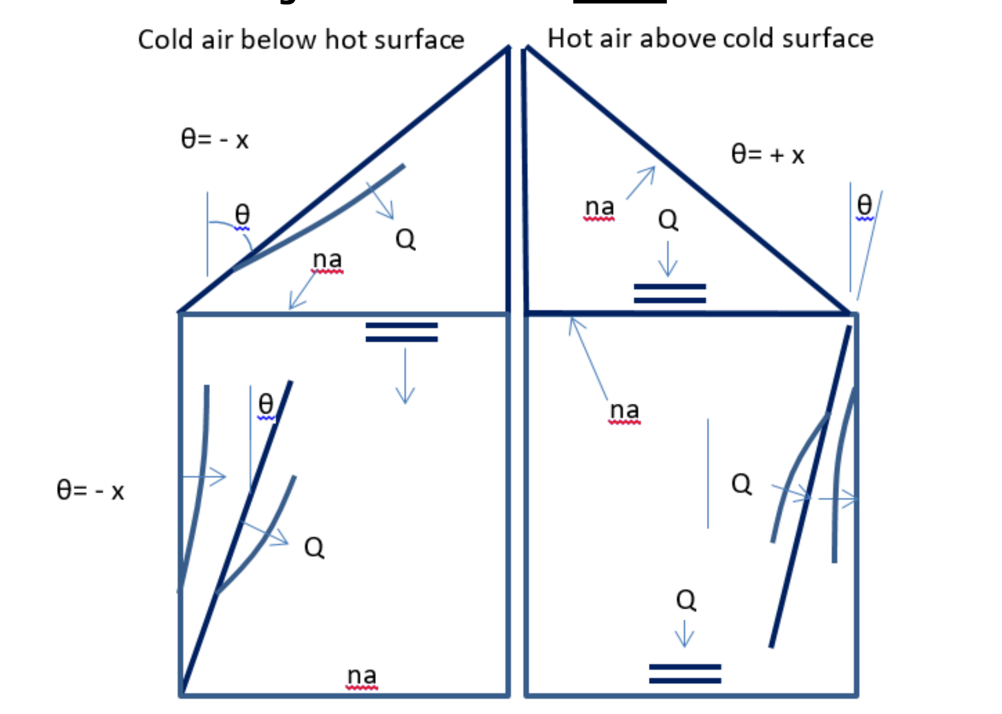
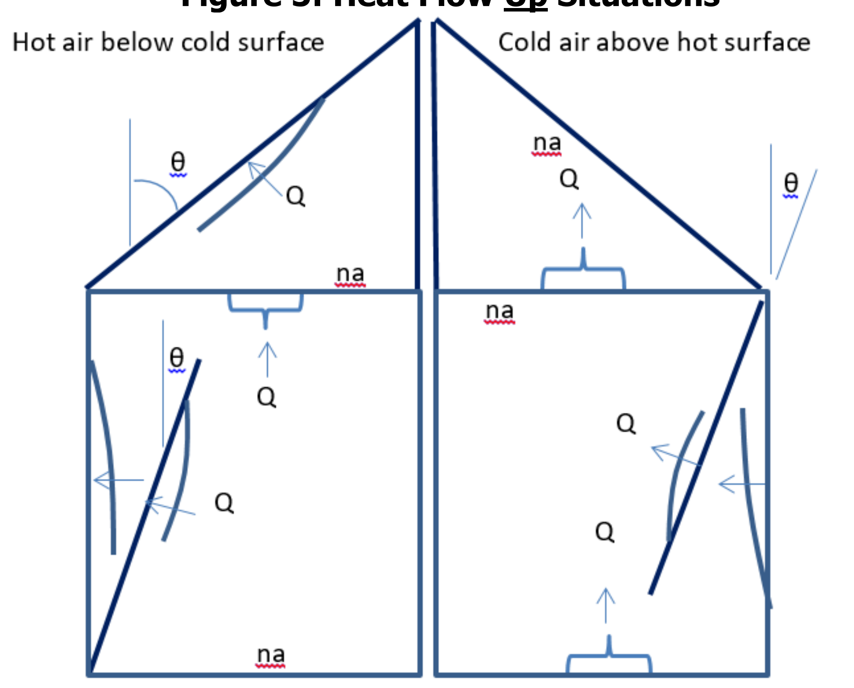


Figure 5: Heat Flow Up Situations



Explanation of Symbols

symbolizes the direction in which the boundary layer is thickening, and the direction of positive heat flow.

symbolizes the air is stratified next to the surface and the direction the heat flow would be if there is any--the figure equations give zero heat flow in this case.

na symbolizes the equations are not applicable to the adjacent surface, because the surface doesn't have an upward or downward facing component, as the case requires.

symbolizes plumes of air buoyantly leaving the adjacent surface, and the direction of heat flow, due to Rayleigh-Benard instability.

1.5.2.3 Natural convection equations

Equation 37, from Churchill and Chu (see Eq. 4.86, Mills (1992)), is used to determine the natural convection coefficients for tilted surfaces. The choice of this equation is partly informed by the work of Wallenten (2001), which compares the Churchill and Chu equation with other correlations and experimental data.

Equation 37 is for turbulent convection ($10^9 < \mathrm{Ra} < 10^{12}$), expected to be the dominant case in room heat transfer.

Equation 37 applies to either side of a tilted surface for angles $(0 \leq \theta \leq 88^o)$if the heat flow has a downward component, or the heat flow is horizontal.

Equation 37 also applies to either side of a tilted surface for angles $\theta < 60^o$ if the heat flow has an upward component, or the heat flow is horizontal.

$$Nu = 0.68 + 0.67(Ra \cdot \psi)^{0.25}(1 + 1.6 * 10^{-8} Ra \cdot \psi)^{\frac{1}{12}} \qquad \textit{Equation 37}$$

where,

$Ra =$ the Rayleigh number.

$Nu =$ the Nusselt number.

$Pr =$ the Prandtl number.

$$\psi = \left[1 + \left(\frac{0.492}{Pr}\right)^{-\frac{16}{9}}\right]$$

Using $\psi = 0.349$ for $Pr = 0.72$, *Equation 37* reduces to:

$$Nu = 0.68 + 0.515Ra^{0.25}(1 + 5.58 * 10^{-9}Ra)^{\frac{1}{12}}$$ *Equation 38*

For high Ra $[Ra \approx> 10^9]$, neglecting the additive terms "1" and "0.68" in *Equation 37* gives:

$$Nu = 0.1057Ra^{\frac{1}{3}}$$ *Equation 39*

By the definition of the Nusselt number, the natural convection heat transfer coef, h_n is:

$$h_n \equiv Nu * \frac{k(air)}{L_{char}}$$

At 70F, $Ra = 1.66x10^6L^3|\Delta T|\,cos(\theta)$, *and* $k = 0.0148$,

reduces to:

$$h_n = 0.185(|\Delta T|cos\theta)^{\frac{1}{3}}$$ *Equation 40*

Note that h_n is independent of characteristic length $\mathrm{L_{char}}$.

Downward heat flow

According to Mill's(1992) *Equation 37* doesn't apply to downward heat flow for $\theta > 88^o$. At 70 F, for a 20 ft characteristic length, the 0.68 term predicted by Equation *38* for $\theta = 90^o$ corresponds to $h_n = \frac{0.68k}{L} = 0.0005$; essentially zero. Although the downward heat flow is ideally stably stratified (three cases shown in Figure 4), most measurements and modeling practice indicate h may be larger than zero. We use the equation of Clear et al. for the minimum, for heat flow down:

$$Nu = 0.27Ra^{0.25}$$ *Equation 41*

Clear's equation reduces to:

$$h_n = 0.27(0.0148)(\frac{4}{L})\left[1.642E6\Delta T\left(\frac{L}{4}\right)^3\right]^{0.25}$$

or

$$h_n = 0.202\left|\frac{\Delta T}{L_{char}}\right|^{\frac{1}{4}}$$ *Equation 42*

where, L_{char} is the wall characteristic length; see Equation 51 definitions.

Adding this h to *Equation 40* gives:

$$h_{down} = MAX\left[0.185(|\Delta T|cos\theta)^{\frac{1}{3}}, 0.202\left|\frac{\Delta T}{L_{char}}\right|^{\frac{1}{4}}\right] \quad 0 \le \theta \le 90 \qquad \textit{Equation 43}$$

The following simplification is made, where the exponent of the second term is changed to 1/3, so that $|\Delta T|^{\frac{1}{3}}$ can be factored out:

$$h_{down} = |\Delta T|^{\frac{1}{3}} MAX\left[0.185(cos\theta)^{\frac{1}{3}}, 0.202 L_{char}^{-\frac{1}{3}}\right] \quad 0 \le \theta \le 90 \qquad \textit{Equation 44}$$

Changing the exponent means *Equation 44* gives same answer as *Equation 43* only when $\frac{\Delta T}{L_{char}} = 1$. But *Equation 44* would have acceptable error for other $\frac{\Delta T}{L_{char}}$ ratios, and gives more or less the right dependence on ΔT. If in addition, one assumes a typical $L_{char} = 15,$ say, then the minimum term becomes: $0.202\mathrm{L}_{\mathrm{char}}^{-\frac{1}{3}} = 0.08$, giving the final reasonable form:

$$h_{down} = |\Delta T|^{\frac{1}{3}} MAX\left[0.185(cos\theta)^{\frac{1}{3}}, 0.08\right] \quad 0 \le \theta \le 90 \qquad \textit{Equation 45}$$

Upward heat flow for $\boldsymbol{\theta} \le \mathbf{60^o}$

For the inside & outside of walls where the heat flow has an upward (or horizontal heat flow at the limit $\theta = 0^o$), and the outside of roofs, *Equation 40* applies:

$$h_n = 0.185(|\Delta T|cos\theta)^{\frac{1}{3}}$$

Upward heat flow for $\boldsymbol{\theta} > \mathbf{60^o}$

To handle cases of upward heat flow for $\theta > 60^o$, h_{up} is found by interpolating between *Equation 40*, evaluated at $\theta = 60^o$, and *Equation 47* at 90^o. Equation *46*, for heat transfer from a horizontal surface $(\theta = 90)$, is from Clear et al. (Eq. 11a). It is close to the much used McAdams equation suggested by both the Mills(1992) and Incropera-Dewitt textbooks.

$$Nu = 0.15Ra^{\frac{1}{3}} \qquad \textit{Equation 46}$$

At 70-F, Equation *46* reduces to

$$h_n = 0.26(\Delta T)^{\frac{1}{3}} \qquad \textit{Equation 47}$$

Interpolating, for upward heat flow cases with $\theta \ge 60^o$:

$$h_{up} = 0.185(\Delta T cos60)^{\frac{1}{3}} + \frac{\left[0.26(\Delta T)^{\frac{1}{3}} - 0.185(\Delta T cos60)^{\frac{1}{3}}\right](\theta - 60)}{30}$$

which reduces to:

$$h_{up} = (0.00377 * \theta - 0.079)|\Delta T|^{\frac{1}{3}} \quad \text{for } 60^o \leq \theta \leq 90 \qquad \textit{Equation 48}$$

where θ is in degrees.

1.5.2.4 Inside forced convection equation

Measured forced convection heat transfer coefficients are frequently correlated using an equation of the form

$$h_{ach} = h_{forcedIN} = C_{ach} * ACH^{0.8} \qquad \textit{Equation 49}$$

The RBH model (Barnaby et al. (2004) suggests using $\mathrm{h_f} = 0.88$ Btu/hr-ft^{2}F at ACH = 8. This gives $C_{ach} = 0.167$. Walton (1983) assumes h = 1.08 when the "air handler system is moving air through the zone." If this was at 8 ach, then this implies $C_{ach} = 0.205$.

1.5.2.5 Outside forced convection equation for all walls and all roofs

From Clear et al. (2001, Eq. (11a)),

$$Nu = W_f R_f 0.037 Re^{0.8} Pr^{\frac{1}{3}} \qquad \textit{Equation 50}$$

Clear et al. used the Reynolds number based on a free-stream wind velocity 26.2 ft (8 m) above the ground.

At 70F, *Equation 50* reduces to:

$$h_V = k * \frac{Nu}{L} = 0.527 W_f R_f \frac{V^{0.8}}{L^{0.2}} \qquad \textit{Equation 51}$$

where for walls,

$$L = wall\ L_{char} = 4\frac{Wall\ Area}{Wall\ Perimeter} = 4\frac{Height*Width}{2(Height+Width)} \approx height\ of\ square\ wall = Z_{eave}$$

V = wind velocity at eave height at building location, in ft/sec, $= 0.16 * \mathrm{Z_{eave}^{0.25}} * V_{met}$ from Section 1.5.1.2.

V_{met} = freestream wind velocity, in ft/sec, 10 m (32.8 ft) above the ground at the meteorological station site.

R_f = Table 3 value.

$W_f = 0.63$

The wind direction multiplier, W_f, is defined as the average h of all of the vertical walls, divided by the h of the windward wall, with this ratio averaged over all wind directions. We estimated W_f using the CFD and wind tunnel data of Blocken et al. (2009) for a cubical house. Blocken's Table 6 gives a windward surface convection coefficient of $\mathrm{h_c} \approx 4.7\mathrm{V}^{0.84}$ (SI units), averaged over wind direction. Blocken's Figure 9 gives $\mathrm{h_c} \approx 7.5$ averaged over all vertical surfaces, for wind speed $\mathrm{V_{met}} = 3$-m/s. Thus, we estimate $\mathrm{W_f} = \frac{7.5}{4.7\mathrm{V}^{0.84}} = 0.63$.

and for roofs,

$$L = Roof\ L_{char} = 4\frac{Roof\ Plan\ Area}{Roof\ Perimeter} = 4\frac{Length * Width}{2(Length + Width)}$$

$$\approx \sqrt{Roof\ Area}\ for\ square\ roof \approx Z_{eave}$$

$$\approx \sqrt{Roof\ Area}\ for\ square\ roof \approx Z_{eave}$$

V = wind velocity 9.8 ft (3 m) above the eave height at building location, in ft/sec.

$$= 0.16 * (Z_{eave} + 9.8)^{0.25} * V_{met}$$

$$_f = 1$$

$_f$ = Table 3 value.

Walton (1983) assumed that the ASHRAE roughness factors of Table 3 apply to the convection coefficient correlations. The Clear et al. (2001) experiments tend to confirm the validity of these factors. Blocken et al. (2009) says, "The building facade has been assumed to be perfectly smooth. Earlier experimental studies have shown the importance of small-scale surface roughness on convective heat transfer. For example, Rowley et al. found that the forced convection coefficient for stucco was almost twice that for glass. Other studies showed the important influence of larger-scale surface roughness, such as the presence of mullions in glazed areas or architectural details on the facade, on the convection coefficient."

Table 3: Surface Roughness Parameter R_f (Walton 1981)

Roughness Index	**Rf**	**Example**
1 (very rough)	2.1	Stucco
2 (rough)	1.67	Brick
3 (medium rough)	1.52	Concrete
4 (Medium smooth)	1.13	Clear pine
5 (Smooth)	1.11	Smooth plaster
6 (Very Smooth)	1	Glass

Source: NORESCO for California Energy Commission

1.5.2.6 Inside combined natural and forced convection

The combined convection coefficient is assumed to be the direct sum of the natural and forced convection coefficients:

For upward and horizontal heat flow:

$$h_{combined} = h_{up} + h_{ach}$$ *Equation 52*

where,

$h_{up} =$ Equation 40 or Equation 48 depending on whether θ is < or > 60°.

h_{ach} = *Equation 49*

For downward heat flow:

$$h_{combined} = h_{down} + h_{ach}$$ *Equation 53*

where,

$h_{down} =$ *Equation 45*

h_{ach} = *Equation 49*

1.5.2.7 Outside combined natural and forced convection

The conclusion of Clear et al. (2001) is that the combined convection coefficient is best correlated by assuming it to be the sum of the natural and forced coefficients. For roofs, Clear et al. (2001) assumes that the natural and forced convection are additive, but that natural convection is suppressed by the factor η given by Equation 56 when forced convection is large ($\eta \rightarrow 0$ as the Reynolds number becomes large). We also assume this attenuation of the natural convection applies to the outside of the walls.

For all vertical walls, and walls with moderate tilts:

$$h_{combined} = \eta h_n + h_V$$ *Equation 54*

where,

h_n = *Equation 40*

h_V = *Equation 51*

$$\eta = 1 \Big/ \left[1 + 1 \Big/ \left(ln\left(1 + \frac{0.06L|\Delta T|}{V^2}\right)\right)\right]$$ (to avoid divide by zero, if V= 0, could set to V = 0.001)

where L & V are the same as used in *Equation 51* for walls.

For roofs, Clear et al. (2001) assumes that the natural and forced convection are additive, but that natural convection is suppressed by the factor η when forced convection is large ($\eta \rightarrow 0$ as the Reynolds number becomes large). Clear gives η as:

$$\eta = 1 \Bigg/ \left[1 + 1 \Big/ \left(ln\left(1 + \frac{Gr_L}{{Re_L}^2}\right)\right) \right]$$

Equation 55

At 70F, with $Gr = 2.28x10^6 L^3|\Delta T|$, $\mathrm{Re}^2 = (6140\mathrm{VL})^2$, and $\mathrm{L} = \mathrm{L_{char}}$ for surface , Equation *55* reduces to:

$$\eta = 1 \Bigg/ \left[1 + 1 \Big/ \left(ln\left(1 + \frac{0.06L|\Delta T|}{V^2}\right)\right) \right]$$

Equation 56

For roofs:

$$h_{combined} = \eta h_n + h_V \qquad \textit{Equation 57}$$

where,

$h_n =$ Equation *45* for downward heat flow.

$h_n =$ *Equation 47* for upward heat flow.

$h_V =$ *Equation 51* for upward or downward heat flow.

η is from Equation 56

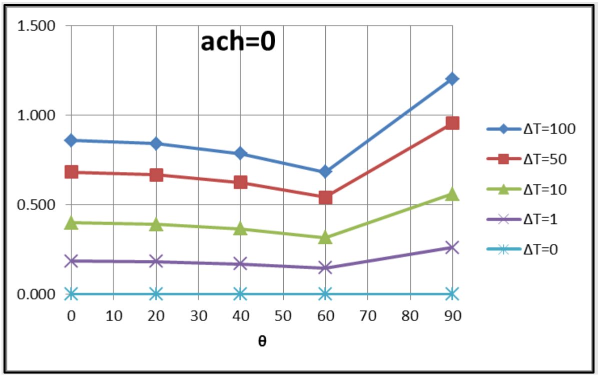
L & V are the same as used in *Equation 51* for roofs.

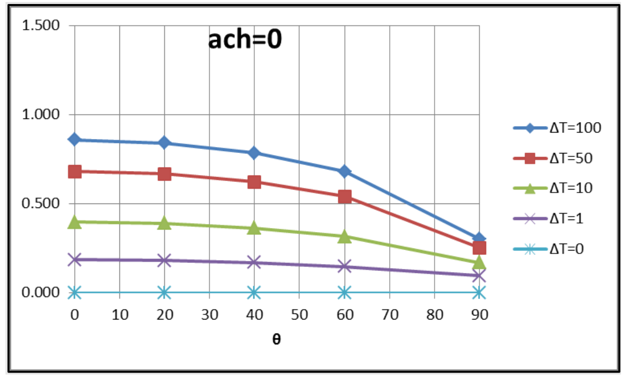
1.5.2.8 Plots of equations

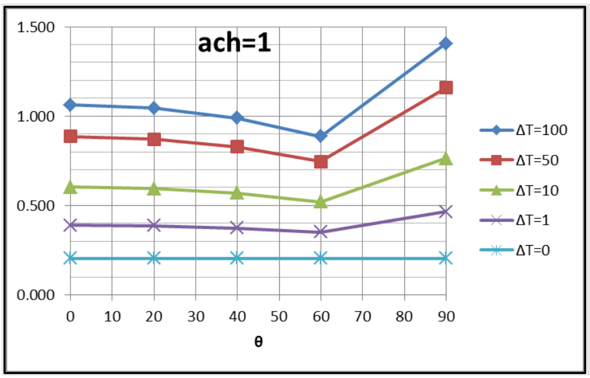
In Figure 6, the left hand column of plots are of *Equation 53*, for the downward heat flow cases shown in Figure 4. The right hand side plots are of *Equation 52*, for upward heat flow cases of Figure 5. All of the plots assume $T_{film} = 70F$, and $L_{char} = Z_{eave} = 20$ ft.

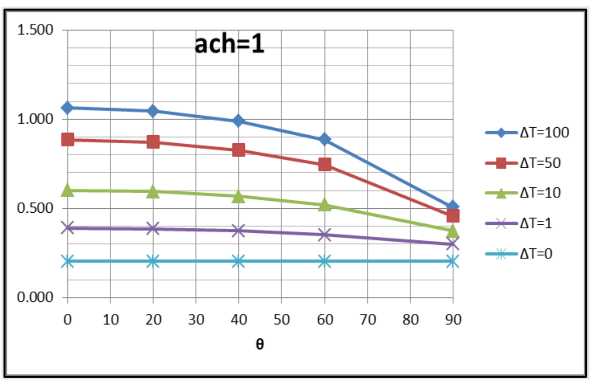
Figure 6: Plots of Equations for Downward and Upward Heat Flow

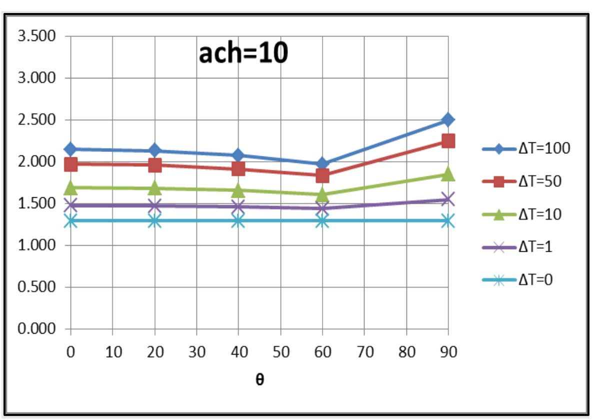
DOWNWARD HEAT FLOW (Equation 53): *UPWARD HEAT FLOW (Equation 52):*

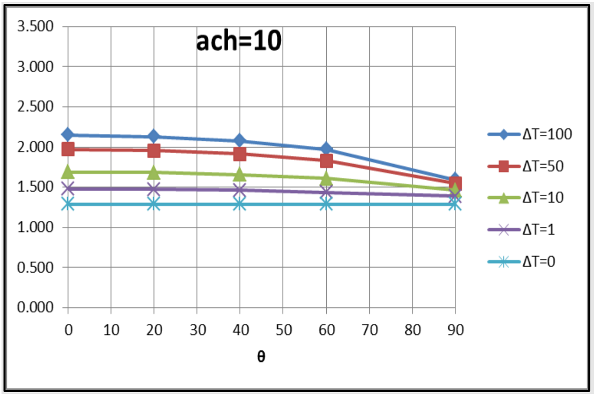

ach=0
1.500
1.000
0.500
0.000
0 10 20 30 40 50 60 70 80 90
θ
ΔT=100
ΔT=50
ΔT=10
ΔT=1
ΔT=0


ach=0
1.500
1.000
0.500
0.000
0 10 20 30 40 50 60 70 80 90
θ
ΔT=100
ΔT=50
ΔT=10
ΔT=1
ΔT=0


ach=1
1.500
1.000
0.500
0.000
0 10 20 30 40 50 60 70 80 90
θ
ΔT=100
ΔT=50
ΔT=10
ΔT=1
ΔT=0


ach=1
1.500
1.000
0.500
0.000
0 10 20 30 40 50 60 70 80 90
θ
ΔT=100
ΔT=50
ΔT=10
ΔT=1
ΔT=0

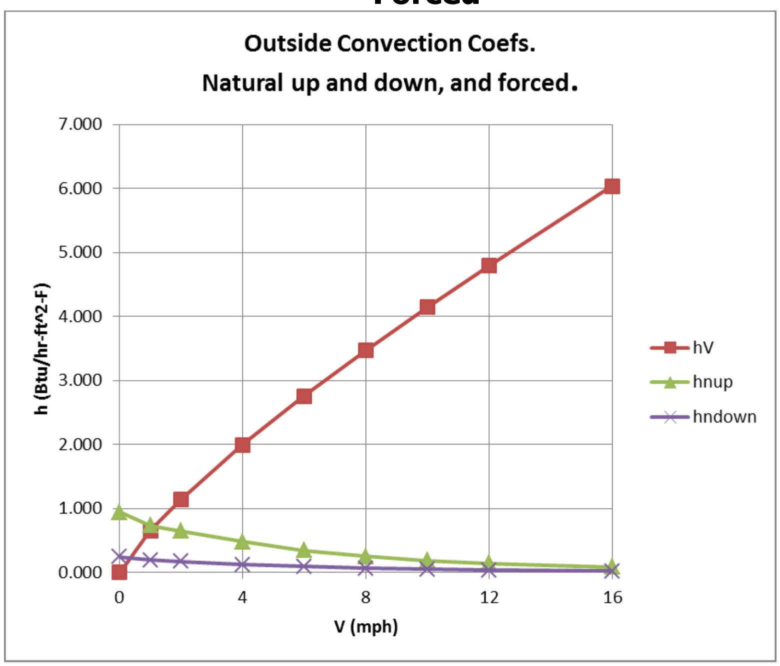

ach=10
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0 10 20 30 40 50 60 70 80 90
θ
ΔT=100
ΔT=50
ΔT=10
ΔT=1
ΔT=0



OUTSIDE surface convection coefficient Plot for a horizontal roof:

For $\Delta T = 50\ F$, $L_{char} = 20$ ft, $R_f = 1.67$:

Figure 7: Outside Convection Coefficients, Natural Up and Down, and Forced



1.5.3 Outside Radiation Coefficients

1.5.3.1 Wall surfaces

The net long wave radiation heat exchange between the outside surface and the environment is dependent on surface temperature, the spatial relationship between the surface and the surroundings, and the properties of the surface. The relevant material properties of the surface, emissivity ε and absorptivity α, are complex functions of temperature, angle, and wavelength. However, it is generally assumed in building energy calculations that the surface emits or reflects diffusely and is gray and opaque ($\alpha = \varepsilon, \tau = 0, \rho = 1 - \varepsilon$).

The net radiant heat loss from a unit area of the outside of a construction surface to the outside environment is given by:

$$q_{rad} = \varepsilon\epsilon_g \, \sigma F_{gnd}\left(T_s{}^4 - T_g{}^4\right) + \varepsilon\epsilon_g \, \sigma F_{sky}\beta\left(T_s{}^4 - T_{sky}{}^4\right) + \varepsilon\sigma F_{sky}(1-\beta)\left(T_s{}^4 - T_a{}^4\right)$$

Equation 58

where,

ε = surface emissivity.

ϵ_g = ground emissivity is assumed to be 1.

σ = Stephan-Boltzmann constant.

T_s = outside surface temperature.

T_a = outside dry bulb temperature.

T_g = ground surface temperature.

T_{sky} = effective temperature of sky.

F_{gnd} = view factor from surface to ground.

F_{sky} = view factor from surface to sky.

$$\beta = cos\left(\frac{\phi}{2}\right)$$

The sky irradiance is taken as a β weighted average of that from $\mathrm{T_{sky}}$ and that from T_a.

1.5.3.2 Fsky, Fgnd, and β

Howell (1982, #C-8, p.94), gives the fraction of the radiation leaving the window surface and reaching the sky by:

$$F_{sky} = \frac{1 + \cos\phi}{2}$$

The fraction leaving the window incident on the ground is:

$$F_{gnd} = \frac{1 - \cos\phi}{2}$$

where, ϕ = surface tilt angle, the angle between ground upward normal and window outward normal (0° corresponds to a horizontal skylight, 90° to a vertical surface).

The parameter β accounts for the sky temperature's approach to the air temp near the horizon. β is the fraction of the sky effectively at Tsky; (1-β) is the fraction of the sky effectively at Ta. β is used by Walton (1983), and Energy Plus (2009), but appears to have little theoretical or experimental basis.

Walton (1983) give β as:

$$\beta = cos\left(\frac{\phi}{2}\right)$$

Since $cos\left(\frac{\varphi}{2}\right) = \sqrt{\frac{1+cos\varphi}{2}}$, it is noted that $F_{sky} = \beta^2$, and $F_{sky}\beta = \beta^3$.

1.5.3.3 Net radiant heat loss from a unit area

Equation 58 can be written as

$$q_{rad} = h_{rg}(T_s - T_g) + h_{rsky}(T_s - T_{sky}) + h_{rair}(T_s - T_a) \qquad \textit{Equation 59}$$

where,

$$h_{rg} = \varepsilon\epsilon_g\, \sigma F_{gnd}({T_s}^2 + {T_g}^2)(T_s + T_g)$$

$$h_{rsky} = \epsilon\sigma F_{sky}\beta({T_s}^2 + {T_{sky}}^2)(T_s + T_{sky})$$

$$h_{rair} = \varepsilon\sigma\, F_{sky}(1-\beta)(T_s^2 + T_a^2)(T_s + T_a).$$

T_g is assumed to be equal to *Ta*, so *Equation 59* becomes

$$q_{rad} = h_{rsky}(T_s - T_{sky}) + h_{ra}(T_s - T_a) \qquad \textit{Equation 60}$$

where,

$$h_{rsky} = \epsilon\sigma F_{sky}\beta({T_s}^2 + {T_{sky}}^2)(T_s + T_{sky}) \qquad \textit{Equation 61}$$

$$h_{rair} = \varepsilon\sigma\left(F_{sky}(1-\beta) + F_{gnd}\right)(T_s^2 + T_a^2)(T_s + T_a). \qquad \textit{Equation 62}$$

For a vertical surface, $F_{sky}\beta = 0.354$, and $F_{sky}(1-\beta) + F_{gnd} = 0.646$, so

$$h_{rsky} = 0.354\epsilon_s\sigma(T_s^2 + T_{sky}^2)(T_s + T_{sky}) \approx 4(0.354)\,\epsilon_s\sigma\overline{T^3}$$

$$h_{rair} = (0.146 + 0.5)\epsilon_s\sigma(T_s^2 + T_a^2)(T_s + T_a) \approx 4(0.646)\,\epsilon_s\sigma\overline{T}^3$$

1.5.3.4 Total effective conductance and outside effective temperature, T_{env}, for walls

Adding the exterior convection coefficient, hco, of *Equation 40* to *Equation 60* gives the total net heat transfer from the outside surface :

$$q_{rad+conv} = h_{rsky}(T_s - T_{sky}) + (h_{rair} + h_{co})(T_s - T_a) \qquad \textit{Equation 63}$$

This can be written as,

$$q_{rad+conv} = h_o(T_s - T_{env}) \qquad \textit{Equation 64}$$

where h_o is the effective exterior conductance to the conductance weighted average temperature, T_{env}.

$$h_o = h_{rsky} + h_{rair} + h_{co}$$ *Equation 65*

$$T_{env} = \frac{h_{rsky}T_{sky} + (h_{rair} + h_{co})T_a}{h_{rsky} + h_{rair} + h_{co}}$$ *Equation 66*

1.5.3.5 Outside window surfaces

The ASHWAT window algorithm of Section 1.7 utilizes the irradiation intercepted by the window. From Equation 58 this can be deduced to be:

$$G = F_{gnd}\sigma T_{gnd}^4 + F_{sky}\beta\sigma T_{sky}^4 + F_{sky}(1-\beta)\sigma T_{air}^4$$ *Equation 67*

1.5.4 Sky Temperature

It is possible to approximate the long wave radiation emission from the sky as a fraction of blackbody radiation corresponding to the temperature of the air near the ground. The sky emittance ε_{sky} is defined such that the sky irradiation on a horizontal surface is $\sigma\varepsilon_{sky}T_a^4$.

The effective temperature of the sky is obtained by equating the blackbody emissive power of the sky at T_{sky}, to the sky irradiation:

$$\sigma\, T_{sky}^4 = \sigma\varepsilon_{sky}T_a^4$$

or,

$$T_{sky} = \varepsilon_{sky}^{0.25}T_a,$$ *Equation 68*

where T_{sky} and T_a are in degrees Rankine.

The value of ε_{sky} depends on the dewpoint temperature, cloud cover, and cloud height data. Martin and Berdahl (1984) give the ε_{sky} for clear skies as ε_o:

$$\varepsilon_0 = 0.711 + 0.56\frac{T_{dew}}{100} + 0.73\left(\frac{T_{dew}}{100}\right)^2 + 0.13cos\left(\pi\frac{hr}{12}\right) + 0.00023(P_{atm} - 1000)$$

Equation 69

where,

T_{dew}= the dewpoint temperature in Celsius.

hr = hour of day (1 to 24).

P_{atm}= atmospheric pressure in millibars.

1.5.4.1 Palmiter version of Martin-Berdahl model

The clear sky emissivity is corrected to account for cloud cover by the following algorithm, developed by Larry Palmiter (with Berdahl's imprimatur), that represents the Martin and Berdahl model when weather tape values of cloud ceiling height, and total and opaque cloud fractions are available.

$$\epsilon_{sky} = \varepsilon_0 + (1-\varepsilon_0)(n_{op}\varepsilon_{op}\Gamma_{op} + n_{th}\varepsilon_{th}\Gamma_{th}) \qquad \textit{Equation 70}$$

where,

n_{op} = the opaque cloud fraction

n_{th} = the thin cloud fraction: $n_{th} = n - n_{op}$

n = the total sky cover fraction

ε_{op} = the opaque cloud emittance is assumed to be 1.

ε_{th} = the thin cloud emittance; assumed to be 0.4.

The cloud factor Γ is used to adjust the emissivity when the sky is cloudy due to the increasing cloud base temperature for decreasing cloud altitudes. The cloud base temperature is not available on the weather tapes, so assuming a standard lapse rate of 5.6°C/km, Γ is correlated with the more commonly measured cloud ceiling height, h (in meters), giving by the general expression:

$$\Gamma = e^{-\frac{h}{8200}}$$

For thin clouds, Γ_{th} is determined using an assumed cloud height of 8000-m, so,

$$\Gamma_{th} = e^{-\frac{8000}{8200}} = 0.377 \qquad \textit{Equation 71}$$

For opaque clouds,

$$\Gamma_{op} = e^{-\frac{h}{8200}} \qquad \textit{Equation 72}$$

If ceiling height data is missing (coded 99999 on TMY2), the Palmiter model assumes that the opaque cloud base is at $h = 2000\ m$. If ceiling height is unlimited (coded as 77777) or cirroform (coded 88888), it is assumed that the opaque cloud base is at $h = 8000\ m$.

Using the assumed cloud cover and emissivity factors, *Equation 70* becomes:

$$\epsilon_{sky} = \epsilon_0 + (1-\epsilon_0)\left[n_0\Gamma_{op} + (n-n_0) * 0.4 * 0.377\right]$$

or,

$$\epsilon_{sky} = \epsilon_0 + (1-\epsilon_0)\left[n_0 e^{-\frac{h}{8200}} + 0.151(n-n_0)\right] \qquad \textit{Equation 73}$$

1.5.4.2 When opaque cloud cover data, $\mathrm{n_o}$, is missing

In this case it is assumed that the cloud cover is opaque, $n_o = n$, when the ceiling height is less than 8000-m, and half opaque, $n_o = \frac{n}{2}$, when the ceiling height is equal or greater than 8000. That is,

for $h < 8000\ m$ (from *Equation 73* with $n_o = n$):

$$\epsilon_{sky} = \epsilon_0 + (1 - \epsilon_0)ne^{-\frac{h}{8200}}$$ *Equation 74*

For $h \geq 8000\ m$ (from Equation 73 with $n_{op} = n_{th} = \frac{n}{-}$):

$$\epsilon_{sky} = \epsilon_0 + (1 - \epsilon_0)n\left[\frac{1}{2}e^{-\frac{h}{8200}} + 0.0754\right]$$ *Equation 75*

1.5.4.3 When both opaque cloud cover and ceiling height data is missing

When only total sky cover is available using an h of 2000-m reduces *Equation 74* to:

$$\epsilon_{sky} = \epsilon_0 + 0.784(1 - \epsilon_0)n$$ *Equation 76*

1.6 Distribution of SW and LW Radiation inside the Zone

1.6.1 Long Wave Radiation Distribution

1.6.1.1 Carroll model

The radiant model used in CSE is based on the "MRT Network Method" developed by Joe Carroll (see Carroll 1980 & 1981, and Carroll & Clinton 1980 & 1982). It was chosen because it doesn't require standard engineering view factors to be calculated, and yet gives a relatively accurate radiant heat distribution for typical building enclosures (see Carroll 1981).

It is an approximate model that simplifies the "exact" network (seeC) by using a mean radiant temperature node, Tr, that act as a clearinghouse for the radiation heat exchange between surfaces, much as does the single air temperature node for the simple convective heat transfer models. For n surfaces this reduces the number of circuit elements from (n-1)! in the exact case, to n with the Carroll model.

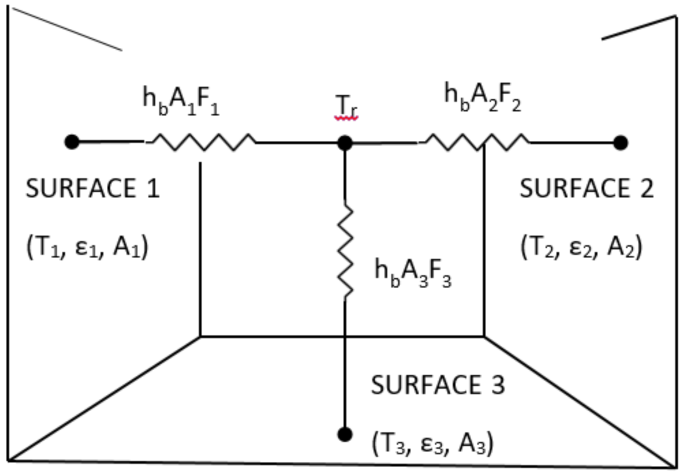
For black surfaces the radiant network is shown in Figure 8. For n surfaces, T_r floats at the conductance, A_iF_i, weighted average surface temperature:

$$T_r = \frac{\sum_1^n A_i F_i T_i}{\sum_1^n A_i F_i}$$

Equation 77

The actual areas, A_i , need not be equal, nor limited to three.

Figure 8: Carroll Network for Black Surfaces



The factor F_i, in the radiant conductance between the T_i surface node and the T_r node is Carroll's "MRT view factor", that corrects for the self-weighting (seeD) of $\mathrm{T_I}$ in the temperature $\mathrm{T_r}$. The $\mathrm{F_I}$ factors are obtained from the set of n nonlinear equations for n surfaces:

$$F_i = \frac{1}{1 - \frac{A_i F_i}{\sum_1^n A_j F_j}}$$

Equation 78

Given the surface areas, these equations are easily solved at the beginning of the simulation by successive substitution, starting with all $F_i = 1$. This converges for realistic enclosures, but won't necessarily converge for enclosures having only two or three surfaces, particularly if there are large area disparities.

F_i is always larger than 1 because it's role is to raise the conductance between T_r and T_i to compensate for the potential difference $|\mathrm{T_r} - \mathrm{T_I}|$ being smaller than it would be had T_I not been part of the conductance weighted average T_r. The $\mathrm{F_I}$ values can be seen to be close to 1, since

Equation 78 is roughly approximated by $F_i \approx 1 + (A_i/A_{all\ surfaces})$.

The net radiant heat transfer [Btu/hr] from surface i is:

$$q_i = h_b A_i F_i (T_i - T_r)$$

Equation 79

Using a Y-Δ transformation, the Figure 8 circuit can put in the form of the exact solution network of Figure C-1 in C, showing the implicit view factors F_{ij} to be:

$$F_{ij} = \frac{F_i A_j F_j}{\sum_{k=1}^n A_k F_k}$$

Equation 80

Thus the implicit view factors are independent of the relative spacial disposition of the surfaces, and almost directly proportional to the surface area Aj of the viewed by surface i. Also, without special adjustments (see Carroll (1980a)), all surfaces see each other, so coplanar surfaces (a window and the wall it is in) radiate to each other.

Equation 79 is exact (i.e., gives same answers as the C model) for cubical rooms; for which

Equation 78 gives $F_i = 1.20$. Substituting this into Equation 80 gives the implied $F_{ij} = 0.2$. This is the correct F_{ij} for cubes using view-factor equations Howell(1982). It is likely accurate for all of the regular polyhedra.

Grey surfaces

Carroll's model handles gray surfaces, with emissivities ε_i, by adding the Oppenheim surface conductance $\frac{A_i\varepsilon_i}{1-\varepsilon_i}$ in series with the conductances $h_b A_i F_i$. As shown in Figure 9, the conductance between T_i and T_r becomes $h_b A_i F_i^{'}$, where the $F_i^{'}$ terms are:

$$F_i^{'} = \frac{1}{\frac{1}{F_i} + \frac{1-\varepsilon_i}{\varepsilon_i}}$$

Equation 81

The net radiant heat transfer [Btu/hr] from surface i is given by:

$$q_i = h_b A_i F_i^{'} (T_i - T_r)$$

Equation 82

where for grey surfaces T_r is the "$h_b A_i F_i^{'}$" weighted average surface temperature given by:

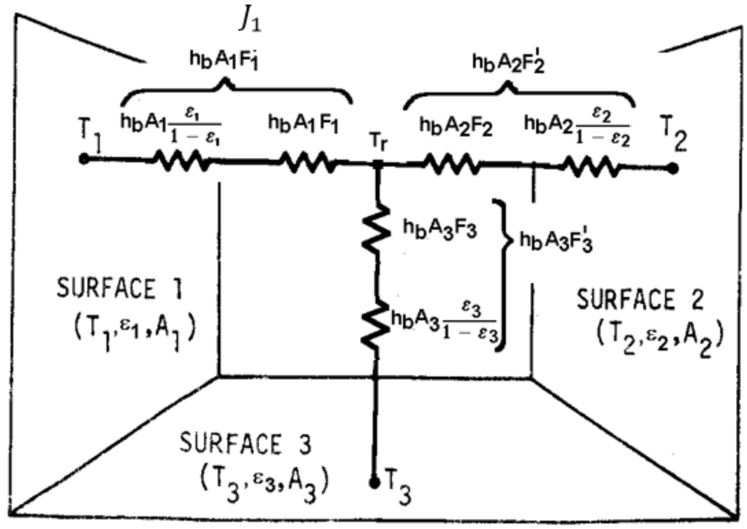
$$T_r = \frac{\sum_1^n A_i F_i^{'} T_i}{\sum_1^n A_i F_i^{'}}$$

Equation 83

Similar to Equation 77 for a black enclosure, Equation 83 shows that T_r for grey surfaces is the conductance, $A_i F_i^{'}$, weighted average surface temperatures.

The role of F_i hasn't changed, but since the conductance $A_i F_i$ is now connected to the radiosity node rather than the surface node, $E_r (= \sigma T_r^4)$ can be thought of as the $A_i F_i$-weighted average radiosity of the surfaces, rather than the $A_i F_i$-weighted average emissive power of the surfaces as in the black enclosure case.

Figure 9: Carroll Radiant Network for Grey Surfaces



This completes the description of the basic Carroll model. The principle inputs are the interior surface areas in the zone, the emissivities of these surfaces, and the typical volume to surface area ratio of the zone (see Section 1.6.1.3). All of the interior surfaces, including ducts, windows, and interior walls, are assumed to exchange heat between each other as diffusely radiating gray body surfaces.

Longwave radiant internal gains can be added, in Btu/hr, to the radiant node Tr. This distributes the gains in proportion to the conductance $A_i F_i^{'}$.

Conversion to delta

Using a Y-Δ transformation, the radiant network of Figure 9 can be converted to the C, Figure C-3 circuit form, eliciting the $F_{ij}^{'}$ interchange factors implicit in Carroll's algorithm. Similar in form to Equation 80,

$$A_i F_{ij}^{'} = \frac{A_i F_i^{'} A_j F_j^{'}}{\sum_{k=1}^{n} A_k F_k^{'}}$$

Equation 84

Using these $A_i F_{ij}^{'}$ values, q_{ij} can be obtained from

$$q_{ij} = h_b A_i F_{ij}^{\prime} \left(T_i - T_j\right)$$

Equation 85

The total net heat transfer from surface *i* (i.e., the radiosity minus the irradiation for the un-linearized circuit) is given by summing Equation 85 for all the surfaces seen by surface i:

$$q_i = \sum_{j=1}^{n} h_b A_i F_{ij}^{\prime} \left(T_i - T_j\right)$$

Equation 86

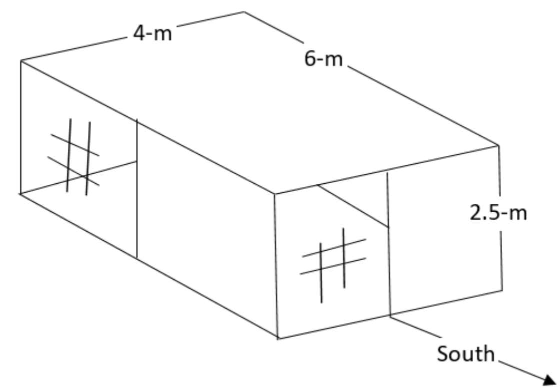
which will agree with the result of Equation 82.

1.6.1.2 Accuracy of Carroll model

The Carroll model of Figure 9 is exact for cubical enclosures with arbitrary surface emissivities. It is surprisingly accurate for a wide variety of shapes, such as hip roof attics and geodesic domes.

Carroll (1981) compared his model, and other simplified models, with the exact solution for the enclosure shown in Figure 10. Half the south wall and half of the west wall are glass with ε = 0.84, and the rest of the interior surfaces have ε = 0.9.

Figure 10: Test Room of Walton (1980)



Comparisons were made primarily regarding three types of errors:

Heat balance errors

The first law requires that the sum of the net radiation emitted by each of the surfaces, plus any internal gain source of long-wave radiation, must equal zero. That is, $q_{int} + \sum_{i=1}^{n} q_i = 0$.

Due to their fixed conductance circuits, both the Carroll method and the Walton(1983) method are inherently free of heat balance errors. Carroll found BLAST and NBSLD algorithms to have rms heat balance errors of 9.8% (12%) and 1.7% (3.4%) for the Figure 10 enclosure.

Individual surface net heat transfer errors

For a given enclosure, these are errors in an individual surfaces net heat flow, q_i, compared to the exact method. For Carroll's method, this finds the error in q_i determined from the $A_i F_{ij}^{'}$ values of Equation, compared to the q_i values found using the exact $A_i F_{ij}^{'}$ values (obtainable from Figure C-3 of C).

Carroll found the % rms error in the q_i values for a given enclosure in two different ways.

The first method, Equation 87, gives the rms error of q_i for each surface divided by the rms of the n net heat transfers from each surface:

$$Err = \left(\frac{\frac{1}{n} \sum_{i=1}^{n} \Delta q_i^2}{\frac{1}{n} \sum_{i=1}^{n} \overline{q}_i^2} \right)^{\frac{1}{2}} * 100$$

Equation 87

where

$\Delta q_i = q_i - \overline{q}_i$, is the error in q_i.

$q_i = \sum_{j=1}^{n} h_b A_i F'_{ij} (T_i - T_j)$, using F'_{ij} values from Carroll's model, Equation 87.

$\overline{q}_i = \sum_{j=1}^{n} h_b A_i F'_{ij} (T_i - T_j)$, using the exact F'_{ij} values of Figure C-3 of C

$T_i - T_j = 1^0F$ assumed in all cases.

n = the number of surfaces

The second method, Equation 88, gives the rms of the percentage error in q_I of each surfaces. This method increases the weight of smaller surfaces such as windows.

$$ERR = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{\Delta q_i}{q_i} \right)^2 * 100$$

Equation 88

Results

For the enclosure of Figure 10, Carroll found his method gives *Err* = 0.11% for the first method and 0.19% for the second method.

These results are shown in Table 4, along with the results for other shape enclosures, and the errors determined by Carroll using the radiant interchange algorithms of Walton (1980) and NBSLD and BLAST simplified models.

Table 4: Err = % rms Error in q_i from Equation 87 and Equation 88 in Parenthesis

	Figure 10 room 2.5:4:6 ε = 0.9 (.84 wdws)	**Corridor 10:1:1 ε = 0.9**	**Warehouse 10:10:1 ε = 0.9**
Carroll	0.11 (0.19)	0.06(0.05)	0.07 (0.04)
Walton(1980)	1.9 (1.30)	0.6 (0.6)	4.4 (3.0)
NBSLD, BLAST	3.2 (2.1)	3.2 (2.6)	7.5 (4.4)

Source: NORESCO for California Energy Commission

Errors in an individual surface's distribution of heat transfer to other surfaces

These are errors in q_{ij}, the heat exchanged between surfaces i and j (both directly and by reflections from other surfaces), relative to the exact total net heat transfer from surface *i* given by Figure C-3 of C.

Carroll gives two percentage error results.

By the first method, for each surface i, the rms of the error, Δq_{ij}, in heat exchange to each of the *n-1* other *j* surfaces is obtained. Then the rms of these n rms error values is obtained, giving a representative distribution error for the enclosure. Dividing this by the rms value of the exact net surface heat transfers, q_i, of all the surfaces gives the final distribution error in percent:

$$ERR = \frac{\sqrt{\sum_{i=1}^{n}\left[\frac{\sum_{j=1}^{n}\Delta q_{ij}^2}{n(n-1)}\right]}}{\sqrt{\sum_{i=1}^{n}\left(\frac{\overline{q}_i^2}{n}\right)}} * 100$$

Equation 89

where

$$\Delta q_{ij} = q_{ij} - \overline{q}_{ij}$$

$q_{ij} = h_b A_i F'_{ij}(T_i - T_j)$ with F'_{ij} values from Equation 84.

$\overline{q}_{ij} = h_b A_i F'_{ij}(T_i - T_j)$ with the exact F'_{ij} values of Figure C-3 of C.

By the second method, for each surface i, the rms of the percentage error in heat exchange q_{ij}, relative to the exact net heat transfer from that surface, q_i, is obtained.

$$Err = 100 * \sqrt{\sum_{i=1}^{n}\left[\frac{\sum_{j=1}^{n}\left(\frac{\Delta q_{ij}}{\overline{q}_i}\right)^2}{n(n-1)}\right]}$$

Equation 90

Distribution error results

For the Figure 10 room, Carroll's model gives errors of 2.1% and 3.9% for methods 1 and 2 respectively. Walton's model has corresponding errors of 2.4% and 3.7%.
Equation 91 was used for the results in parenthesis.

Table 5: % rms Error in q_i from Equation 90

	Figure 10 room 2.5:4:6 ε = 0.9 (.84 wdws)	Corridor 1:10:1 ε = 0.9	Warehouse 1:10:10 ε = 0.9
Carroll	2.1 (3.9)	3.3 (2.8)	0.6 (1.9)
Walton(1980)	2.4 (3.7)	3.3 (2.8)	2.8 (3.0)
BLAST	2.8 (4.4)	3.4 (4.4)	3.4 (15)
NBSLD	1.7 (3.5)	1 (0.83)	3.3(1.9)

(Equation *91* was used for the results in parenthesis.)

Source: NORESCO for California Energy Commission

Carroll's model is seen to give very respectable results, despite giving no special treatment to coplanar surfaces.

1.6.1.3 Air absorption

The Carroll model also accounts for the absorption of long-wave radiation in the air, so that the air and mrt nodes are thermally coupled to each other as well as to the interior surfaces. Carroll (1980a) gives an air emissivity by the following dimensional empirical equation that is based on Hottel data from McAdams(1954):

$$\varepsilon_a = 0.08\varepsilon_s ln\left[1 + \left(\frac{4v}{\varepsilon_s A} RP_{atm}\right) e^{\frac{TaF-32}{30.6}}\right] \textit{Equation 91}$$

The logarithm is natural, and,

ε_s = the area-weighted average long-wave emissivity for room surfaces, excluding air.

V/A = the room volume to surface area ratio, in meters.

R = the relative humidity in the zone. (0 ☐ R ☐ 1).

Patm = atmospheric pressure in atmospheres.

☐a = zone air temperature, in ☐F.

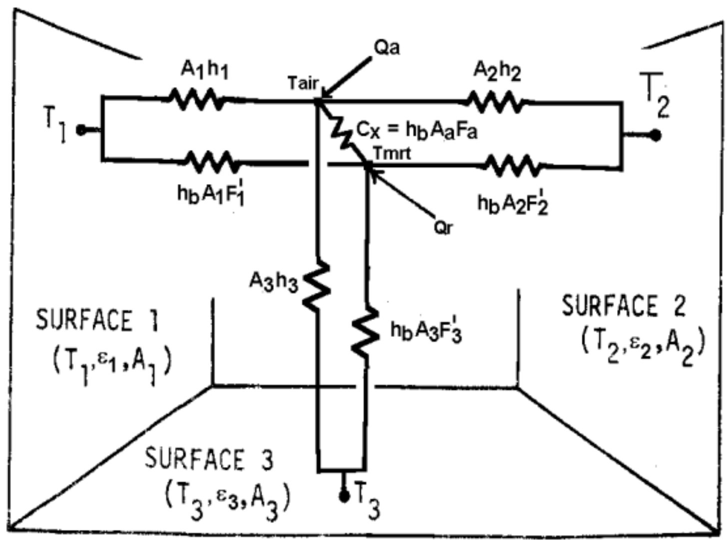
Following a heuristic argument Carroll assigns an effective area *Aa* to the air that is the product of *☐a* and the sum of all of the zone surface areas, as if the absorbing part of the air were consolidated into a surface of area A_a.

$$A_a = \varepsilon_a \sum A_i \qquad \text{Equation 92}$$

Using this area, the value of F_a for this 'surface' can be calculated along with the other F_i by Equation 80. The value of the conductance between the air and radiant nodes in Figure 11 is given by:

$$C_x = h_b A_a F_a \qquad \text{Equation 93}$$

Figure 11: Like Figure 9 but with Convective Network Added



Facets

Suppose one of the interior surfaces of total area A_i is composed of N_i identical flat sub-surfaces, each at the same temperature, and similar views to each other, like the facets of a geodesic dome. The F_i values would be the same if each facet is treated as a separate surface. To avoid redundant solutions to Equation 80, it is easy to show that A_i can be treated as one surface in Equation 6-4 if N_i is introduced into Equation 80 as follows:

$$F_i = 1 \Big/ \left[1 - \frac{A_i F_i / N_i}{S(A_i F_i)}\right] \qquad \text{Equation 94}$$

The facet feature is utilized in the simulation to represent attic truss surfaces.

Short Wave Radiation Distribution

This routine was used in the development code for this program. It is not currently implemented in CSE, being replaced by a simplified but similar routine.

The short wave radiation (solar insolation from hourly input) transmitted by each window can, at the users discretion, be all distributed diffusely inside the zone, or some of the insolation from each window can be specifically targeted to be incident on any number of surfaces, with the remaining untargeted radiation, if any, from that window, distributed diffusely. The insolation incident on any surface can be absorbed, reflected, and/or transmitted, depending on the surface properties inputted for that surface. The radiation that is reflected from the surfaces is distributed diffusely, to be reflected and absorbed by other surfaces ad infinitum.

Since some of the inside surfaces will be the inside surface of exterior windows, then some of the solar radiation admitted to the building will be either lost out the windows or absorbed or reflected by the widows.

1.6.1.4 Radiation removed at each surface of a zone by a single source of targeted insolation

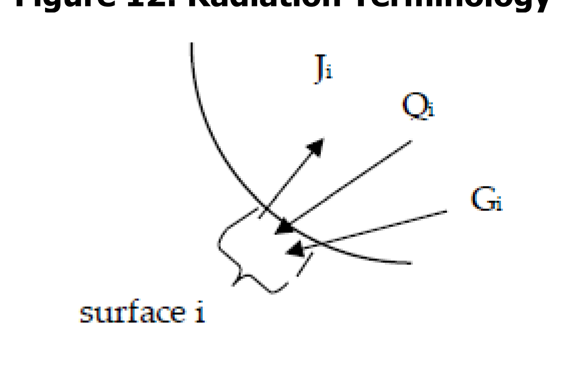
Assume a spherical zone with total insolation S(Btu/hr) admitted into the zone through one window. Assume that the portion a_iQ_i (ft^2*Btu/(hr-ft^2)) of S(Btu/hr) is targeted to surface i with area a_i such that,

$$\sum_i a_iQ_i = S \qquad \textit{Equation 95}$$

where the sum is over all surfaces *i.* The total spherical area is $a_S = \sum_i a_i$. Also incident on surface i will be the irradiation G_i (Btu/hr-ft^2) from other surfaces that have reflected a portion of the radiation they have received. We distinguish between the Q_i incident on the surface directly from the window, and the irradiation G_i which is composed of radiation reflected to i from all the surfaces, and that reflected by windows. All radiation (including Incident beam) is assumed to be reflected diffusely.

Each surface i will also reflect short-wave radiation, with a radiosity J_i [Btu/hr-sf].

Figure 12: Radiation Terminology



The derivation below determines the equations to obtain J_i and G_i for known Q_i values, for all the surfaces of the sphere, i = 1 to n.

First a relationship between Gi and Ji is developed:

Since G_i is composed only of reflected radiation,

$$a_iG_i = \sum_k J_k a_k F_{ik} \qquad \textit{Equation 96}$$

where the sum is over all surfaces n of the sphere of area a_S.

Using the view-factor reciprocity principle,

$$a_k F_{ki} = a_i F_{ik}$$

G_i becomes

$$G_i = \sum_k J_k F_{ik}$$

For spherical geometry, the view factor is $F_{ik} = \frac{a_k}{a_S}$, where $a_S = \sum a_k$, so G_i can be written

$$G_i = \frac{1}{a_S} \sum_k J_k a_k \qquad \text{Equation 97}$$

The right hand side is the area-weighted average radiosity, showing that G_i is independent of i,

$$G_i = \bar{J} \qquad \text{Equation 98}$$

Next a separate relationship between J_i and G_i is obtained, G_i eliminated and J_i solved for explicitly:

The radiosity of surface *i* is composed of the reflected part of both the irradiation and the targeted solar

$$J_i = \rho_i (G_i + Q_i) \qquad \text{Equation 99}$$

Substituting *Equation 97* for G_i gives

$$\frac{J_i}{\rho_i} = \frac{1}{a_S} \sum_k J_k a_k + Q_i \qquad \text{Equation 100}$$

Since by *Equation 98* G_i is independent of *i*, then Equation 99 shows that the radiosity of any surface *i* is related to the radiosity of any surface k by the relationship

$$\frac{J_i}{\rho_i} - Q_i = \frac{J_k}{\rho_k} - Q_k$$

Substituting this into Equation 100 gives

$$\frac{J_i}{\rho_i} = \frac{1}{a_s} \sum_k \left[a_k \rho_k \left(\frac{J_i}{\rho_i} + Q_k - Q_i \right) \right] + Q_i$$

This can be solved explicitly for J_i:

$$J_i = \frac{\frac{1}{a_s} \rho_i}{1 - \bar{\rho}} \left(\sum_k a_k \rho_k Q_k \right) + Q_i \rho_i \qquad \text{Equation 101}$$

From Equation 101, the area weighted average *J* is

$$J_i = \frac{\frac{1}{a_s}\bar{\rho}}{1-\bar{\rho}}\left(\sum_k a_k \rho_k Q_k\right) + \frac{1}{a_s}\sum_i a_i Q_i \rho_i$$

Equation 102

where $\bar{\rho}$ is the area weighed average reflectivity.

Now that J_i and G_i are known an energy balance will give the net heat transfer:

The net energy rate (Btu/hr) absorbed and/or transmitted by surface i, is:

$$Qnet_i = (G_i + Q_i - J_i)a_i = (\bar{J} - J_i + Q_i)a_i$$

Equation 103

Substituting Equation 101 and Equation 102 into this gives

$$Qnet_i = \frac{a_i}{a_s}\left(\frac{1-\rho_i}{1-\bar{\rho}}\right)\sum_k a_k \rho_k Q_k + a_i Q_i (1-\rho_i)$$

Equation 104

The first term in Equation 104 is from the absorption and/or transmission of radiation that reached and is absorbed by surface i after having been reflected, ad infinitum, by the interior surfaces. The second term is from the absorption of the "initially" incident insolation Q_i on surface *i*.

If none of the insolation is specifically targeted, and instead S is assumed to be distributed isotropically then Q_i is the same for each surface:

$$Q_i = \frac{S}{a_S}$$

Equation 105

Substituting this into Equation 104 gives $Qnet_i$ for isotropically distributed insolation:

$$Qnet_i = \frac{a_i}{a_s}\left(\frac{1-\rho_i}{1-\bar{\rho}}\right)S$$

Equation 106

1.6.1.5 Radiation removed at each surface of a zone by multiple window sources of targeted insolation

The targeting can be different for each window. Adding an additional subscript "j" to Equation 104 allows it to represent the energy removal for each surface separately for each window j. That is, Equation 104 becomes Equation 107, the rate of energy removal at each surface due to insolation S_j, that is distributed according to the assigned targeted values Q_{ji}.

$$Qnet_i = \frac{a_i}{a_s}\left(\frac{1-\rho_i}{1-\bar{\rho}}\right)\sum_k a_k \rho_k Q_k + a_i Q_{ji}(1-\rho_i)$$

Equation 107

The targeting fractions H_{jk}, to be user input, are defined as the fraction of insolation from window j that is incident on surface k:

$$H_{jk} = \frac{a_k Q_{jk}}{S_j}$$

Equation 108

With this definition, Equation 107 can be written as

$$Qnet_{ji} = a_i S_j (1 - \rho_i) \left[\frac{H_{ji}}{a_i} + \frac{1}{a_s (1 - \overline{\rho})} \sum_k \rho_k H_{jk} \right]$$

Equation 109

The effective absorptivity of the targeted surfaces is defined as

$$\alpha effT_{ji} = \frac{Qnet_{ji}}{S_j}$$

Equation 110

Replacing the spherical surfaces a_i in Equation 109 by $a_i = A_i F_i$, and substituting Equation 109 into Equation 110 gives the targeted gain equation used in the CZM code:

$$\alpha effT_{ji} = A_i F_i (1 - \rho_i) \left[\frac{H_{ji}}{A_i F_i} + \frac{1}{(1 - \overline{\rho}) \sum_i A_i F_i} \sum_k \rho_k H_{jk} \right]$$

Equation 111

If $\sum_k H_{jk} < 1$ then it is assumed that the remaining insolation $S_j(1 - \sum_k H_{jk})$is distributed isotropically. From Equation 105 it is

$$isotropic\ Qnet_{ji} = \frac{a_i}{a_s} \left(\frac{1-\rho_i}{1-\overline{\rho}} \right) S_j \left(1 - \sum_k H_{jk} \right)$$ Equation 112

The definition of the effective absorptivity for isotropic insolation is:

$$\alpha effI_{ji} = \frac{Qnet_{ji}}{S_j}$$

Equation 113

Changing Equation 112 to utilize zone areas, $a_i = A_i F_I$, and substituting Equation 112 into Equation 113 gives the amount of the diffuse part of the insolation from each window j that is absorbed in each surface i. This is used in the CZM code.

$$\alpha effI_{ji} = \frac{A_i F_i}{\sum_k A_k F_k} \left(\frac{1-\rho_i}{1-\overline{\rho}} \right) S_j \left(1 - \sum_k H_{jk} \right)$$ Equation 114

Note that no distinction has been made between surfaces that are opaque like walls, and partially transparent window surfaces. They are treated equally. The difference is that the energy removed by an opaque wall is absorbed into the wall, whereas that removed by the window surfaces is partly transmitted back out the window, and partly absorbed at the window inside surface. The CZM development code lets the user specify a fraction of the radiation that is absorbed in the room-side surface of the window, which slightly heats the window and thus the zone.

Adding Equation 111 and Equation 114 gives the total effective absorptivity of surface i from the insolation admitted through window j:

$$\alpha eff_{ji} = A_i F_i (1-\rho_i)\left(\frac{1}{(1-\bar{\rho})\sum_k A_k F_k}\left[1-\sum_k (1-\rho_k) H_{jk}\right]+\frac{H_{ji}}{A_i F_i}\right)$$

Equation 115

The net radiation absorbed in surface i from window j is thus

$$Qnet_{ji} = A_i F_i (1-\rho_i) S_j \left(\frac{1}{(1-\bar{\rho})\sum_k A_k F_k}\left[1-\sum_k (1-\rho_k) H_{jk}\right]+\frac{H_{ji}}{A_i F_i}\right)$$

Equation 116

Summing this over all windows gives the total SW radiation absorbed and/or transmitted by surface i as:

$$Qnet_i = A_i F_i (1-\rho_i) \sum_j \left[S_j \left(\frac{1}{(1-\bar{\rho})\sum_k A_k F_k}\left[1-\sum_k (1-\rho_k) H_{jk}\right]+\frac{H_{ji}}{A_i F_i}\right)\right]$$

Equation 117

1.7 Window Model

The ASHWAT algorithm is used to model complex windows with diatherminous layers and curtains, etc. (Wright and Kotey 2006, Wright, J.L. 2008). Given the environmental conditions on each side of the window, ASHWAT determines the long wave, short wave and convection heat transfers to the conditioned space.

For the following input and output discussion, ASHWAT is treated as a black box.

1.7.1 Inputs

Each time step, for each window, ASHWAT is given the environmental inputs:

I = insolation incident on window system.

I_{refl} =insolation reflected diffusely from the other room surfaces.

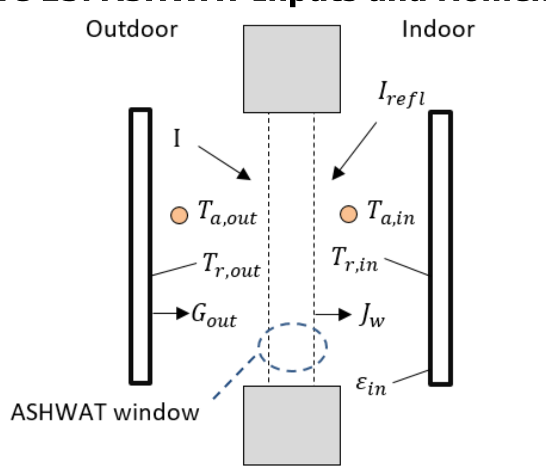
$T_{a,out}$ = outside dry bulb air temperature.

$T_{a,in}$ = inside dry bulb air temperature.

$T_{r,in}$ = the temperature of the indoor plate.

$T_{r,out}$ = the temperature of the outdoor plate.

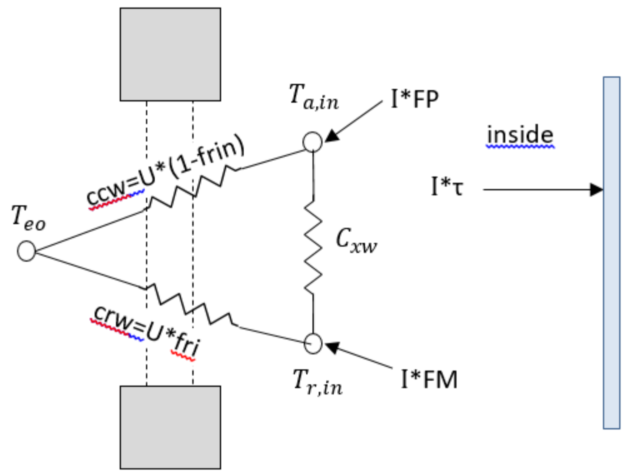
Figure 13: ASHWAT Inputs and Nomenclature



1.7.2 Outputs

ASHWAT's output gives heat transfer rates and circuit elements of Figure 14. The circuit of Figure 14 is part of the conditioned zone radiant network of Figure 2 and Figure 3 (with some different nomenclature).

Figure 14: Window System Representation in CSE



In Figure 14,

FP = fraction of the heat from Insolation absorbed in the various window layers that ends up being transferred to the inside radiant node.

FM = fraction of the heat from Insolation absorbed in the various window layers that ends up being convected to the inside air node.

$frin$ = fraction of total non-solar heat transfer that goes to the inside radiant node; dimensionless.

frout = fraction of non-solar heat transfer to the outside that goes to the outside radiant node.

U = conductance between the inside and outside effective temperatures T_{ei} and T_{eo}; Btu/(hr-sf-F), where $T_{ei} = T_{a,in}(1 - frin) + T_{r,in}frin$.

$T_{eo} = T_{a,out} * (1 - frout) + T_{r,out} * frout$ = the effective outdoor temperature; F.

C_{xw} = the cross coupling term; Btu/(hr-sf-F).

τ = the short wave transmissivity of the window system.

Note that the solar heat gain coefficient is: $SHGC = \tau + FP + FM$.

Net energy into zone via window, per unit COG area = + $I\ (\tau + FP + FM) - I_{refl} + U(T_{eo} - T_{ei})$

1.7.3 Matching ASHWAT to CSE Radiant Network

1.7.3.1 Outside boundary conditions

ASHWAT models the irradiation on the outside of the window system as if it were emitted by a black plate parallel to the window at temperature $T_{r,out}$, as shown in Figure 13. The irradiation on the window system from the outside plate is thus $G_{out} = \sigma T_{r,out}^4$, so

$$T_{r,out} = \left(\frac{G_{out}}{\sigma}\right)^{0.25} = \left[F_{sky}\beta\, T_{sky}^4 + \left[F_{gnd} + F_{sky}(1-\beta)\right]T_{air}^4\,\right]^{0.25}$$

Equation 118

where G_{out} has been replaced by *Equation 67*.

1.7.3.2 Inside boundary conditions

From Figure 13, the equivalent network between the radiosity of the window system, J_w, and the inside plate is shown in Figure 15. The circuit parameters are in the conductance form. The "1" is the view factor between the plate and the window.

Figure 15: Equivalent Network between the Radiosity of the Window System, J_w, and the Inside Plate

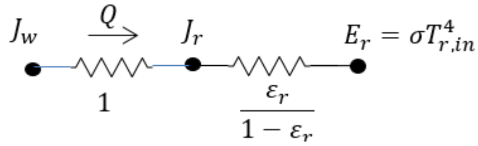
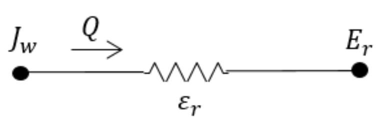


Figure 15 reduces to:

Figure 16: Reduced Figure 15



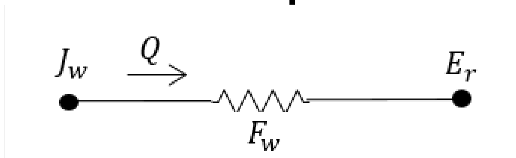
Thus the heat transfer rate per unit area, with Q positive from window to room, is:

$$Q = \varepsilon_r(J_w - E_r)$$

Equation 119

From Figure 9 the network between the radiosity of a surface and the mean radiant temperature node is shown in Figure 17. This corresponds to Figure 16 for the ASHWAT algorithm:

Figure 17: Network between the Radiosity of a Surface and the Mean Radiant Temperature Node



with the corresponding heat transfer rate:

$$Q = F_w(J_w - E_r)$$

Equation 120

Comparing Equation 119 and Equation 120 shows that to obtain the heat flow consistent with the Carroll network ASHWAT must model the window by setting inside plate's emissivity to the value of F_w.

$$\varepsilon_r = F_w$$

Equation 121

F_w is the Carroll MRT view factor defined in Section 1.6.1. F_w is slightly larger than 1, and serves to increase the heat transfer between J_w and E_r to compensate for the fact that $|J_w - E_r|$ is smaller than it would if $T_{r,in}$ had not included the window temperature in its average. This MRT view factor effect cannot be simulated by a parallel plate model without the trick of artificially raising the emissivity of the inside plate to the value F_w.

1.8 Slab Model

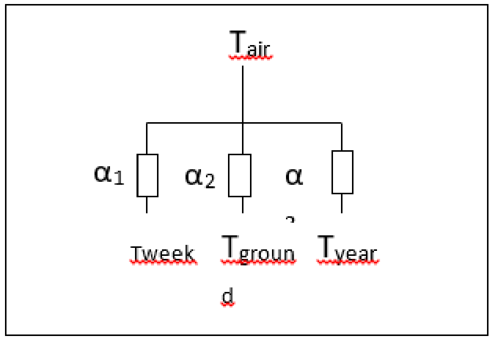
1.8.1 Bajanac Simplified Model

The CZM slab model is partly based on the Simplified Method for the calculation of heat flow through foundations, presented by Bazjanac et al. (2000). They divide a slab into two regions.

1.8.1.1 Perimeter region

The perimeter area of the slab is defined as a 2 ft wide strip along external walls. Through this perimeter path, the interior air is assumed to be coupled via conductances α_1, α_2, and α_3 to three environmental temperatures: $\mathrm{T_{week}}$, , $\mathrm{T_{ground}}$, *and* $\mathrm{T_{year}}$:

Figure 18: Perimeter Coupling



Thus the instantaneous heat flow from the room Temp node to perimeter slab, in Btu/hr-sf-F, is given by:

$$Qperim = [\alpha_1(T_{air} - T_{week}) + \alpha_2(T_{air} - T_{ground}) + \alpha_3(T_{air} - T_{year})]$$

Equation 122

where,

T_{air} = the current interior-space effective temperature (involving both Ta and Tr).

T_{week} = the average outside air temperature of the preceding two-weeks.

T_{ground} = the current average temperature of the earth from the surface to a 10 ft depth.

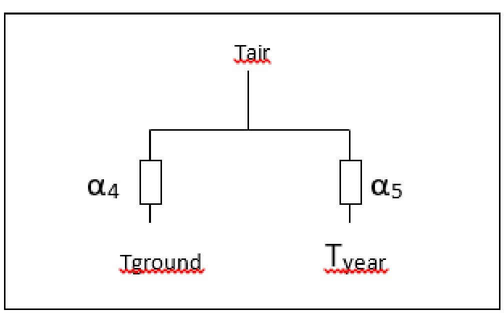
T_{year} = the average yearly dry bulb temperature.

α*'s* = conductances from Table 3 of Bazjanac et al; Btu/sf-hr-F.

1.8.1.2 Core region

The core region couples *T* to T_{ground} and T_{year}, via conductances α_4 and α_5.

Figure 19: Core Coupling



$$Qcore = [\alpha_4(T_{air} - T_{ground}) + \alpha_5(T_{air} - T_{year})]$$

Equation 123

Bazjanac et al. determined the conductances α_1, through α_5 by multi-linear regression analysis of the numerical results from a two-dimensional finite-difference slab-earth model. The conductances were determined for 52 slab foundation conditions and given in their Table 3.

1.8.1.3 Properties

The Bozjanac Table 3 conductances were obtained assuming the following properties:

1. Properties of earth:
   - conductivity = 1 Btuh/ft-F. (The k chosen was justified by assuming that lawns and other vegetation around California houses was watered during the dry season).
   - density =115 lbm/ft^3
   - specific heat = 0.2 Btu/lbm-F
   - thermal diffusivity = 0.0435 ft^2/hr.
2. Slab: "heavy construction grade concrete"
   - thickness = 4-inches
   - conductivity = 0.8
   - density = 144
   - specific heat = 0.139
3. Rrug = 2.08 hr-ft^2-F/Btu (ASHRAE 2005HF, p.25.5 'carpet fibrous pad').
4. Rfilm = 0.77 Btu/hr-ft^{2}F, the inside surface-to-room-temperature combined convective and radiative conductance.

1.8.1.4 Ground temperature

The above model uses the ground temperature determined by Kusuda and Achenbach (1965). Using the classical semi-infinite medium conduction equations for periodic surface temperature variation (Carslaw and Jaeger), they found the average ground temperature from the surface to a depth of 10 ft to be given by:

$$\mathrm{T_{ground}} = \mathrm{T_{yrAve}} - \mathrm{GM}\left(\frac{\mathrm{TyrMax - TyrMin}}{2}\right) cos\left(\left(\frac{2\pi}{8760}\right)\theta - PO - \phi\right) \qquad \text{Equation 124}$$

where,

$\mathrm{T_{yrAve}}$ = average outdoor temperature over year; F.

$\mathrm{T_{yrMax}}$ = highest average monthly outdoor temperature for the year; F.

$\mathrm{T_{yrMin}}$ = lowest average monthly outdoor temperature for the year; F.

$\mathrm{GM} = \sqrt{\frac{e^{-2\beta} - 2e^{-\beta} \cos\beta + 1}{2\beta^2}}$ = dimensionless amplitude for integrated depth average.

$\beta = \mathrm{L}\sqrt{\frac{\pi}{D * PY}}$ = dimensionless depth.

L = 10 ft, the depth over which average is taken.

D = thermal diffusivity of soil, ft^2/hr.

$PY = 8760$ hr = period of 1 year.

$\theta = 24\left(\frac{365M}{12} - 15\right)$ ≈ elapsed time from Jan-1 to middle of month M; hours.

M = month, 1à12.

$\phi = atan\left(\frac{1-e^{-\beta}(cos\beta+sin\beta)}{1-e^{-\beta}(cos\beta-sin\beta)}\right)$ = phase angle for depth averaged T_{ground}; radians.

$PO = 0.6$ *radians* = phase lag of ground surface temperature (assumed equal to air temperature) relative to January 1. From measured data, see Fig. 7 in Kusuda and Achenbach.

1.8.2 Addition of a Layered Slab and Earth

The Bazjanac model assumes a constant indoor temperature, so cannot be applied directly to a whole building thermal-balance simulation model that allow changing indoor temperatures. To apply this model to CZM, with changing indoor temperatures, requires incorporating the dynamic effects of the slab and earth due to changing inside conditions.

This is done by putting a one-dimensional layered construction, representing the slab and some amount of earth mass, into the steady-state Bazjanac model circuit--replacing part of its resistance by a thermal impedance (which is equal to the resistance for steady state conditions). In this way the correct internal temperature swing dynamics can be approximated.

First, the circuit of Figure 18 is alternately expressed as shown in Figure 20(a), with Equation 122 taking the form:

$$Q = A * U_g\left(T_{air} - T_{geff}\right)$$

Equation 125

where T_{geff} is the α-weighted average ground temperature:

$$T_{geff} = \frac{\alpha_1 T_{week} + \alpha_2 T_{ground} + \alpha_3 T_{yrAve}}{\alpha_1 + \alpha_2 + \alpha_3}$$

Equation 126

and

$$R_g = \frac{1}{\alpha_1 + \alpha_2 + \alpha_3}$$

Equation 127

Similarly for the core region,

$$T_{geff} = \frac{\alpha_4 T_{ground} + \alpha_5 T_{yrAve}}{\alpha_4 + \alpha_4}$$

Equation 128

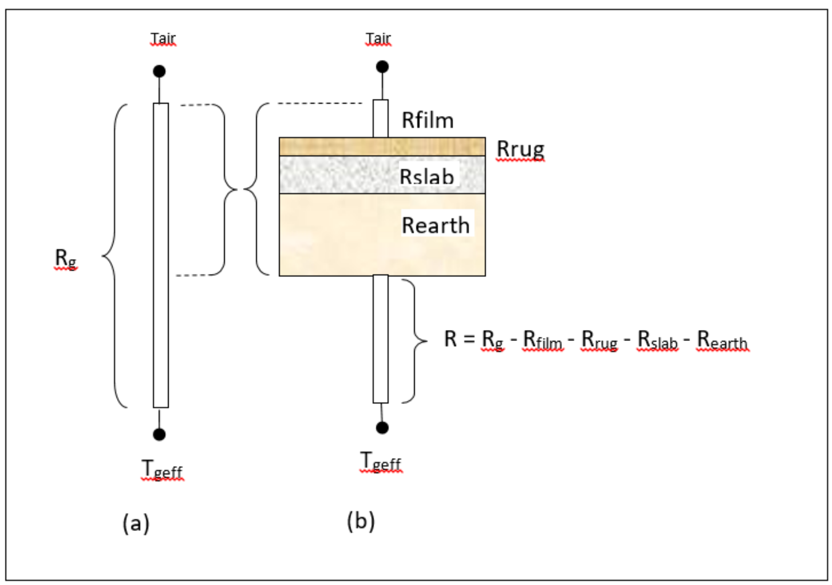
$$R_g = \frac{1}{\alpha_4 + \alpha_5}$$

Equation 129

Now a one-dimensional layered construction is added into the circuit as shown in Figure 20(b), consisting of a surface film layer, a carpet (if any), the concrete slab, and earth layer. The bottom of the earth layer is then connected to T_{geff} through the what's left of R_g.

A one-dimensional representation of the mass is appropriate for the core region. It is a bit of a stretch for the perimeter slab modeling, because the real perimeter heat flow is decidedly 2-dimensional, with the heat flow vectors evermore diverging along the path of heat flow.

Figure 20: Addition of Film, Rug, Slab, and Earth



The earth thicknesses required to adequately model the dynamic interaction between the room driving forces (sun and temperature) and the slab/earth model was determined by considering the frequency response of the slab earth model of Figure 20(b). In the frequency domain, the periodic heat flow from the Tair node is given by Equation 130.

$$\tilde{Q}_{air} = \tilde{T}_{air} X - \tilde{T}_{geff} Y$$

Equation 130

where,

X = the driving point admittance at the air (or combined air/radiant effective temp) node, in the units of Btu/hr-sf-F. It is the contribution to Q_{air} per degree amplitude of T_{air}. X and Y are complex numbers determined from the layer properties (conductivity, heat capacity, density) of the circuit layers in Figure 20(b). See Carslaw and Jaeger; Subbarao and Anderson.

Y = the transfer admittance at the air node. It is the contribution to Q_{air} per degreee amplitude of T_{geff}. [The same value of transfer admittance applies to the T_{geff} node, even if the circuit is not symmetrical, being the contribution to the T_{geff} node per degree amplitude of T_{air}]

Q_{air} = the amplitude (Btu/hr-ft^2-F) and phase of the heat transfer rate leaving T_{air}, and is composed of the contribution from all of the frequencies that may be extant in the driving temperatures T_{air} and T_{geff}.

Note that the layers shown, when modeled as a mass construction, may need to be subdivided into thinner layers, particularly the earth, in order to satisfy the discretization procedure discussed in Section 1.4; but this subdivision is irrelevant to the slab model discussion in this section.

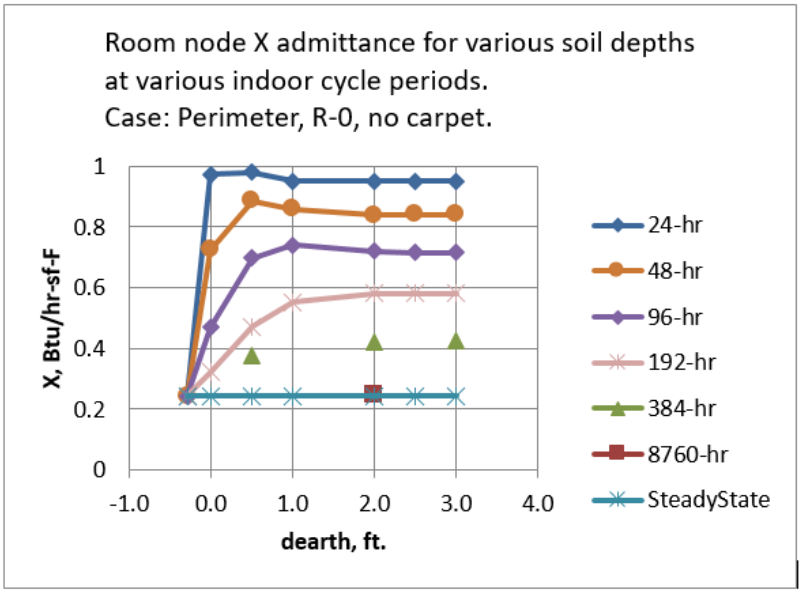
The maximum possible thickness of the earth layer is limited by the need for R to be positive. The limiting maximum possible thickness value, dmax, occurs in the perimeter case, when the foundation is uninsulated (i.e., the foundation insulation value R-0 in Bazjanac et al), and the slab is uncarpeted. In this case, dmax = 2.9 ft. The corresponding numbers for an uncarpeted core slab case is 11.8 ft

A depth of 2 ft is implemented in the code, for both the perimeter and core slab earth layers.

The 2 ft value was chosen primarily because, for the frequencies of concern, the magnitude of the X admittance from the Tair node was almost independent of earth layer depth for earth layer depths greater than 2 ft. See Figure 21. The phase shift is similarly essentially independent of depth after 2 ft. This was also the case for the core region.

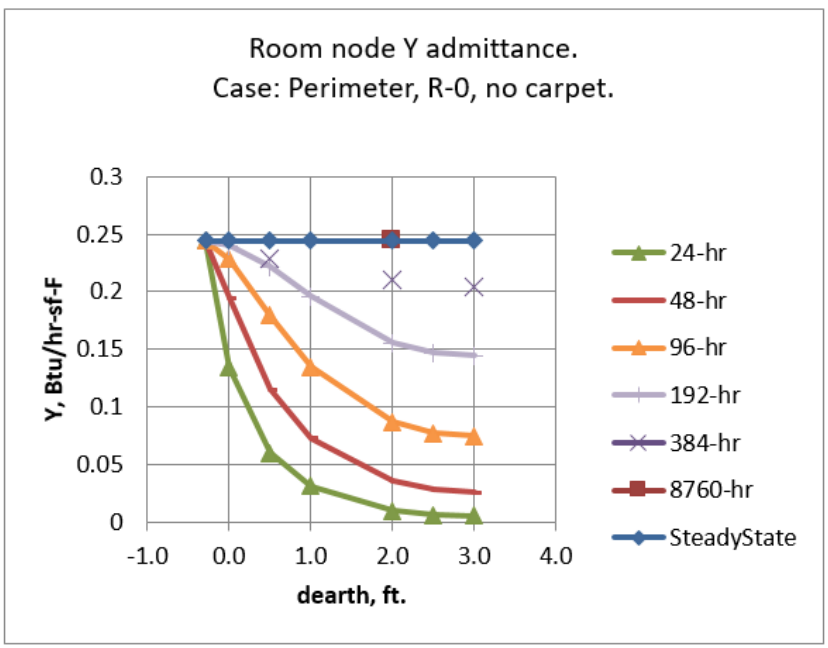
This is the case for all indoor driving frequencies periods of up to at least 384-hr = 16-days. Thus 2 ft of earth is able to portray the dynamics resulting from a cycle of 8-cloudy days followed by 8 sunny days.

Figure 21: Room Node X Admittance



The transfer admittance Y shown in Figure 22 also contributes to Q_{air} according to the frequencies extant in the driving temperature T_{geff}.

Figure 22: Room Node Y Admittance



As seen in Equation 128, for the slab core region, T_{geff} has the same frequency content as T_{ground} and T_{year}. T_{year} is a constant, i.e., zero frequency, steady-state.

As seen in Equation 124, T_{ground} contains only the annual 8760-hr period. Figure 22 shows that the 8760-hr waves are transmitted unaffected by the mass layer. That is, Y

becomes essentially equal to the steady state transfer admittance, which is the U factor of the assembly, the reciprocal of the R_g value. Thus, for the core region, the magnitude of the slab loss rates produced by Equation 125 are preserved and unaffected by the added earth layers.

However, although the mass layers don't affect the magnitude of the Bazjanac model slab losses, they do introduce a time lag that is in addition to that already implicit in the T_{geff} values. For a 2 ft earth layer the lag is ~40-hours. A 22-day lag is already included by φ of Equation 124. To eliminate double-counting, the 40-hrs could be subtracted from phi, but this has not been done since 40-hr is inconsequential compared to 22 days.

For the perimeter region, T_{geff} has the additional frequency content of the T_{week}, the two-week running average outdoor temperature. T_{week} is dominated by the annual period, but has small amplitude 6-month period component, and a bit of signal at higher frequencies. Like the annual cycle, the 6-month period component is transmitted through the layered construction without damping, but again with a small but inconsequential phase lag.

Thus it was concluded that 2 ft of earth thicknesses below a 4-inch concrete slab adequately models changes in room side conditions, and at the same time adequately preserves the same average "deep earth" slab losses and phase lags of the Bazjanac model.

The validity of the response of the core slab construction is expected to be better than for the perimeter slab construction since the perimeter layers added do not properly account for the perimeter two-dimensional effects.

1.8.2.1 Warm-up time

The longest pre-run warm-up time is expected to be for a carpeted core slab with the 2 ft earth layer. Using the classical unsteady heat flow charts for convectively heated or cooled slabs (Mills) , the time to warm the slab construction 90% (of its final energy change) was found to be about 20-days. Most of the heat-up heat transfer is via the low resistance rug and air film, with less through the higher ground resistance (R in Figure 20(b)), so the 20- day estimate is fairly valid for the complete range of foundation insulation options given in Bazjanac's Table 3.

1.8.2.2 Input properties

Strictly speaking, the same properties assumed in the Bazjanac model in Section 1.8.1.3 should also be used in describing the rug, the concrete slab, and the earth in the layered constructions inputs.

This is particularly true for the carpet, if a carpet is specified, because the regression coefficients (the conductances a1, a2...) obtained for the carpeted slabs were sensitive to the Rrug value used. While inputting a different value than Rrug = 2.08 may give the desired carpeted room admittance response, the heat conducted from the deep ground will still give the heat flow based on Rrug = 2.08.

Small differences between the inputted and above properties is less important for the other layers, and is violated in the code with regard to Rfilm; its value is calculated each time-step and is used instead of 0.77, even though 0.77 is still the value subtracted from Rg in the code. This allows the correct modeling of the admittance of the slab floor, at the expense of a slight error in the overall resistance of the slab earth circuit.

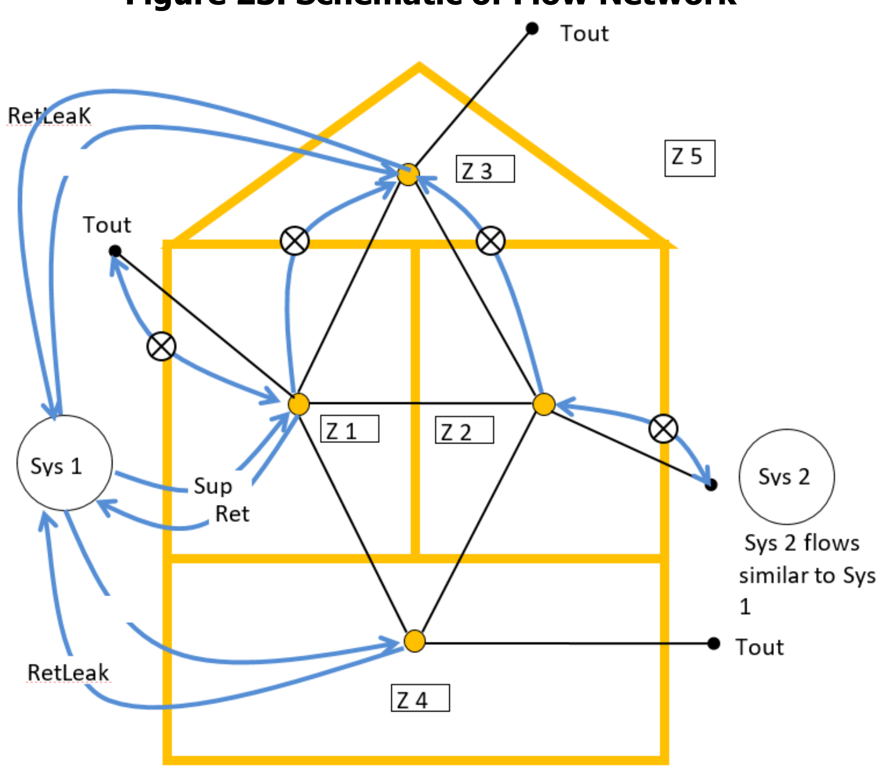
1.9 Ventilation and Infiltration Air Network

1.9.1 Overview

This section describes the flow network algorithm used to model infiltration and ventilation air flows between conditioned zones, unconditioned zones, and the outdoors based on pressure and density differences and leakage areas between the zones.

Figure 23 shows the flow network interconnecting two conditioned zones (Z1 and Z2), the unconditioned attic and crawl space zones (Z3 and Z4), and the outside zone (Z5).

Figure 23. Schematic of Flow Network



The black lines represent one or more pressure difference driven and/or buoyancy driven flows between zones.

The blue lines in Figure 23 represent scheduled fan flows not directly dependent on zone-to-zone pressure differences. These include individual house fans (circled x's) and fan driven duct system supply, return, and leakages flows. The fans will affect the zone pressures, but the pressures won't affect the fan flow. The duct flows, determined by the load and air handler capacity, are assumed to not constitute leakage paths when the air handler is not operating.

Small leakage or ventilation openings will be modeled as orifices using a power law equations of Section 1.9.3 with an exponent of 0.5. Infiltration leaks are modeled with the power law equation exponent of 0.65.

Large vertical holes or infiltration surfaces, large enough that the vertical pressure difference distribution allows two-way flow, are modeled as two vertically separated small holes using the Wolozyn method (see Section 1.9.5– Large Vertical Openings).

The following kind of elements are modeled using the power law equations:

- Wall infiltration for vertical envelope walls, vertical interzone walls, and roof decks.
- Ceiling, floor, and wall base infiltration.
- Interzone doors, door undercuts, jump ducts, relief vents.
- Openable window flow.
- Attic soffit vents, gable vents, roof deck vents, ridge vents.
- Crawl space vents.
- Trickle vents.
- Fire place leakage.
- Infiltration to garage.

Additional equations are used to model large horizontal openings, like stairwells; Section 1.9.4. This type of opening would typically be between zones Z1 and Z2 in Figure 23 when the zones are stacked vertically. The algorithm used is based on that implemented in Energy Plus (2009). In addition to using the power law equation above, the algorithm calculates buoyancy induced flows that can occur when the density of the air above the opening is larger than the density of the air below the opening, causing Rayleigh-Taylor instability.

To determine the flow rates at each time step, the flow through each flow element in the building is determined for an assumed set of zone reference pressures. If the flow into each zones does not match the flow out of the zone, the pressures are adjusted by the Newton-Raphson iterative method until the flows balance in all the zones within specified tolerances.

1.9.1.1 Wind direction independent air-network solution

For energy standards application, the air network for the four zone building model is designed to give results that are wind direction independent. In computing ventilation or infiltration air flows from holes in vertical walls exposed to outdoors, the program automatically calculates the sum of the flows through 4 holes each ¼ the area, one with each cardinal compass orientation, or an offset thereof. Thus, there will be wind induced flows through the envelope leakages that approximate the average flow expected over long periods, and they will be independent of wind direction. This approach is applied to all zone ventilation or infiltration flow elements connected to the outdoor conditions.

1.9.2 Vertical Pressure Distribution

The pressure at a given elevation in a zone, including outdoors, is a combination of stack and wind effects added to the zones reference pressure. The difference in pressure in the zones on each side of a leakage element connecting the zones determines the flow rate through the element.

The pressure on the zone *i* side of a flow element is given by:

$$\mathrm{p_i = Pz_i - \rho_i g z_i}$$

Equation 131

z_i is the height of the element above some datum $z = 0$. The datum is arbitrary but is nominally taken as ground level. Pz_i is zone *i's* reference pressure. This is the pressure zone *i* would have at elevation $z = 0$, regardless of whether the zone actually extends to this level. For the interior zones the Pz_i reference pressures are the unknowns that are solved for using the Newton-Raphson method. This method determines what values of zone pressures simultaneously result in a balanced flow in each zone. The value of Pz_i for the outdoor side of a flow element is given by (*i* is 5 if there are 4 conditioned and unconditioned zones):

$$\mathrm{Pz_i = patm + CP * Pu}$$

Equation 132

The weather tape atmospheric pressure, patm, is assumed to exist at the elevation z = 0 far from the building. Patm is taken as zero so that the unknown zones pressures will be found relative to the weather tape atmospheric pressure. Of course the actual weather tape atmospheric pressure is used in determining inside and outside zone air densities.

The wind velocity pressures, Pu, is:

$$\mathrm{Pu = \frac{\rho_{out}\,(S * U)^2}{2}}$$

Equation 133

where,

U is the wind velocity at eave height.

S is the shelter coefficient equal to SC of Table 2: Local Shielding Parameters.

ρ_{out} is the outside air density.

CP is the orientation sensitive pressure coefficient.

1.9.2.1 Pressure coefficients used

The wall pressure coefficients in Table 6 are those used by Walker et al. (2005). They are for the four vertical walls of an isolated rectangular house, with the wind perpendicular to the long wall (short wall = ½ long wall). As discussed in regard to hip roofs below, only data for the normal wind direction is used. These coefficients are used for all ventilation and infiltration holes in the walls. Soffit vents also use these values since they are assumed to have the same pressure coefficient as the walls under them. This assumption is roughly corroborated by the data of Sharples (1997).

Table 6: Pressure Coefficients for Wind Normal to One Wall

Pressure Coefficient Upwind Wall	Pressure Coefficient Side walls	Pressure Coefficient Downwind Wall
+0.6	-0.65	-0.3

Source: NORESCO for California Energy Commission

Table 7 gives hip roof's pressure coefficients for a range of roof angles. These are used to determine the outside pressure on ridge vents and roof deck vents.

There is little data available for hip roof surface pressure coefficients, or for ridge pressure coefficients (needed to model ridge vents) for any roof type. The data in Table 7 is a simplified synthesis of the data given by Xu (1998) and Holmes (1993, 2003, etc.), informed by a review of ASHRAE, EU AIVC, and other data sets and research papers.

Xu used a wind tunnel to measure pressure coefficients for a hip roofed building which was otherwise identical to the gable roof building wind tunnel data obtained by Holmes. The building had an aspect ratio of 2:1, with 0^{o} wind direction normal to the long side (and normal to the gable ridge and hip roof top ridge). The building eave height was 0.4 the length of the short side. The building had a relatively large eave overhang of about 35% of the eave height. Xu and Holmes presented data for this building for roof pitch angles of 15, 20, and 30^{o} . Other Holmes data, for both larger and smaller roof angles was used to estimate the pressure coefficients beyond the 15 to 30 degree range. Neither Xu nor Holmes presented average surface pressures, so the average surface data and average ridge pressures given in the table are based on estimates from their surface pressure contour data.

The table is for wind normal to the long side of the building. Similar tables were obtained from Xu's data for the 45 and 90 degree wind angles. Table 7 would ideally be wind direction independent, implying some kind of average pressure coefficient; for example, for each surface take the pressure coefficient that is the average for the 0, 45, and 90 degree angles. However, infiltration flows depend on pressure differences, and the average of the pressure differences is not necessarily indicative of the difference of the average pressures. The soffit vents flows, driven by the pressure difference between the adjacent wall and the various roof vents complicate any averaging schemes.

Comparison of the pressure coefficients for the three wind directions, while showing plausible differences, arguably does not show a discernable pattern that would obviate just using the normal wind direction data. Given the variety of roofs and building shapes that will be represented by these coefficients, the variety of vent locations and areas, and the deficiencies of the data, using a consistent set of data for only one wind direction is deemed appropriate.

Table 7: Hip Roof Wind Pressure Coefficients

Roof Pitch ψ	Upwind Roof	Side Hip Roof	Downwind Roof	Ridge
$\psi < 10^o$	-0.8	-0.5	-0.3	-0.5
$10 \leq \psi < 15$	-0.5	-0.5	-0.5	-0.8
$15 \leq \psi < 25$	-0.3	-0.5	-0.5	-0.5
$25 \leq \psi < 35$	+0.1(pos)	-0.5	-0.5	-0.3
$35 \leq \psi < 50$	+0.3 (pos)	-0.5	-0.5	-0.2

Source: NORESCO for California Energy Commission

1.9.2.2 Density

Zone *i*'s air density ρ_i is assumed to be only a function of zone temperature T_i. That is, assuming the air is an ideal gas, at standard atmospheric conditions, the pressure change required to change the density by the same amount as a change in temperature of 1°F is $\frac{\partial\rho}{\partial T} / \frac{\partial\rho}{\partial p} = -\rho R_{air}$, which is approximately - 200 Pascals/F. Since zone pressure changes are much smaller than 200 Pa, they are in the range of producing the same effect as only a fraction of a degree F change in zone temperature; thus the density is assumed to always be based on patm. (This has been changed in code so that ρ_i depends on both T_i and Pz_i).

Using the ideal gas approximation, with absolute temperature units,

$$\rho_i = \frac{P_{atm}}{R_{air} T_i}$$

Equation 134

The pressure difference across the flow element is given by

$$\Delta p_{ij} = p_i - p_j = Pz_i - Pz_j - gz_i(\rho_i - \rho_j)$$

Equation 135

1.9.3 Power Law Flow Equation

1.9.3.1 Orifice flow power law

For an orifice, with fixed density of air along the flow path (from inlet to vena contracta), Bernoulli's equation gives:

$$m = C_D A\sqrt{2\rho_{in} g_c}\,(\Delta p)^{\frac{1}{2}}$$

Equation 136

where

C_D is the dimensionless orifice contraction coefficient.

$C_D = \frac{\pi}{\pi+2}$ = Kirchoff's irrotational flow value for a sharp edge orifice.

$C_D = 0.6$ default for CSE windows

$C_D = 1$ for rounded inlet orifice as used in ELA definition, and consistent with no vena contracta due to rounded inlet.

A = Orifice throat area, ft^2.

ρ_{in} = density of air entering the orifice; $\frac{lb_m}{ft^3}$.

$g_c = 32.2\frac{lb_m ft}{lb_f\ sec^2}$

1.9.3.2 Infiltration flow power law

The following is based on Sherman (1998). English units are used herein. Measured blower door infiltration data is expressed empirically as a power law:

$$Q = \kappa \Delta P^n$$

Equation 137

or

$$m = \rho_{in}\kappa \Delta P^n$$

Equation 138

where

Q = volume flow in ft^3/sec.

m = mass flow in lb_m/sec.

ρ_{in} = entering air density, $\frac{lb_m}{ft^3}$

ΔP = pressure difference in $\frac{lb_f}{ft^2} = psf$.

n= measured exponent, assumed to be n = 0.65 if measured value is unavailable.

κ = measured proportionality constant.

Equation 137 and Equation 138 are dimensional equations. Thus κ is not a dimensionless number but implicitly has the dimensions $ft^{3+2n}/(sec*lb_f^n)$. See Section 1.9.3.8–Converting Units of κ.

Sherman defines equivalent leakage area, ELA, as the area of a rounded-entrance orifice that gives the same flow as the infiltration of Equation 137 when the pressure difference ΔP is equal to the reference pressure P_r = 0.08354 psf (= 4 Pa) By Equation 136, a rounded-entrance nozzle with throat area ELA and $\Delta P = P_r$ has a flow rate:

$$m = ELA\sqrt{2\rho_{in}g_c}\,(P_r)^{\frac{1}{2}}$$

Equation 139

Equation 137 and Equation 139 with $\Delta P = P_r$ gives the ELA as:

$$ELA = \kappa P_r^{\,n-\frac{1}{2}}\sqrt{\frac{\rho_{in}}{2g_c}}$$

Equation 140

Solving Equation 140 for κ, gives

$$\kappa = ELA\sqrt{\frac{2g_c}{\rho_{in}}}P_r^{\frac{1}{2}-n}$$

Equation 141

Substituting Equation 140 into Equation 137 gives the general equation, equivalent to Equation 137, that is the infiltration flow at any pressure difference ΔP:

$$m = ELA\sqrt{2\rho_{in}g_c}P_r^{\frac{1}{2}-n}\Delta P^n$$

Equation 142

(Note that substituting Equation 140 into Equation 142 recovers the empirical Equation 137).

1.9.3.3 General power law flow equation

CSE uses Equation 136 to model flow through elements such as windows, doors, and vents. Equation 142 is used for infiltration flows for elements with a defined ELA.

Both equations are special cases of the generalized flow power law Equation 143. For flow from zone *i* to zone *j*.

$$m_{i,j} = SP * A_e\sqrt{2\rho_{in}\,g_c}\left|\Delta p_{i,j}\right|^{n_g}$$

Equation 143

SP is the sign of the pressure difference $\Delta p_{i,j} = p_i - p_j$, utilized to determine the sign of the flow, defined as + from i to j. The exponent is n_g, "g" for generalized.

Equation 143 reduces to the orifice Equation 136 if:

- $A_e = A * C_D$ with $C_D = 0.6$.
- $n_g = \frac{1}{2}$

Equation 143 reduces to the infiltration Equation 142 if:

- $A_e = \left(P_r^{\frac{1}{2}-n}\right) ELA$, where n here is the measured exponent.
- $n_g = n$
- $P_r = 0.08354 \frac{lb_f}{ft^2}$

[Although C_D is dimensionless in Equation 136, the generalization to Equation 143 requires C_D to implicitly have the units of$(lb_m)^{\frac{1}{2}-n_g}(ft)^{2n_g-1}$].

1.9.3.4 Dealing with unbounded derivative at $\Delta \mathrm{P} = 0$

The partial derivative of the mass flow of Equation 143 with respect to the pressure in zone i is given by:

$$\frac{\partial \mathrm{m_{i,j}}}{\partial \mathrm{p_i}} = \mathrm{A_e n_g} \sqrt{2\rho_{\mathrm{in}}} |\Delta \mathrm{p_{i,j}}|^{\mathrm{n_g}-1}$$

Equation 144

Since $n_g < 1$ this derivative à∞ as ΔPà zero, potentially causing problems with the Newton-Raphson convergence. In order to make the derivative finite for small pressure drops, whenever the pressure difference is below a fixed value, ΔP_L, the power law is extended to the origin by a linear power law ($n_g = 1$),

$$m_{i,j} = SP * A_{elinear} \sqrt{2\rho_{in}\, g_c}\, |\Delta p_{i,j}|^1$$

Equation 145

as shown in Figure 24.

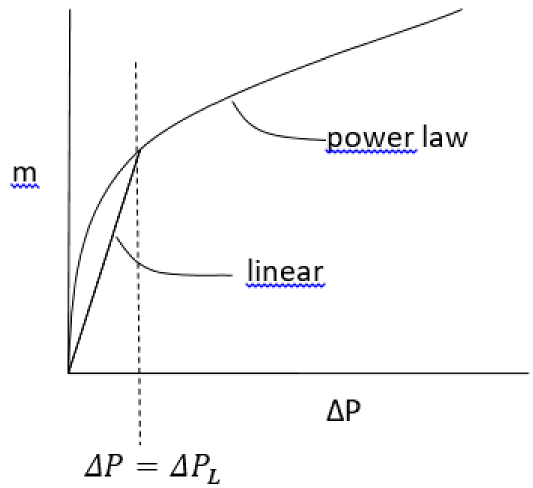
So that the flow rates match when $\Delta P = \Delta P_L$, $A_{elinear}$ is determined by equating Equation 145 to Equation 143 with $\Delta p = \Delta P_L$, giving:

$$A_{elinear} = A_e \Delta {P_L}^{ng-1}$$

Equation 146

Note that the derivative of m will be discontinuous when $\Delta p = \Delta P_L$, which conceivably could also cause Newton-Raphson problems, but during extensive code testing, none have occurred.

Figure 24: Mass Flow m versus Pressure Drop ΔP



1.9.3.5 Summary of inputs to the generalized flow equation

The generalized flow equation, Equation 143,

$$m_{i,j} = SP * A_e \sqrt{2\rho_{in}\, g_c}\, \left|\Delta p_{i,j}\right|^{ng}$$

is used with the following parameter values, depending on element type and pressure drop ΔP.

1.9.3.6 For windows, doors, and vents

If $\Delta P > \Delta P_L$:

- $A_e = A * C_D$
- $A =$ area of flow element; ft^2.
- $C_D = 0.6$.
- $n_g = \frac{1}{2}$

If $\Delta P < \Delta P_L$:

- $Ae\ = C_D\, A * \Delta {P_L}^{0.5-1}\ = C_D \frac{A}{\sqrt{\Delta P_L}}$
- $A =$ area of flow element; ft^2.
- $C_D = 0.6$
- $n_g = 1$
- $\Delta \mathrm{P_L} =$ determined by computational experiment.

1.9.3.7 For infiltration leakage elements

If $\Delta P > \Delta P_L$:

- $A_e = \left(P_r^{\frac{1}{2}-n}\right) ELA$, *n* here is the measured exponent, or 0.65 if not known. (Note that if $n = 0.65$, $A_e = 1.45 * ELA$, used in CEC ACM manual).
- $n_g = n$
- $P_r = 0.08354 \frac{lb_f}{ft^2}$
- ELA is determined from either:
  - the measured parameters κ and n using Equation 140. See Section 1.9.3.8–Converting units of κ.
  - code regulations, in which case $n = 0.65$ is assumed.

If $\Delta P < \Delta P_L$:

- $A_e = \Delta {P_L}^{n-1} \left(P_r^{\frac{1}{2}-n}\right) ELA$, where n here is the measured value, or 0.65.
- $n_g = 1$
- $P_r = 0.08354 \frac{lb_f}{ft^2}$

1.9.3.8 Converting units of κ

The κ in Equation 137 is not dimensionless, so κ changes value depending on the units of Q and ΔP in Equation 137. The analysis herein (Section 1.9) assumes Q in $\frac{ft^3}{sec}$d ΔP in $\frac{lb_f}{ft^2}$.

However, conventionally κ is obtained from measured data with $Q \text{ in } \left(\frac{ft^3}{\min}\right)$ and $\Delta P \text{ in } Pascals$. With these units Equation 137 takes the form:

$$Q[cfm] = \kappa'(\Delta P(Pa))^n$$

Equation 147

Using dimensional analysis the value of κ to be used in Equation 137 with Q in $(\mathrm{ft}^3/\sec)$ and $\Delta \mathrm{P} \text{ in } \left(\frac{\mathrm{lb_f}}{\mathrm{ft}^2}\right)$ is:

$$\kappa = \left(\frac{47.88^n}{60}\right)\kappa'$$

Equation 148

where the numbers are from the conversion factors $47.88\frac{\mathrm{Pa}}{\frac{\mathrm{lb_f}}{\mathrm{ft}^3}}$ and 60 sec/min. $\kappa = 0.206\kappa'$ for $\mathrm{n} = 0.65$.

κ' = the measured value from data with $Q \text{ in } \left(\frac{ft^3}{\min}\right)$ and $\Delta P \text{ in } Pascals$.

1.9.3.9 ACM Manual relationship between CFM50 and ELA

Using Equation 142 (in volume flow form) the infiltration volume flow, CFS50, with 50 Pa pressurization is:

$$\text{CFS50} = \text{ELA}\sqrt{\frac{2g_c}{\rho}}P_r^{\frac{1}{2}-n}\Delta P^n = ELA\sqrt{\frac{64.4}{0.075}}0.08354^{-0.15}\,1.04428^{0.65} = 43.738 * ELA$$

Equation 149

where

ΔP = 50 Pa = 1.04428 psf

CFS50 = flow in units of $\frac{ft^3}{sec}$or cfm units, and ELA in square inches,

CFM50 = (60/144)CFS50 = 18.224*ELA

Equation 150

or alternately,

ELA [in^2] = 0.055*CFM50

Equation 151

This is the equation used to get ELA from blower door data at 50 Pa pressure difference.

1.9.3.10 Heat Flow

When the flow $m_{i,j}$ is positive, the heat delivered to zone j by this flow is given by

$$Q_j = m_{i,j} C_p (T_i - T_j)$$

Equation 152

while the heat delivered to zone *i* by the flow $m_{i,j}$ is zero:

$$\mathrm{Q_i} = 0$$

Equation 153

When the flow $m_{i,j}$ is negative, the heat delivered to zone j is zero,

$$Q_j = 0$$

Equation 154

while the heat delivered to zone *i* by the flow $m_{i,j}$ is:

$$Q_i = m_{i,j} C_p (T_i - T_j)$$

Equation 155

1.9.4 Large Horizontal Openings

An additional set of equations is needed to model large horizontal openings such as stairwells. The algorithm used is similar to that implemented in Energy Plus, which is based on that given by Cooper (1989). In addition to pressure driven flow using the power law equations of Section 1.9.3.3 this algorithm involves buoyancy induced flows that can occur when the density of the air above the opening is larger than the density of the air below the opening, causing Rayleigh-Taylor instability.

For a given rectangular opening this algorithm can produce three separate flows components between the zones:

a) a forced orifice flow in the direction dictated by the zone to zone pressure difference, Δp. This flow is independent of the following instability induced flows.
b) a buoyancy flow downward when the air density in the upper zone is greater than that is the lower zone, i.e., $T_{upper\text{-}zone} < T_{lower\text{-}zone}$. This flow is maximum when Δp is zero, and linearly decreases with increasing Δp until the buoyancy flow is zero, which occurs when the pressure difference is large enough that the forced flow "overpowers" the instability flow. The latter occurs if Δp is greater than the "flooding" pressure ΔpF.
c) an upward buoyancy flow equal to the downward buoyancy flow.

These three flows are modeled by two flow-elements. The first element handles the forced flow (a) and in addition whichever of the buoyancy flow component, (a) or (c), that is in the same direction as the forced flow. The second element handles the alternate buoyancy flow component.

1.9.4.1 Pressure driven flow

The pressure forced flow is modeled as orifice flow using Equation 143, except the area A in the Section 1.9.3.5 is replaced by:

$$Aeff = L1 * L2 * sin(StairAngle) * (1 + cos(StairAngle))$$

Equation 156

L1 and *L2* are the dimensions of the horizontal rectangular hole. To include the effect of stairs, a $StairAngle$ can be set, where $StairAngle = 90\ \mathrm{deg}$ corresponds to vertical stairs. The angle can be set to 90 degrees to exclude the effect of the stairs.

Equation 144 is used for the partial derivative of the flow, with the area A_e using *Aeff* in place of A.

1.9.4.2 Buoyancy flow

When the zone on top has a higher density than the zone on the bottom, the maximum possible buoyancy flow, mbm, occurs when the pressure difference across the hole is zero:

$$mbm = 0.055\sqrt{g\bar{\rho}|\Delta\rho|Dhyd^5}$$

Equation 157

The 0.055 factor is dimensionless ; g = 32.2 ft/s^2.

The hydraulic diameter of the hole is defined as:

$$Dhyd = 2 * \frac{Aeff}{L1 + L2}$$

Equation 158

When the zone on top has a higher density than the zone on the bottom, and the pressure difference is lower than the flooding pressure, then the buoyancy flow is given by:

$$mb = mbm * \left(1 - \frac{|\Delta p|}{\Delta pF}\right)$$

Equation 159

The flooding pressure difference ΔpF is defined as:

$$\Delta pF = \frac{C_s^2 g|\Delta\rho|Dhyd^5}{2\mathrm{A}_{\mathrm{eff}}^2}$$

Equation 160

The shape factor C_s is

$$C_s = 0.942\left(minimum\left(\frac{L1}{L2},\frac{L2}{L1}\right)\right)$$

Equation 161

If the top zone density is lower than the bottom zones, or if $|\Delta p| > \Delta pF$ then the buoyancy flow mb is zero.

The partial derivatives of the buoyancy flows with respect to adjacent zone pressures are all zero since the buoyancy flows are equal and opposite. That is, although the buoyancy flow magnitudes are sensitive to zone pressures, they have no influence on the zone mass balance.

Although the buoyancy flows don't directly influence zone pressures, they do affect the heat transfer rates.

When buoyancy flows exists, the heat transfer due to the buoyancy flow to the upper zone, *i* say, is

$$\mathrm{Q_i} = \mathrm{mb} * \mathrm{C_p}(\mathrm{T_j} - \mathrm{T_i})$$

Equation 162

and to the lower zone is

$$\mathrm{Q_j} = \mathrm{mb} * \mathrm{C_p}(\mathrm{T_i} - \mathrm{T_j})$$

Equation 163

1.9.5 Large Vertical Openings

The flow through large vertical rectangular openings are handled using the method suggested by Woloszyn (1999).

Woloszyn uses a simplified version of the common integrate-over-pressure-distribution scheme as used by Walker for example. Rectangular holes are divided in two, with the flow through the top half driven by a constant Δp equal to the pressure difference ¾ the way up the opening (the midpoint of the top half of the opening area). Similarly, the flow through the bottom half uses the Δp at ¼ the way up the hole, and assumes it is constant over the bottom half. Although approximate compared to the integration methods, it is expected to be able to reasonably accurately, if not precisely, portray one and two way flows through such elements. This procedure has the virtue of eliminating the calculation of the neutral level, thereby greatly reducing the number of code logic branches and equations. It also eliminates a divide by zero problem when *Δp* à *0* in the exact integration methods.

Besides being used for large vertical holes, like open windows and doorways, the method is also used for distributed infiltration. That is, a rectangular wall with an effective leakage area ELA is represented by two holes, each of area ELA/2, located at the ¼ and ¾ heights. These holes are then modeled using Equation 138, Equation 141, Equation 144, and Equation 145.

1.9.5.1 Triangular surfaces

The method is generalized further to treat the tilted triangular surfaces assumed for hip roofs. In this case the lower Woloszyn hole, of area ELA/2, is placed at the height that is above ¼ of the area of the triangle. This can be shown to be a height of:

$$H_{lower\ hole} = Z_{soffit} + \left(1 - \frac{\sqrt{3}}{2}\right)\left(Z_{ridge} - Z_{soffit}\right)$$

Equation 164

Similarly, the top hole is placed at the height above ¾ of the area of the triangle:

$$H_{upper\ hole} = Z_{soffit} + \left(\frac{1}{2}\right)\left(Z_{ridge} - Z_{soffit}\right)$$

Equation 165

1.9.6 Newton-Raphson Solution

Assume there are a total of *nuc* conditioned and unconditioned zones with unknown pressures. The outside conditions, of known pressure, are assigned a zone number *nout = nuc+1*.

The mass flow rate from zone *i* to zone *j* (including *j=nout*) is designated as $m_{i,j}$, and can be positive (flow out of zone i) or negative (flow into zone i).

$$m_{i,j} = \sum_{k=1}^{K_{i,j}} m_{i,j,k}$$

Equation 166

where $m_{i,j,k}$ is the flow rate through the *k*'th element of the $K_{i,j}$ elements in surface *i,j*. By symmetry,

$$m_{i,j,k} = -\, m_{j,i,k}$$

Equation 167

and

$$\mathrm{m_{I,j}} = -\,\mathrm{m_{j,i}}$$

Equation 168

From Equation 167, $\mathrm{m}_{\mathrm{I,j},k}$ values are functions of the zone pressure difference $(P_i - P_j)$.

$$\mathrm{m_{i,j,k}} = +\,\mathrm{A_e}\sqrt{2\rho_{in}}\left(\mathrm{P_i} - \mathrm{P_j}\right)^{\mathrm{n}}$$ for positive $\Delta\mathrm{P}$

$$\mathrm{m_{i,j,k}} = -\mathrm{A_e}\sqrt{2\rho_{in}}\left(\mathrm{P_j} - \mathrm{P_i}\right)^{\mathrm{n}}$$ for negative $\Delta\mathrm{P}$

Equation 169

This shows that in general,

$$\frac{\partial m_{i,j,k}}{\partial P_i} = -\frac{\partial m_{i,j,k}}{\partial P_j}$$

Equation 170

The net flow leaving zone *i* (*i=1 to nuc)* is the defined as the residual r_i:

$$r_i = \sum_{j=1,j\neq i}^{nout} m_{i,j} = \sum_{j=1,j\neq i}^{j=nout} \sum_{k=1}^{K_{i,j}} m_{i,j,k}$$

Equation 171

The $j \neq i$ criterion on the sums eliminates summing $m_{i,i}$ terms which are zero by definition. The zone pressures P_I are to be determined such that the residuals r_I all become zero.

Equation 169 and Equation 171 constitute a set of n = nuc nonlinear equations with n = nuc unknown pressures. To linearize the equations, a Taylor's series is used to determine the residual $r_i^{'}$ at the pressure $P_j^{'}$ near the guessed value of pressures P_j, where the residual is r_i. Keeping only first order terms:

$$r_i' = r_i + \sum_{j=1}^{nuc} \frac{\partial r_i}{\partial P_j} \left(P_j{}' - P_j\right)$$

Equation 172

In matrix form this is written:

$$\boldsymbol{r}^{'} = \boldsymbol{r} + \boldsymbol{J}(\boldsymbol{P}^{'} - \boldsymbol{P})$$

Equation 173

where $\boldsymbol{r}^{'}$ is the vector with elements $r_i^{'}$, and $\boldsymbol{r}$ is the vector with elements r_i.

$\boldsymbol{J}$ is the nuc-by-nuc Jocobian matrix with elements:

$$J_{i,l} = \frac{\partial r_i}{\partial P_l} = \sum_{j=1}^{nout} \frac{\partial m_{i,j}}{\partial P_l} = \sum_{j=1,j\neq i}^{j=nout} \sum_{k=1}^{k=K_{i,j}} \frac{\partial m_{i,j,k}}{\partial P_l}$$

Equation 174

where $i = 1\ to\ nuc, and\ l = 1\ to\ nuc$.

Setting $r_i^{'} = 0$ and solving for $P_j^{'}$, Equation 173 becomes

$$\boldsymbol{P}^{'} = \boldsymbol{P} - \boldsymbol{J}^{-1}\boldsymbol{r}$$

Equation 175

$$\boldsymbol{P}^{'} = \boldsymbol{P} - \boldsymbol{C}$$

Equation 176

where ***C*** is the correction vector:

$$\boldsymbol{C} = -\boldsymbol{J}^{-1}\boldsymbol{r}$$

Equation 177

$$P_i' = P_i - C_i$$

Equation 178

Equation 178 gives the pressures P_i' that are predicted to make r_i' zero.

1.9.6.1 Convergence

Convergence is attained when the residuals r_i are sufficiently small. As employed by Energy Plus and Clarke, both absolute and relative magnitude tests are made.

Convergence is assumed when the absolute magnitude of the residual in each zone *i* is less than a predetermined limit *ResMax*:

$$|res_i| < ResMax$$

Equation 179

OR, the magnitude of the residual divided by the sum of the magnitudes of the flow through each element connected to zone *i*, is less than a predetermined limit $ResErr$:

$$\frac{|res_i|}{resmag_i} < ResErr$$

Equation 180

where

$$resmag_i = \sum_{j=1}^{nout} |m_{i,j}|$$

Equation 181

(code uses: sum of magnitude of flows to & from zone iz, resmag(iz) += ABS(mdot(iz,jz,ke)).

1.9.6.2 Relaxation

Equation 178 is more generally written as

$$P_i' = P_i - relax * C_i$$

Equation 182

where $relax$ is the relaxation coefficient, a factor less than one that reduces the correction applied to P_i. Relaxation factors on the order of 0.75 have been shown to reduce the number of iterations in cases normally having slowly decreasing and oscillating corrections. But a fixed value of 0.75 can slow what were formerly rapidly converging cases. The following approach is used to reduce the relaxation factor only when necessary.

Following Clarke, when the corrections C_i from one iteration to the next changes sign, and the latest C_i has a magnitude over half as big as the former C_i, then it is assumed that the convergence is probably slow and oscillating. This symptom is typically consistent over a few iterations, and if this were precisely the case, the correction history would follow a geometric progression with a negative common ratio $\frac{C_i}{C_i^{last}}$. Thus by extrapolation a better estimate of correct solution will be obtained if the relaxation factor is taken as the sum of the infinite termed geometric progression:

$$relax = \frac{1}{1 - \frac{C_i}{C_i^{last}}}$$

Equation 183

Thus, whenever, during an iteration for zone *i*,

$$\frac{C_i}{C_i^{last}} < -0.5$$

Equation 184

then Equation 178 is replaced by

$$P_i' = P_i - \frac{1}{1 - \frac{C_i}{C_i^{last}}} * C_i$$

Equation 185

Insofar as the extrapolation is warranted, this should give a better prediction of the pressure P_i' than would using *relax* = 1 for this iteration. For the iteration following that using Equation 185, *relax* = 1 is reverted to (i.e., Equation 178) so that only unrelaxed correction values are used to evaluate $\frac{C_i}{C_i^{last}}$. The following iteration, if any, is then again tested by Equation 184. The first iteration is always done with *relax = 0.75* since at this point there is no value available for C_i^{last}.

It would be reasonable to add a max Ci limit; i.e., max pressure change allowed, a la Clarke, but code testing has not shown the need.

1.9.6.3 Off diagonal terms

Consider Equation 174 for off-diagonal terms. Since $i \neq l$, zone *i's* flow $m_{i,j}$ varies with P_l only if *j = l*. Thus setting *j = l*, and $i \neq l$, Equation 174 reduces to:

$$J_{i,l,i \neq l} = \sum_{k=1}^{K_{i,l}} \frac{\partial m_{i,l,k}}{\partial P_l}$$

Equation 186

where $i = 1 \ to \ nuc, and \ l = \ 1 \ to \ nuc$.

Equation 186, along with Equation 170, shows that all off diagonal terms have a negative magnitude. Since $m_{i,l,k} = - m_{l,i,k}$,

$$J_{i,l,i\neq l} = \sum_{k=1}^{K_{i,l}} \frac{\partial m_{i,l,k}}{\partial P_l} = -\sum_{k=1}^{K_{i,l}} \frac{\partial m_{l,i,k}}{\partial P_l}$$

Equation 187

Using Equation 170, Equation 187 becomes:

$$J_{i,l,i\neq l} = \sum_{k=1}^{K_{i,l}} \frac{\partial m_{l,i,k}}{\partial P_i} = J_{l,i,i\neq l}$$

Equation 188

Thus the Jacobian matrix is symmetric:

$$J_{i,l} = J_{l,i}$$

Equation 189

Thus only the upper (or lower) diagonal terms need be determined, with the other half determined by transposition. The off diagonal terms only involve partials of flows between zones with unknown pressures.

1.9.6.4 Diagonal terms

For *i = j* Equation 174 gives:

$$J_{i,i} = \frac{\partial r_i}{\partial P_i} = \sum_{j=1}^{nout} \frac{\partial m_{i,j}}{\partial P_i} = \sum_{j=1}^{j=nout} \sum_{k=1}^{k=K_{i,j}} \frac{\partial m_{i,j,k}}{\partial P_i}$$

Equation 190

where $i = 1\ to\ nuc$.

Equation 190 terms can be regrouped to show a simpler numerical way to determine $J_{i,i}$, by using the off diagonal terms already calculated:

$$J_{i,i} = \frac{\partial m_{i,nout}}{\partial P_i} - \sum_{k=1,k\neq i}^{k=nuc} J_{k,i}$$

Equation 191

This shows that the diagonal elements use the derivatives of mass flows to the outdoors minus the off diagonal terms in the same column of the Jacobian.

Equation 191 shows that matrix will be singular if $\frac{\partial m_{i,nout}}{\partial P_i} = 0$, so that at least one connection to outdoors is necessary.

1.10 Duct System Model

1.10.1 Description of Model

The duct model builds on the procedure given by Palmiter (see Francisco and Palmiter, 2003), that uses a steady state heat exchanger effectiveness approach to get analytical expressions for instantaneous duct loss and system efficiencies. The duct model, developed for this program by Palmiter, makes use of many of the same fundamental steady state equations and approach, but given the considerable complexity of the multiple duct systems, does not do a simultaneous solution of all the equations which a generalized Francisco and Palmiter scheme may imply. Instead the approach takes advantage of the small time steps used in the code, and in effect decouples the systems from each other and the zone by basing all losses and other heat transfers occurring during the time step on the driving conditions of Tair and Tmrt known at the beginning of the time step, similar to how heat transfers are determined during mass temperature updates .

Other assumptions made in the duct program: mass and thermal siphon effects in the duct system are ignored.

The duct system performance is analyzed at every time step. The duct air temperatures are calculated assuming they are operating at steady state, in equilibrium with the thermal conditions at the beginning of the time-step in the attic. Heat capacity effects of the ducts are ignored.

During each time step, the following steps are taken to find the duct system operating conditions such as the air temperatures in each duct, the losses, the heating or cooling delivered, etc.

Initially, for each time step, the duct systems performance is determined when operating at full capacity, independent of the load. The procedure starts at the return registers in each conditioned zone, where the duct air temperatures are the current timesteps conditioned zone air temperatures. The conditioned zone air entering the return register heats or cools, or both, as it traversed through each component of the duct system: the return duct, the return plenum, the heating/cooling device, and the supply ducts. That is, the duct air temperature rises or drops immediately downstream of the return register (where returns leaks are assigned to occur) due to mixing of leakage air at the air temperature in the unconditioned zone in which the return duct is located with the return air from the conditioned zone. It may also increase or decrease in temperature in the return plenum as it mixed with the air from the return duct in another unconditioned zone. After being heated or cooled by the air handler at its applicable heating/cooling capacity, it is then additionally heated or cooled by supply duct conductive gains/losses to the interior of the unconditioned zone.

Summing all the gains and losses in temperature of the duct air as it travels through the system gives the supply temperature for the supply duct, allowing the heat delivered at full capacity, $Qdel$, to be determined.

If the above useful heat delivered at full capacity is more than required by the load, then the equipment capacity is reduced to meet the load by assuming the system is only running the fraction $\frac{Qload}{}Qdel$ of the time step. The needed capacity, $Qneed$, is this fraction of the nominal capacity. The duct losses for the time step are also reduced by this fraction.

The above calculations are done each time step and the average Qneed summarized in the hourly output.

The above steps are presented in detail in the following sections, in the same sequence as described above.

1.10.2 Duct System Inputs

1.10.2.1 Subscripts

In most cases in this section, the subscripted variables stand for arrays.

The subscript u stands for the unconditioned zone in which the duct is located.

The subscript c stands for conditioned zone number and its associated air handler system.

The subscript m stands for the mode of air handler operation: 0 off, 1 heating, 2 cooling.

1.10.2.2 Annual run inputs

The following data is input to model the duct/air handler system(s):

Duct inside areas

$Asd_{c,u}$ = supply duct inside area for air handler c in unconditioned zone u.

$Ard_{c,u}$ = return duct inside area for airhandler c in unconditioned zone u.

Duct insulation rated R values

$Rsd_{c,u}$ = supply duct rated R for air handler c in unconditioned zone u; hr-ft^2-F/Btu.

$Rrd_{c,u}$ = return duct rated R for air handler c in unconditioned zone u; hr-ft^2-F/Btu.

Inside duct area and inside area based resistance, and the outside duct area and outside area based resistance when there is a single duct segment in the return and supply branches

Consider one duct of constant inside diameter, d_i, and length L. The duct is insulated with insulation having a thermal conductivity k, and rated R value, R_{rate}. All R values herein are in the units of (hr-ft2-F/Btu).

Layed flat, the thickness the insulation layer is:

$$t = Rrate * k$$

Equation 192

If the insulation is wrapped at this thickness around a duct of diameter d_i, the outside diameter, d_o, of the insulation will be:

$$d_o = d_i + 2 * Rrate * k$$

so,

$$\frac{d_o}{d_i} = 1 + \frac{2kR_{rate}}{d_i}$$

Equation 193

Conduction heat transfer texts gives the overall conductance C of length L of an annular insulation layer as:

$$C = \frac{2\pi kL}{ln\left(\frac{d_o}{d_i}\right)}$$

Equation 194

Dividing this by inside area, $A_i = \pi d_i L$, gives the conductance per unit inside area:

$$C_i = \frac{2k}{d_i ln\left(\frac{d_o}{d_i}\right)}$$

The duct resistance value per unit inside area is the reciprocal,

$$R_i = \frac{d_i ln\left(\frac{d_o}{d_i}\right)}{2k}$$

Equation 195

This can be written in terms of areas, and length L, as:

$$R_i = \frac{A_i ln\left(\frac{A_o}{A_i}\right)}{2\pi kL}$$

Equation 196

The duct resistance value based on outside area can be determined from $R_i and\ A_i$ as:

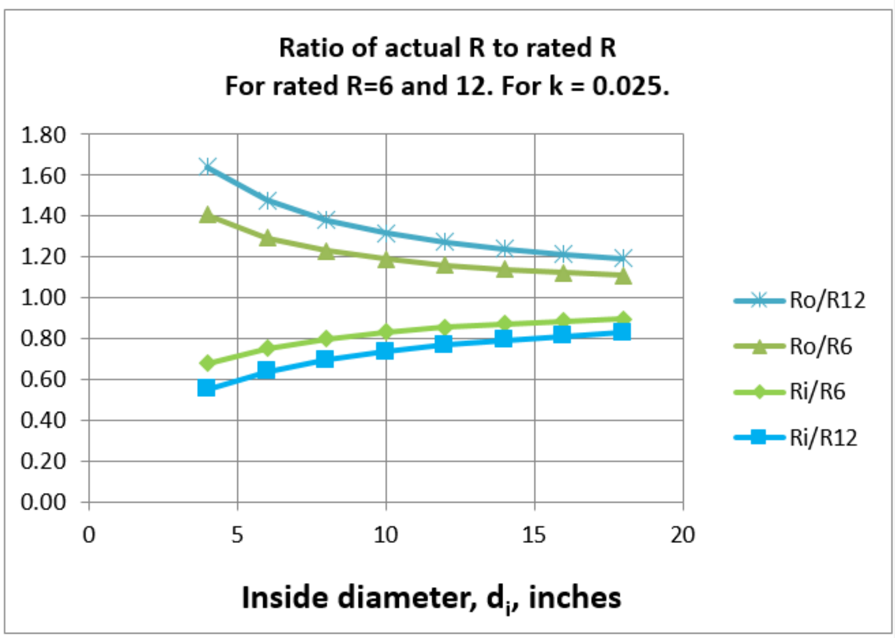
$$R_o = \frac{d_o}{d_i} R_i$$

Equation 197

$$A_o = \frac{d_o}{d_i} A_i$$

The R values of Equation 195 and Equation 197, divided by R_{rated}, are plotted in Figure 25 as a function of the inside diameter of the duct branch.

Figure 25: Ratio of Actual R to Rated R



Duct system composed of multiple segments in the supply and return branches

Suppose the supply ducts from an air handler system are branched, with each branch having different sizes, lengths, rated insulation Rrate, and conductivity k values, and all the branches are in one unconditioned zone. These could be combined into one equivalent duct as follows.

The duct branches, j=1à n, are combined, each of inside areas $A_i(j)$, outside areas $A_o(j)$, conductivities $k(j)$, and inside area based resistances $R_i(j)$. Using the method of

Palmiter and Kruse (2003), the overall conductance of the branched duct system, based on inside area, is the sum of the conductances of each branch:

$$'UA' = \sum_{j=1\rightarrow n} \left(\frac{A_i(j)}{R_i(j)}\right)$$

Equation 198

where R_i for each branch segment j is given by Equation 196 as

$$R_i(j) = \frac{A_i(j) ln\left(\frac{A_o(j)}{A_i(j)}\right)}{2\pi k(j)L(j)}$$

Equation 199

With $A_i(j) = \pi d_i(j)L(j)$, and using Equation 193, this can be written as

$$R_i(j) = \frac{d_i(j) ln\left(1 + \frac{2k(j)R_{rate}(j)}{d_i(j)}\right)}{2k(j)}$$

Equation 200

The total branch inside area is:

$$A_i = \sum_{j=1\rightarrow n} A_i(j)$$

Equation 201

The effective overall resistance of the branched duct, based on inside area A_i, is thus:

$$R_i = \frac{A_i}{'UA'} = \frac{A_i}{\sum_{j=1\rightarrow n}\left(\frac{A_i(j)}{R_i(j)}\right)} = \frac{A_i}{\sum_{j=1\rightarrow n}\left[\frac{A_i(j)}{\frac{d_i(j) ln\left(1 + \frac{2k(j)R_{rate}(j)}{d_i(j)}\right)}{2k(j)}}\right]}$$

Equation 202

The values of the terms needed for each branch segment, shown on the right hand side of Equation 202 are not available since the former ACM manual only requires that the following R is known:

$$"R" = \frac{A_i}{\sum_{j=1\rightarrow n}\frac{A_i(j)}{R_{rate}(j)}}$$

Equation 203

Equation 202 and Equation 203 would be equivalent if Equation 203 had the term $R_i(j)$ in place of $R_{rate}(j)$. As it is, Equation 203 gives the area weighted average R_{rate}, not $R_i(j)$.

The total outside area is:

$$A_o = \sum_{j=1 \to n} A_o(j)$$

Equation 204

Based on outside area, the effective duct system resistance would be:

$$R_o = \frac{A_o}{A_i} R_i$$

Equation 205

1.10.2.3 Emissivities

$epss_{c,u}$ = supply duct emissivity for air handler c in unconditioned zone u.

$epsr_{c,u}$ = return duct emissivity for air handler c in unconditioned zone u.

1.10.2.4 Duct leakage

$Ls_{c,u}$ = the fraction of the flow through the system c air handler fan that is leaked from the supply duct in unconditioned zone u. The leak is assigned to occur near the supply register so that the leakage air is at the supply register temperature.

$Lr_{c,u}$ = the fraction of the flow through the system c air handler fan that is leaked into the return duct in unconditioned zone u. The leak is assigned to occur at the return register. The air leaking into the duct is at the unconditioned zone temperature.

1.10.2.5 System flow

$Flow_{m,c}$ = the flow rate in cfm (at standard conditions) through the air handler for the cooling and heating modes, for of each system.

1.10.2.6 Flow distribution

How much of the air handler flow of system c goes through each of its return and supply ducts is given by the per run input flow fractions:

> $Fmr_{c,u}$ = fraction of flow of system c in the return duct located in unconditioned zone u.
>
> $Fms_{c,u}$ = fraction of flow of system c in the supply duct located in unconditioned zone u.
>
> $Fmrc_c$ = fraction of flow of system c in the return duct located in conditioned zone c.

$Fmsc_c$ = fraction of flow of system c in the supply duct located in conditioned zone c.

For a given system c, the sum of the return duct fractions must add to one: $Fmr_{c,1}$ + $Fmr_{c,2}$ + $Fmrc_c$ = 1. Similarly for the supply duct fractions.

1.10.3 Return Duct Air Temperatures

Following the procedure indicated in Section 1.10.1, the return duct air temperatures are determined first. Utilizing the heat exchanger effectiveness approach (see Mills (1992), andA), the temperature of the system c return duct air entering the return plenum from a return duct located in unconditioned zone number u is given by:

$$Tout_{c,u} = Er_{m,c,u} Teqr_{c,u} + \left(1 - Er_{m,c,u}\right) \cdot Tmix_{c,u}$$

where $Er_{m,c,u}$ is the effectiveness of the return duct of system c in unconditioned zone u when operating in mode m:

$$Er_{m.c.u} = 1 - e^{\frac{-Urtot_{c,u}}{Mcpr_{m,c,u}}}$$

where $Urtot_{c,u}$ is the total conductance between the return duct air and the equivalent surroundings temperature $Teqr_{c,u}$:

$$Teqr_{c,u} = \left(Frda_{c,u} \cdot Tair_u + Frdr_{c,u} \cdot Tmrt_u\right)$$

$Frda_{c,u}$ is the fraction of return duct (dissolved surface node) conductance that goes to the $Tair_u$ node.

$$Frda_{c,u} = \frac{Urc_{c,u}}{(Urc_{c,u} + Urr_{c,u}}$$

$Frdr_{c,u}$ is the fraction of the conductance from the c,u return duct air that goes to the $Tmrt_u$ radiant node.

$$Frdr_{c,u} = \frac{Urr_{c,u}}{Urc_{c,u} + Urr_{c,u}}$$

The U terms are the conductances from the duct air to the mrt and air nodes, determined as described inA. These conductance values, and the similar supply duct values of Section 1.10.6 are used in the energy balance of the unconditioned zone(s) containing ducts.

Urr_{cu} = conductance from return duct air to Tmrt.

$Urc_{c,u}$ = conductance from return duct air to Tair.

$Urtot_{c,u} = Urc_{c,u} + Urr_{c,u}$

The term $Mcpr_{m,c,u}$ is the flow conductance (see below) for the return duct flow:

$Mcpr_{m,c,u} = Mcp_{m,c} Fmr_{c,u}$

The total system flow, $Mcp_{m,c}$ is in the "flow conductance" form with the units Btu/hr-F:

$$Mcp_{m,c} = Flow_{m,c} \cdot c_p$$

where c_p is the volumetric heat capacity, which is taken as 1.08 Btu/(hr-F-cfm) for dry air at the ASHRAE standard conditions of density = 0.075 lb_m/ft^3 and c_p = 0.24 Btu/lb_m-F.

The term $Tmix_{c,u}$ is the mixed air just downstream of the return duct leakage, given by:

$$Tmix_{c,u} = Lr_{c,u}Tair_u + \left(1 - Lr_{c,u}\right)Temp_c$$

where $Temp_c$ is the temperature of conditioned zone c's air, assumed to be well-mixed.

1.10.4 Return Plenum Temperature and Return Duct Conductive Heat Losses

The heat loss rate from the return duct via convection and radiation, needed in the unconditioned zone energy balance, is:

$$qlr_{c,u} = Mcpr_{m,c,u} \cdot \left(Tmix_{c,u} - Tout_{c,u}\right)$$

The final return plenum temperature of system c is found by summing the contributions to its plenum temperature from the return ducts in each unconditioned zone and the return ducts located in the conditioned zone. That is,

$$Trp_c = Fmrc_c \cdot Temp_c + \sum_{all\ u} Fmr_{c,u} \cdot Tout_{c,u}$$

1.10.5 Temperature Rise through Air Handler Heating or Cooling Equipment

If the mode is heating or cooling, the temperature rise through the air handler heating or cooling equipment of system c at sensible capacity Cap_c is given by:

$$dte_c = \frac{Cap_c}{Mcp_{m,c}}$$

Equation 206

The program considers no heat losses or gains from the air handler components other than from the ducts.

1.10.6 Supply Plenum and Supply Register Temperatures

The supply plenum temperature is given by:

$$Tsp_c = Trp_c + dte_c$$

Equation 207

The supply register temperature for the supply duct of system c in unconditioned space u is:

$$Tsr_{c,U} = Teqs_{c,u} + \left(1 - Es_{m,c,u}\right) \cdot \left(Tsp_c - Teqs_{c,u}\right)$$

Equation 208

where $Es_{m,c,u}$ is the effectiveness of the supply duct of system c in unconditioned zone u when operating in mode m:

$$Es_{m,c,u} = 1 - e^{\frac{-Ustot_{c,u}}{Mcps_{m,c,u}}}$$

Substituting the Tsp_c equation above into Equation 208and rearranging gives:

$$Tsr_{c,u} = \left(1 - Es_{m,c,u}\right)dte_c + Tsrhx_{m,c,u}$$

Equation 209

Where

$$Tsrhx_{m,c,u} = \left(1 - Es_{m,c,u}\right)Trp_c + Es_{m,c,u}Teqs_{c,u}$$

$Tsrhx$ is the temperature that would be delivered to the supply register with the current mode's flow rate but with zero capacity such that $dte_c = 0$. The duct system is then acting as a heat exchanger (thus the 'hx') between the connected conditioned and unconditioned zones.

The term $s_{c,u}$, similar to $Teqr_{c,u}$ of Section 1.10.3, is an equivalent environmental temperature defined by

$$Teqs_{c,u} = \left(Fsda_{c,u} \cdot Tair_u + Fsdr_{c,u} \cdot Tmrt_u\right)$$

where

$$Fsda_{c,u} = \frac{Usc_{c,u}}{Usc_{c,u} + Usr_{c,u}}$$

$$Fsdr_{c,u} = \frac{Usr_{c,u}}{Usc_{c,u} + Usr_{c,u}}$$

$Usr_{c,u}$= conductance from supply duct air to Tmrt.

$Usc_{c,u}$ = conductance from supply duct air to Tair.

$$Ustot_{c,u} = Usc_{c,u} + Usr_{c,u}$$

The supply duct flow rate is:

$$Mcps_{m,c,u} = Mcp_{m,c} \cdot Fms_{c,u}$$

1.10.7 Heating/Cooling Delivered and Supply Duct Conductive Heat Loss

Given $Tsr_{c,u}$, from above, the heat delivered to the conditioned zones by way of the supply ducts located in one or more of the unconditioned zones is given by summing the sensible heat delivered via each unconditioned zones:

$$\text{Q delivered from ducts} = \sum_u Mcpsr_{m,c,u} \cdot (Tsr_{c,u} - Temp_c)$$

Equation 210

where $Mcpsr_{m,c,u}$, the flow out the supply register after the supply leakage is removed, is given by:

$$Mcpsr_{m,c,u} = (1 - Ls_{c,u}) \cdot Mcps_{m,c,u}$$

The heat delivered to the conditioned zones by way of ducts in the conditioned zone, which are assumed to have no losses or unbalanced leakage, is given by:

$$\text{Q delivered directly to conditioned zone} = Fmsc_c \cdot Cap_c$$

Equation 211

Adding the Q's of Equation 210 and Equation 211 gives the net heating (+), or cooling (-), delivered by the system c as:

$$Qdel_c = Fmsc_c \cdot Cap_c + \sum_{\text{over } u}[Mcpsr_{m,c,u} \cdot (Tsr_{c,u} - Temp_c)]$$

Substituting the expression for $Tsr_{c,u}$ from Equation 209 into this, $Qdel_c$ can be put in the form:

$$Qdel_c = Qdel1_c + Qdel2_c,$$

where $Qdel1_c$ is the part of Qdel that is independent of air handler capacity. That is, it is the Q delivered if dte is zero, and is the heat exchanged between the unconditioned and conditioned zones via the duct system:

$$Qdel1_c = \sum_{all\, u} [Mcpsr_{m,c,u}(Tsrhx_{m,c,u} - Temp_c)]$$

$Qdel2_c$ is the part of $Qdel$ that is linearly dependent on the air handler capacity:

$$Qdel2_c = Fmsc_c \cdot Cap_c + \sum_{over\, u} [Mcpsr_{m,c,u} \cdot (1 - Es_{m,c,u}) \cdot dte_c]$$

The rate of supply duct conduction losses this time step is given by:

$$qls_{c,u} = Mcps_{m,c,u} \cdot (Tsp_c - Tsr_{c,u})$$

1.10.8 Duct System Performance when the Load is Less than the Heat Delivered at Full Capacity

If Qld_c is smaller than the capacity $Qdel_c$, then the system runs only part of the time step. In this case the run time fraction is:

$$Frun_c = \frac{Qld_c}{Qdel_c}$$

The capacity required to meet the load is $Qneed_c$:

$$Qneed_c \ = \ Frun_c \cdot Cap_c$$

The duct conductive and leakage losses are also reduced by the same $Frun_c$ fraction.

1.10.9 Duct System Performance when the Load is Greater than the Heat Delivered at Full Capacity

In principle this won't occur because the conditioned zone load is limited to the system capacity when it is calculated by the conditioned zone thermostat logic However, the capacity thus calculated is based on the duct efficiency [defined as η=Qload/Qneed] determined for the unconditioned zone during the last time-step, and as a result the load might exceed the capacity determined by the duct model efficiency this time-step.

That is, when the conditioned zone energy balance is performed, and for example heating is called for, then the output capacity of the heating system needs to be known, which requires knowing the duct system efficiency. But the duct efficiency is only known after the attic simulation is run.

To avoid iteration between the conditioned zone and attic zone modules, the most recent duct efficiency is used to determine the capacity in the conditioned zones thermostat calculations. When the attic simulation is next performed, if the conditioned zone was last running at capacity, and if the efficiency now calculated turns out to be higher than was assumed by the thermostat calculations, then the load will have exceeded the limiting capacity by a small amount depending on the assumed vs. actual efficiency. In cases like this, to avoid iteration, the limiting capacity is allowed to exceed the actual limit by a small amount, so that the correct air handler input energy demand is determined for the conditioned zone load allowed.

In this case, the system is set to run for the full sub-hour time step and the air handler meets the load by increasing its capacity with the following procedure. This procedure, a carryover from the 2008 Residential Building Standards ACM procedures, wherein no capacity limits were imposed on the air handler systems, is as follows.

From the $Qdel1$ and $Qdel2$ equations it can be seen that the capacity needed in this case is:

$$Qneed_c = \frac{Qld_c - Qdel1_c}{Qdel2_c} Cap_c$$

Thus, the temperature rise through the air handler needs to be:

$$dte_c = \frac{Qneed_c}{Mcp_{m,c}}$$

The supply plenum temperature becomes:

$$Tsp_c = Trp_c + dte_c$$

The supply register temperatures is determined reusing Equation 208:

$$Tsr_{c,u} = Teqs_u + \left(1 - Es_{m,c,u}\right) \cdot \left(Tsp_c - Teqs_{c,u}\right)$$

The supply duct losses now become:

$$qls_{c,u} = Mcps_{m,c,u} \cdot \left(Tsp_c - Tsr_{c,u}\right)$$

The $Qneed_c$'s from each of the time steps during the hour are summed over the hour and reported in the output as $Qneed_c$. The supply and return duct conduction loss terms $qls_{c,u}$ and $qlr_{c,u}$ are used in the energy balance of the unconditioned zone each time step.

1.11Variable Insulation Conductivity

The following correlation is used. It is based on the correlation used in EnergyGauge USA (Parker, et al, 1999) which is based on Wilkes (1981) data:

$k = (kn) \cdot \left(1 + 0.00418(T_{insul} - 70)\right)$; temperatures in °F.

where,

k = insulation conductivity (Btu/hr-ft-R) at the average insulation temperature, T_{insul}(F).

kn = nominal insulation conductivity (Btu/hr-ft-R) for insulation at 70 F

1.12 Ceiling Bypass Model

A simple model was implemented to simulate ceiling bypass heat transfer, the heat that is transported from the conditioned zone to the attic via miscellaneous inter-wall cavities in the conditioned zone that may be partially open to the attic, as for example around a fireplace unit. Natural convection in the cavity when the conditioned zone is hotter than the attic is assumed to be the main mechanism for the bypass heat transfer. The conductance, when the conditioned zone air temperature $Tair_c > Tair_u$, the attic air temperature:

$$qbp = U(Tair_c - Tair_u)$$

where, the conductance follows a simple power law dependence on the temperature difference:

$$U = U_{bp}(Temp_1 - Tair_u)^{nbp}$$

Ubp is a coefficient depending on the cavity geometry. Although an exponent of nbp on the order of 1/4 can be assumed for laminar convection, there is no current empirical basis for determining the exponent. If the ACM rule of $U = 0.02Aceil$ were implemented, then nbp would be chosen as zero.

1.13 Zone Humidity Balance

1.13.1 Zone Humidity Balance

Given a zone with various flows, m_j, with humidities w_j, entering the zone, and with a scheduled source of water vapor, m_{sched}, a water mass balance on the zone gives:

$$\frac{dMw}{dt} = \sum_j m_j(w_j - w) + m_{sched}$$

Equation 212

which can be written as:

$$M\frac{dw}{dt} = \sum_j m_j(w_j - w) + m_{sched} - w\frac{dM}{dt}$$

Equation 213

where,

M = mass of dry air in the zone; lbm of dry air.

$\frac{dw}{dt}$ = the rate of change of humidity ratio in zone.

m_j = air flow rate from source j into zone; lbm-dry-air/unit-time. Source j can be outdoors, a supply register, adjacent zone, etc.

w_j = humidity ratio of air coming from source j; lbm H_2O/lbm dry air.

w = humidity ratio of air in zone; lbm H_2O/lbm dry air.

m_{sched} = scheduled rate of moisture addition to zone; lbm H_2O/unit time.

Using the air perfect gas equation the last term in Equation 213 can be written

$$w\frac{dM}{dt} = -w\frac{M}{T}\frac{dT}{dt}$$

so that Equation 213 becomes

$$M\frac{dw}{dt} = \sum_j m_j(w_j - w) + m_{sched} + w\frac{M}{T}\frac{dT}{dt}$$

Equation 214

where T is the air temperature in absolute degrees.

This equation is solved using a forward difference rather than a backward or central difference since a forward difference uncouples the moisture balance equations of each of the zones. Integrating from time t to time $t + \delta t$, where δt is the time step, using a forward difference, gives:

$$w(t+\delta t) = \left(m_{sched}(t) + \sum_j m_j(t)w_j(t)\right)\frac{\delta t}{M(t)} + w(t)\left(1 - \frac{\delta t}{M(t)}\sum_j m_j(t) - \frac{T(t+\delta t) - T(t)}{T(t)[\deg R]}\right)$$

Equation 215

Notice that all of the values on the right hand side of Equation 215 are determined at t (the beginning of the integration period) except for the $T(t+\delta t)$ term which represents the zone air temperature at the end of the integration period. $T(t+\delta t)$ is known from the zone energy sensible energy balance at time t (see Section 1.3). The term $\frac{T(t+\delta t)-T(t)}{T(t)[\deg R]}$ is assumed to be negligible and not included in the CSE code.

1.13.2 Stability of Solution

The time series solution of Equation 215 will become unstable unless the second term is positive. That is, stability requires

$$\left(\frac{\delta t}{M(t)}\sum_j m_j(t) + \frac{T(t+\delta t)-T(t)}{T(t)[\deg R]}\right) < 1$$

Equation 216

Solving for δt, stability requires

$$\delta t < \frac{M(t)}{\sum_j m_j(t)}\left(1 - \frac{T(t+\delta t)-T(t)}{T(t)[\deg R]}\right)$$

Equation 217

Since the zone air changes per unit time is $AC = \frac{\sum_j m_j(t)}{M(t)}$ then the stability requirement can be written in terms of air changes as:

$$AC < \frac{1}{\delta t}\left(1 - \frac{T(t+\delta t)-T(t)}{T(t)[\deg R]}\right)$$

Equation 218

If the solution is unstable at the given δt, the zone air mass M(t) can be temporarily boosted up such that:

$$M(t) > \frac{\delta t \sum_j m_j(t)}{\left(1 - \frac{T(t+\delta t)-T(t)}{T(t)[\deg R]}\right)}$$

This will lead to a higher latent capacity for the zone air, introducing some error in the zone humidity prediction. This will also lead to a zone latent heat imbalance unless this artificial increase in zone air is accounted for.

1.13.3 Hygric Inertia of Zone

The absorption/desorption of moisture in the zone is accounted for using the hygric inertial model of Vereecken et al. whereby a multiplier X is added to the M(t) term of Equation 10 and Equation 11. An appropriate value of X can be measured for the complete zone and all of its furnishings by using the protocol given by [Vereecken E, Roels S, Janssen H, 2011. In situ determination of the moisture buffer potential of room enclosures, Journal of Building Physics, 34(3): 223-246.]

1.14 Zone Comfort Algorithm

CSE includes an implementation of the ISO 7730 comfort model. The model is documented in ASHRAE Standard 55-2010 (ASHRAE 2010) among other places. The model calculates Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) for each zone at each time step. These statistics are averaged over days, months, and the full year.

The inputs to the ISO 7730 model are:

- Air dry-bulb temperature
- Air humidity ratio
- Mean radiant temperature
- Air velocity
- Occupant metabolic rate
- Occupant clothing level

Zone conditions calculated by CSE are used for the first three of these inputs. The remaining inputs are set by user input. They can be varied during the simulation using the CSE expression capability.

1.15HVAC Equipment Models

Air conditioning systems shall be sized, installed, tested and modeled according to the provisions of this section.

1.15.1 Compression Air-Conditioner Model

The Compliance Software calculates the hourly cooling electricity consumption in kWh using Equation 219. In this equation, the energy for the air handler fan and the electric compressor or parasitic power for the outdoor unit of a gas absorption air conditioner are combined. The Compliance Software calculates the hourly cooling gas consumption in therms using Equation 219.

$$AC_{kWh} = \frac{Fan_{Wh} + Comp_{Wh}}{1{,}000}$$

Equation 219

Where:

AC_{kWh} = Air conditioner kWh of electricity consumption for a particular hour of the simulation. This value is calculated for each hour, combined with the TDV multipliers, and summed for the year.

Fan_{Wh} = Indoor fan electrical energy for a particular hour of the simulation, Wh.

$Comp_{Wh}$ = Electrical energy for all components except the indoor fan for a particular hour of the simulation, Wh. This value includes consumption for the compressor plus outdoor condenser fan and is calculated using Equation 221.

CSE calculates the energy for electrically driven cooling using the algorithms described in this section.

Primary model parameters. The following values characterize the AC unit and are constant for a given unit:

Cap95 = AHRI rated total cooling capacity at 95 °F, Btuh

$CFM_{per\ ton}$ = Air flow rate per ton of cooling capacity, cfm/ton.

$$= \frac{\text{Operating air flow rate, cfm}}{\text{Cap95} — 12000}$$

EFan = Fan operating electrical power, W/cfm. Default = 0.365.

SEER = AHRI rated Seasonal Energy Efficiency Ratio, Btuh/W. EER shall be used in lieu of the SEER for equipment not required to be tested for a SEER rating.

EER = AHRI rated energy efficiency ratio at 95 °F, Btuh/W. If EER is not available, it is derived from SEER as follows:

SEER >=16 EER = 13

SEER >= 13 and <16 EER = 11.3 + 0.57 x (SEER - 13)

SEER < 13EER = 10 + 0.84 x (SEER – 11.5)

F_{chg} = Refrigerant charge factor, default = 0.9. For systems with a verified refrigerant charge (Reference Residential Appendix RA3), the factor shall be 0.96.

F_{size} = Compressor sizing factor, default = 0.95. For systems sized according to the Maximum Cooling Capacity for compliance software Credit (see Section <TODO>), the factor shall be 1.0.

Derived model parameters. The following values are used in the formulas below and depend only on model parameters.

Tons = Nominal cooling capacity defined as Cap95 / 12000

$QFan_{rat}$ = Assumed fan heat included at AHRI test conditions, Btuh

Fan motor type	$QFan_{rat}$
PSC	500 x Cap95 / 12000
BPM	283 x Cap95 / 12000

Source: NORESCO for California Energy Commission

$QFan_{op}$ = Fan heat assumed during operation (i.e., during simulation), Btuh

$$QFan_{op} = \frac{CFM_{per\ ton} \times Cap95 \times EFan \times 3.413}{12000}$$

Equation 220

Model inputs. The following values vary at each time step in the simulation and are used in the formulas below to determine AC unit performance under for that time step.

DB_t = Dry bulb temperature of air at the condensing unit, °F (typically outdoor air temperature).

WB_{ec} = Coil entering air wet bulb temperature, °F (return air temperature adjusted for blow-through fan heat if any)

DB_{ec} = Coil entering air dry bulb temperature, °F (return air temperature adjusted for blow through fan heat if any)

Qneed = Cooling system sensible cooling output, Btuh. Qneed is calculated across the unit and thus includes both the building load and distribution losses.

Compressor energy for a particular time step of the simulation shall be calculated using Equation 221.

$$Comp_{wh} = \frac{QFan_{op} + Qneed}{CE_t}$$

Equation 221

Where:

Fan_{wh} = Fan power for this time step, Wh.

CE_t = Sensible energy efficiency at current conditions, Btuh/W. This is calculated using Equation 222 below.

$$CE_t = EER_t \times SHR$$

Equation 222

Where:

EER_t = Energy efficiency ratio at current conditions, Btuh/W. EER_t is calculated using Equation 226 below.

SHR = Sensible Heat Ratio (sensible capacity / total capacity), derived as follows:

$$
\begin{aligned}
SHR = \text{minimum}(1,\; & A_{SHR} \times DB_{ec} + \\
& B_{SHR} \times WB_{ec} + \\
& C_{SHR} \times DB_t + \\
& D_{SHR} \times CFM_{per\ ton} + \\
& E_{SHR} \times DB_{ec} \times DB_t + \\
& F_{SHR} \times DB_{ec} \times CFM_{per\ ton} + \\
& G_{SHR} \times WB_{ec} \times DB_t + \\
& H_{SHR} \times WB_{ec} \times CFM_{per\ ton} + \\
& I_{SHR} \times DB_t \times CFM_{per\ ton} + \\
& J_{SHR} \times WB_{ec}^2 + \\
& K_{SHR} / CFM_{per\ ton} + \\
& L_{SHR})
\end{aligned}
$$

SHR coefficients:

A_{SHR}	0.0242020
B_{SHR}	-0.0592153
C_{SHR}	0.0012651
D_{SHR}	0.0016375
E_{SHR}	0
F_{SHR}	0
G_{SHR}	0
H_{SHR}	-0.0000165
I_{SHR}	0
J_{SHR}	0.0002021
K_{SHR}	0
L_{SHR}	1.5085285

CAP_{nf} = Total cooling capacity across coil (that is, without fan heat) at current conditions, Btuh

$$CAP_{nf} = (Cap95 + QFan_{rat}) \times F_{chg} \times F_{size} \times F_{cond_{cap}}$$

Equation 223

$$
\begin{aligned}
F_{cond\_cap} = \; & A_{CAP} \times DB_{ec} + \\
& B_{CAP} \times WB_{ec} + \\
& C_{CAP} \times DB_t +
\end{aligned}
$$

$D_{CAP} \times CFM_{per\ ton}$ +
$E_{CAP} \times DB_{ec} \times DB_t$ +
$F_{CAP} \times DB_{ec} \times CFM_{per\ ton}$ +
$G_{CAP} \times WB_{ec} \times DB_t$ +
$H_{CAP} \times WB_{ec} \times CFM_{per\ ton}$ +
$I_{CAP} \times DB_t \times CFM_{per\ ton}$ +
$J_{CAP} \times WB_{ec}^2$ +
$K_{CAP} / CFM_{per\ ton}$ +
L_{CAP}

Coefficients as follows:

SHR Condition	SHR < 1	SHR = 1
A_{CAP}	0	0.009483100
B_{CAP}	0.009645900	0
C_{CAP}	0.002536900	-0.000600600
D_{CAP}	0.000171500	-0.000148900
E_{CAP}	0	-0.000032600
F_{CAP}	0	0.000011900
G_{CAP}	-0.000095900	0
H_{CAP}	0.000008180	0
I_{CAP}	-0.000007550	-0.000005050
J_{CAP}	0.000105700	0
K_{CAP}	-53.542300000	-52.561740000
L_{CAP}	0.381567150	0.430751600

Source: NORESCO for California Energy Commission

CAP_{sen} = Sensible capacity including fan heat, Btuh

$$CAP_{sen} = CAP_{nf} \times SHR - QFan_{op}$$

Equation 224

CAP_{lat} = Latent capacity, Btuh

$$CAP_{lat} = CAP_{nf} - CAP_{sen}$$

Equation 225

Note: The air leaving the AC unit is limited to 95% relative humidity. If that limit is invoked, CAP_{lat} is reduced and CAP_{sen} is increase.

EER_t is calculated as follows:

When

DB_t £ 82 ºF	$EER_t = SEER_{nf}$
82 < DB_t < 95 °F	$EER_t = SEER_{nf} + ((DB_t - 82)*(EER_{nf} – SEER_{nf}) / 13)$
DB_t ³ 95 °F	$EER_t = EER_{nf}$

Equation 226

Where:

$SEER_{nf}$ = Seasonal energy efficiency ratio at current conditions without distribution fan consumption (“nf” = no fans). This is calculated using Equation 227.

EER_{nf} = Energy efficiency ratio at current conditions without distribution fan consumption (“nf” = no fans) and adjusted for refrigerant charge and airflow. This is calculated using Equation 228.

$$SEER_{nf} = \frac{F_{chg} \times F_{size} \times F_{cond_{SEER}} \times (1.09 \times Cap95 + QFan_{rat})}{1.09 \times Cap95/SEER - QFan_{rat}/3.413}$$

Equation 227

$$\begin{aligned}
F_{cond_SEER} = F_{cond_cap} / \quad (&A_{SEER} \times DB_{ec} + \\
&B_{SEER} \times WB_{ec} + \\
&C_{SEER} \times DB_t + \\
&D_{SEER} \times CFM_{per\ ton} + \\
&E_{SEER} \times DB_{ec} \times DB_t + \\
&F_{SEER} \times DB_{ec} \times CFM_{per\ ton} + \\
&G_{SEER} \times WB_{ec} \times DB_t + \\
&H_{SEER} \times WB_{ec} \times CFM_{per\ ton} + \\
&I_{SEER} \times DB_t \times CFM_{per\ ton} + \\
&J_{SEER} \times WB_{ec}^2 + \\
&K_{SEER} / CFM_{per\ ton} + \\
&L_{SEER})
\end{aligned}$$

Coefficients as follows:

SHR Condition	SHR < 1	SHR = 1
A_{SEER}	0	0.0046103
B_{SEER}	-0.0202256	0
C_{SEER}	0.0236703	0.0125598
D_{SEER}	-0.0006638	-0.000512
E_{SEER}	0	-0.0000357
F_{SEER}	0	0.0000105
G_{SEER}	-0.0001841	0
H_{SEER}	0.0000214	0
I_{SEER}	-0.00000812	0
J_{SEER}	0.0002971	0
K_{SEER}	-27.95672	0
L_{SEER}	0.209951063	-0.316172311

Source: NORESCO for California Energy Commission

$$EER_{nf} = \frac{Cap_{nf}}{F_{cond_{EER}} \times (Cap95/EER - QFan_{rat}/3.413)}$$

Equation 228

Where:

$$\begin{aligned} F_{cond\_EER} = \; & (A_{EER} \times DB_{ec} + \\ & B_{EER} \times WB_{ec} + \\ & C_{EER} \times DB_t + \\ & D_{EER} \times CFM_{per\ ton} + \\ & E_{EER} \times DB_{ec} \times DB_t + \\ & F_{EER} \times DB_{ec} \times CFM_{per\ ton} + \\ & G_{EER} \times WB_{ec} \times DB_t + \\ & H_{EER} \times WB_{ec} \times CFM_{per\ ton} + \\ & I_{EER} \times DB_t \times CFM_{per\ ton} + \\ & J_{EER} \times WB_{ec}^2 + \\ & K_{EER} / CFM_{per\ ton} + \end{aligned}$$

L_{EER})

Coefficients as follows:

SHR Condition	SHR < 1	SHR = 1
A_{EER}	0	0.004610300
B_{EER}	-0.020225600	0
C_{EER}	0.023670300	0.012559800
D_{EER}	-0.000663800	-0.000512000
E_{EER}	0	-0.000035700
F_{EER}	0	0.000010500
G_{EER}	-0.000184100	0
H_{EER}	0.000021400	0
I_{EER}	-0.000008120	0
J_{EER}	0.000297100	0
K_{EER}	-27.956720000	0
L_{EER}	0.015003100	-0.475306500

Source: NORESCO for California Energy Commission

1.15.2 Air-Source Heat Pump Model (Heating mode)

The air source heat pump model is based on methods presented in AHRI Standard 210/240-2008.

Primary model parameters. The following values characterize the ASHP and are constant for a given unit:

Cap47 = Rated heating capacity at outdoor dry-bulb temperature = 47 °F

COP47 = Coefficient of performance at outdoor dry bulb = 47 °F (if available, see below)

Cap35 = Heating capacity under frosting conditions at outdoor dry-bulb temperature = 35 °F (if available, see below)

COP35 = Coefficient of performance at outdoor dry bulb = 35 °F (if available, see below)

Cap17 = Rated heating capacity at outdoor dry-bulb temperature = 17 °F

COP17 = Coefficient of performance at outdoor dry bulb = 17 °F (if available, see below)

HSPF = Rated Heating Seasonal Performance Factor, Btuh/Wh

COPbu = COP of backup heating, default = 1 (electric resistance heat)

Capbu = Available backup heating capacity, Btuh

Fchgheat = Heating refrigerant charge factor, default = 0.92. For systems with verified charge indicator light (Reference Residential Appendix RA3.4) or verified refrigerant charge (Reference Residential Appendix RA3), the factor shall be 0.96

Derived model parameters.

Inp47 = Electrical input power at 47 °F = Cap47 / COP47, Btuh (not W)

Inp17 = Electrical input power at 17 °F = Cap17 / COP17, Btuh (not W)

Estimation of unavailable model parameters.

$$COP47 = (0.3038073 \times HSPF - 1.884475 \times \frac{Cap17}{Cap47} + 2.360116) \times Fchgheat$$

$$COP17 = (0.2359355 \times HSPF + 1.205568 \times \frac{Cap17}{Cap47} - 0.1660746) \times Fchgheat$$

$$Cap35 = 0.9 \times [Cap17 + 0.6 \times (Cap47 - Cap17)]$$

$$Inp35 = 0.985 \times [Inp17 + 0.6 \times (Inp47 - Inp17)]$$

$$COP35 = \frac{Cap35}{Inp35}$$

Simulation

Full-load capacity and input power of the ASHP is determined each time step as a function of outdoor dry-bulb temperature T, as follows --

If (17 °F < T < 45 °F)

$$Cap(T) = Cap17 + \frac{(Cap35 - Cap17) \times (T - 17)}{35 - 17}$$

$$Inp(T) = Inp17 + \frac{(Inp35 - Inp17) \times (T - 17)}{35 - 17}$$

Else

$$Cap(T) = Cap17 + \frac{(Cap47 - Cap17) \times (T - 17)}{47 - 17}$$

$$Inp(T) = Inp17 + \frac{(Inp47 - Inp17) \times (T - 17)}{47 - 17}$$

Resistance heat.

Load in excess of Cap(T) is met with backup heating at COPbu.

1.15.3 Equipment Sizing

CSE determines the capacity of HVAC equipment via an auto-sizing capability. Autosizing is conducted prior to the main annual simulation. It is done by using the hourly simulator for a set of design days and increasing capacity as needed to maintain thermostat set points. Each design day is repeated several times until the required capacity converges. The set of design days includes one cold day with no solar gain and several hot days at with clear-sky solar at different times of the year. This ensures that maximums of both heating and cooling loads will be found. Equipment characteristics other than capacity are specified on a per-unit basis (e.g. "cfm per ton"), so a full description of the system can be derived from the primary capacity.

The sizing procedure uses the equipment models in an inverse mode. For example, the sensible cooling load for a given set up conditions is back-converted to the required rated total capacity (Cap95) by using inverted forms of the model equations. The general simulation calculation sequence is used, but the logic of the HVAC models is altered during the autosizing phase.

Note that for air-source heat pumps, only the backup heating capacity is autosized. In addition, modeled duct sizes are not sized and must be specified.

The equipment sizes calculated by CSE are used for compliance analysis only and are not substitutes for load calculations used for selecting equipment or meeting other code requirements.

2 Compliance Manager

2.1 Overview

2.2 One-dimensional Roof Edge Heat Transfer Model

2.2.1 Construction Practice

This document describes the one-dimensional model used to represent the heat flow between the conditioned zone and the outdoors through the portion of the ceiling insulation, along the outside edge of the attic, through which the heat flows to the outdoors without passing through the attic air. This portion will be modeled in CSE as cathedral ceilings, and is referred herein as the roof edge. The rest of the heat flow path through the ceiling insulation will be modeled as part of the attic zone, and is not discussed here.

Two types of roof construction are considered, standard-heel and raised-heel trusses, shown in Figure 26 and Figure 27, with the geometries assumed to be representative of current practice. The roof trusses are assumed to be framed with 2x4's. Although the figures are for a roof with a 4-in-12 pitch, the 1-D model will handle any standard pitch. The distance between the wall plate and roof deck (shown, for example, as 12 inches in Figure 27) is also not restricted to the distances implied by Figure 26 and Figure 27.

The 1-D model is developed in order to simplify the heat transfer calculation for roof edges, while preserving the steady state and transient characteristics (layer mass) of the typical roof constructions addressed. The 1-D model produces the dimensions of the construction layers needed to represent the roof edges.

Figure 26: Standard-Heel Geometry

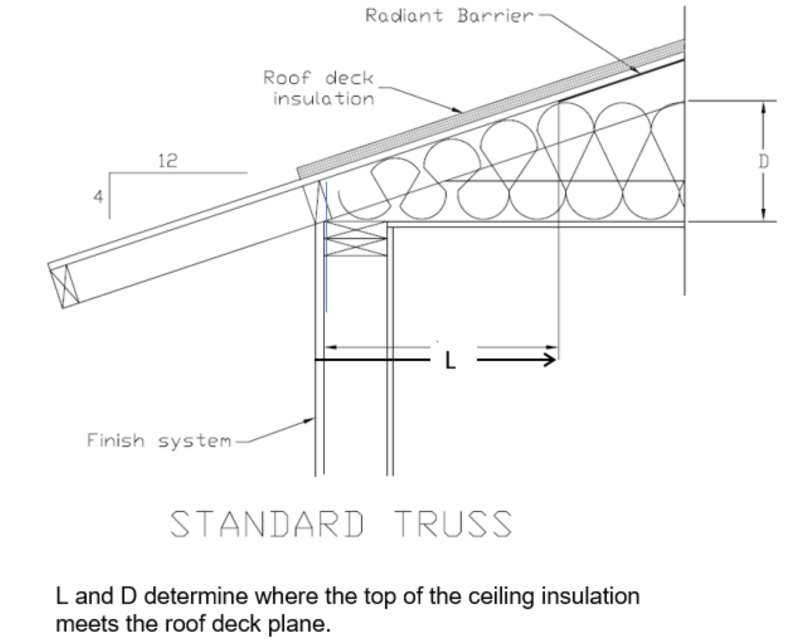
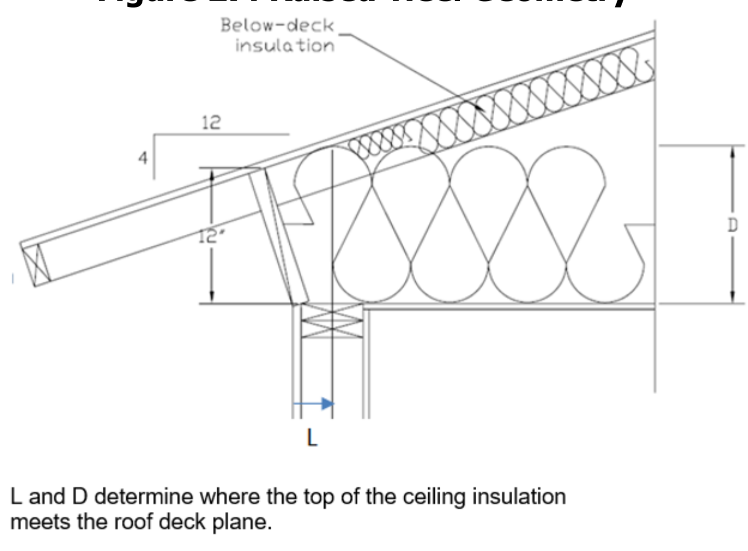


Figure 27: Raised-Heel Geometry



2.2.2 One-Dimensional Model

Using the parallel path method, the heat transfer is determined separately for the insulation and framing paths of the constructions.

First consider modeling the standard-heel truss of Figure 26.

2.2.2.1 Standard heel insulation path

For the path through the insulation, Figure 26 is approximated as the simpler 2-D configuration of Figure 28 and Figure 30, with the left vertical edge assumed to be adiabatic and of height Y. The right vertical edge is also assumed to be adiabatic. To partly compensate for not allowing heat flow out the left side tilted edge board in Figure 26, the ceiling is assumed to extend to the outer edge of the vertical wall.

The width, W_A of roof edge path A, is taken as the width of the vertical path of solid wood in the framing section view of Figure 30.

Figure 28: Standard-Heel Simplified Geometry for Insulation Path

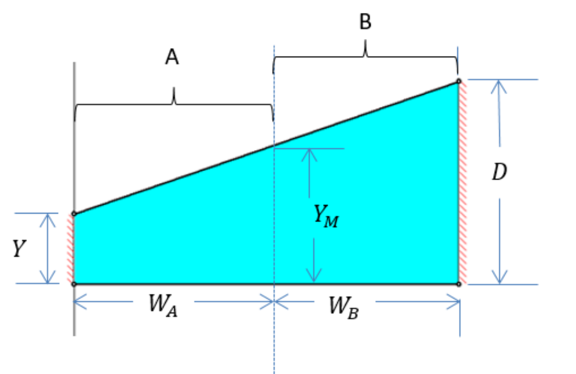
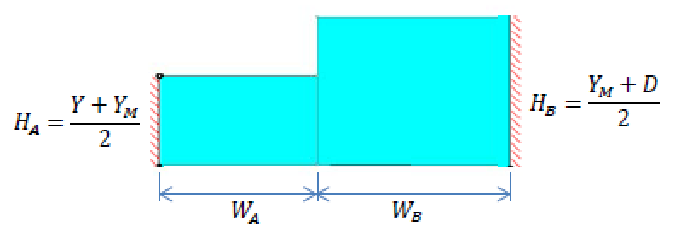


Figure 28 is then reduced to the 1-D form shown in Figure 29, where the layer thicknesses are taken as the average height of the layer in Figure 28.

Figure 29: Standard-Heel 1-D Geometry for Insulation Path



The left hand portion represents the insulation path of the 1-D model of roof edge A. The right side represents the insulation path of the 1-D model of roof edge B.

The 1-D model just considers the ceiling insulation and framing. When implemented as part of a cathedral ceiling in CSE, a sheetrock layer would be added to the bottom of Figure 29 paths. Layers added to the tops of the layers in Figure 29 would be decking, asphalt shingles, and tile, for example.

2.2.2.2 Standard heel framing path

Similar to the insulation path, the framing heat transfer path starts with Figure 30, which is reduced to Figure 31. The widths of A and B are the same as for the insulation path figures. H_{B1}, and H_{B3} are the vertical thickness of the 2x4's and H_{B2} is the average thickness of insulation.

Figure 30: Standard-Heel Simplified Geometry for Framing Path

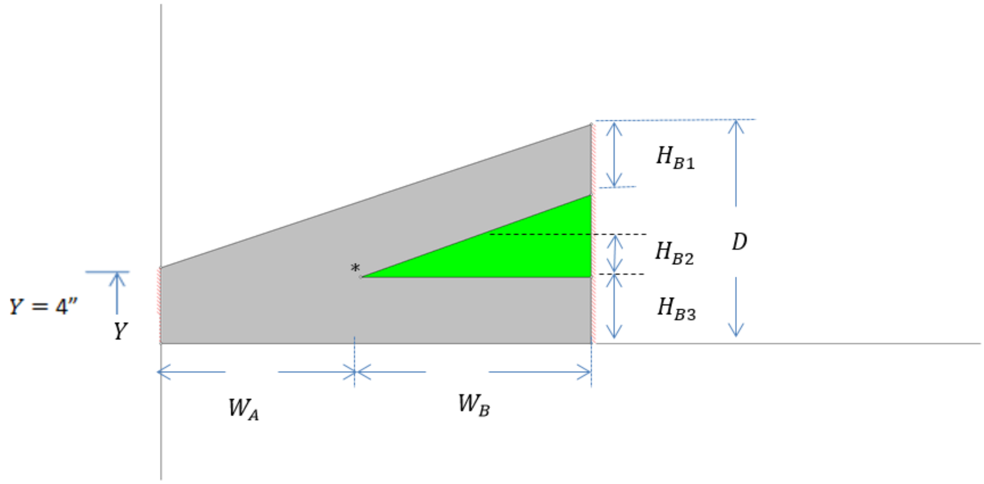
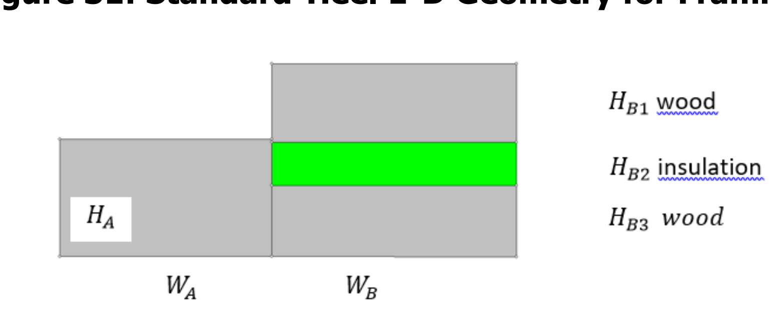


Figure 31: Standard-Heel 1-D Geometry for Framing Path



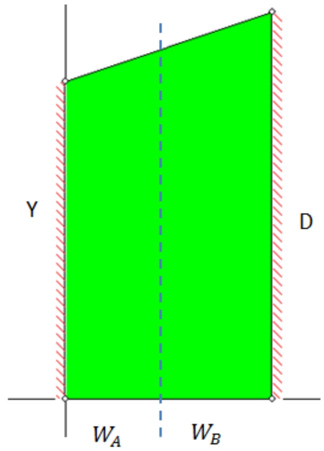
2.2.2.3 Raised heel

The 1-D model for the raised-heel case of Figure 27 is different than for the standard-heel case of Figure 26. The geometry is illustrated in Figure 32 and Figure 33 for a ceiling insulation of R38.

As the edge height, Y, in Figure 30 is increased, the deck and ceiling 2x4's separate vertically near the roof edge, and a vertical 2x4 is assumed to fill the gap. That is, as Y is increased, the standard truss geometry of Figure 28 and Figure 30 morphs into the raised truss geometry of Figure 32 and Figure 33. The 1-d roof edge algorithm below, gives the layering outputs for both the standard-heel truss and the raised-heel truss and everything in between.

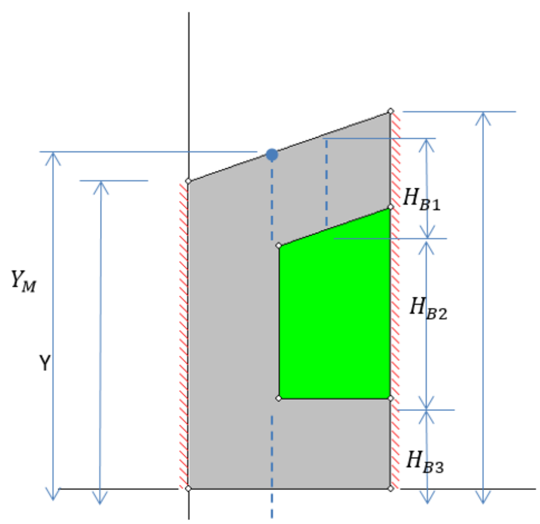
2.2.2.4 Raised heel insulation path

Figure 32: Raised-Heel 1-D Insulation Path Geometry



2.2.2.5 Raised heel frame path

Figure 33: Raised-Heel 1-D Framing Path Geometry



H_{B1}, and H_{B3} are the vertical thickness of the 2x4's and H_{B2} is the average thickness of insulation.

2.2.2.6 Roof edge algorithm

The following algorithm, written in succinct pseudo-code form, determines the layer widths and thicknesses for roof edge paths A and B. [This algorithm is implemented in RoodEdgeAlgorithm-1.xlsx].

All dimensions are assumed to be feet.

Input:

Y = edge height, ft.

w = framing width, ft. [nominally (3.5/12)-ft]

$Rtot$ = total R value of ceiling insulation, hr-ft^2-F/Btu.

R_{perin} = R value of the ceiling insulation for one inch thickness, hr-ft^2-F/Btu.

P = pitch = rise/12

Calculation of $\mathbf{W_A, W_B, H_A, H_B, H_{B1},\ H_{B2}, and\ H_{B3}}$:

$D = \frac{Rtot}{12*R_{perin}}$ insulation depth, ft

$Y_I = w\left(1 + \sqrt{1 + P^2}\right)$ vertical thickness at position $x = X_I$.

$X_I = \frac{Y_I - Y}{P}$ horiz distance from left edge to intersection of deck and ceiling 2x4's (see * in Figure 30). In Figure 33, the corresponding point would be outside the roof section, and near the left edge of the page, and as opposed to the * point, this X_I will is a negative number since it is to left of origin at outside surface of top wall plate.

IF $X_I \geq w$:

$Y_M = Y_I$ Y_M is the height of roof section at the vertical line between A and B.

ELSE $X_I < w$:

$Y_M = (w - X_I)P + Y_I$

END IF

IF $D \geq Y_M$:

$$W_B = \frac{D - Y_M}{P}$$

$$H_A = \frac{Y + Y_M}{2}$$

$$H_B = \frac{Y_M + D}{2}$$

$$H_{B1} = w\sqrt{1 + P^2}$$

$$H_{B2} = H_B - Y_I$$

$$H_{B3} = w$$

IF $X_I \geq w$:

$W_A = X_I$

ELSE $X_I < w$:

$W_A = w$

END IF

ELSE IF $D < Y_M$ AND $D > Y$:

$$W_A = \frac{D - Y}{P}$$

$$H_A = \frac{D + Y}{2}$$

$W_B = H_B = H_{B1} = H_{B2} = H_{B3} = 0$

ELSE (D ≤ Y)

$W_A = H_A = 0$

$W_B = H_B = H_{B1} = H_{B2} = H_{B3} = 0$

END IF

PRINT OUTPUT: $W_A, W_B, H_A, H_B, H_{B1}, H_{B2}, H_{B3}$

2.2.3 Roof Edge Model Validation

The roof edge heat transfer is basically a 3-D problem. The 1-D model makes a number of simplifications. For example, the parallel insulation and framing path assumption ignores lateral heat transfer between the insulation and framing path, and leads to an underestimation of the overall heat transfer. The assumption of an adiabatic right hand border, where in reality the heat flow lies are not quite vertical, also underestimates the heat transfer through the cathedral ceilings with an accompanying overestimation of the remaining heat transfer through the attic portion of the ceiling insulation. The assumption of the layer thicknesses taken as the average layer thickness ignores 2-D effects. The complicated 2-D heat transfer at the junction of the vertical wall and roof is simplified by assuming the left border is adiabatic, and the ceiling continuation to the outside of the wall. Corner effects for the roof edge, where vertical walls meet at right angles, results in a 3-D heat flow situation that can only be estimated.

Because of these complexities, it is difficult to assess the accuracy of the 1-D model.

However, in order to obtain some perspective on the accuracy of the 1-D model, the heat transfer was calculated for two cases, of different insulation depths, using both the 1-D roof edge algorithm, and a 2-D (using FEHT finite-element program) solution with the roof edge 2-D geometry of Figure 26. The 2-D model still requires many of the assumptions made in the 1-D model, including the parallel path assumption.

2.2.3.1 1-D model, Rtot = 30, Y = 4-inches

Using the 1-D Roof Edge Algorithm, the heat transfer rates through roof edges A and B was calculated for the following inputs.

Input to Roof Edge Algorithm

$\mathrm{R_{tot}} = 30$ hr-ft^2-F/Btu.

$\mathrm{P} = \frac{4}{12}$

Y = 0.3333 ft

w = 0.2917 ft

R_{perin} = 2.6 hr-ft^2-F/Btu.

Output of Roof Edge Algorithm

$\mathrm{W_A}$ =0.797 ft

$\mathrm{W_B} = 1.087$ ft

$\mathrm{H_A}$ =0.466 ft

$\mathrm{H_B}$ =0.780 ft

$\mathrm{H_{B1}} = 0.292$ ft

$\mathrm{H_{B2}} = 0.182$ ft

$\mathrm{H_{B3}} = 0.307$ ft

Insulation Path Results

The insulation conductivity is $k = \frac{1}{12R_{perin}} = 0.03205$ Btu/hr-ft-F.

The thermal resistance of A and B are:

$$R_A = \frac{H_A}{k_{insul}} = 14.546 \text{ hr-ft}^2\text{-F/Btu}$$

$$R_B = \frac{H_B}{k_{insul}} = 24.346 \text{ hr-ft}^2\text{-F/Btu}$$

If no additional layers are added (sheetrock, etc.), and the top and bottom surface temperature difference is 100 F, the heat transfer rate in this case, per foot of roof perpendicular to the section, becomes:

$$Q_A = \frac{W_A * \Delta T}{R_A} = \frac{0.797 * 100}{14.546} = 5.48 \text{ Btu/hr-ft}$$

$$Q_B = \frac{W_B * \Delta T}{R_B} = \frac{1.087 * 100}{24.346} = 4.465 \text{ Btu/hr-ft}$$

The total is:

$Q_{insulpath} = Q_A + Q_B =$ 9.944 Btu/hr-ft

Framing Path Results

Assume wood framing conductivity k = 0.084 hr-ft-F/Btu.

The thermal resistance of A, per foot of roof edge perpendicular to the section:

$R_A = \frac{H_A}{k_{wood}} =$ 5.55 hr-ft^2-F/Btu

The thermal resistance of path B; sum of layer resistances:

$R_B = \frac{H_{B1}}{k_{wood}} + \frac{H_{B2}}{k_{insul}} + \frac{H_{B3}}{k_{wood}} =$ 3.66+5.654+3.473=12.786 hr-ft^2-F/Btu

The sum of the heat transfers in this case is (from CathedralWorksheet.xlsx).

$$Q_A = \frac{W_A * \Delta T}{R_A} = \frac{0.797 * 100}{5.550} = 14.36$$

$$Q_B = \frac{W_B * \Delta T}{R_B} = \frac{1.087 * 100}{12.786} = 8.50$$

$Q_{framingpath} = Q_A + Q_B =$ 22.86 Btu/hr-ft

2.2.3.2 1-D model, Rtot = 60, Y = 4-inches

Input to Roof Edge Algorithm

Rtot = 60; other inputs the same as in Rtot = 30 case above.

Output of Roof Edge Algorithm

$W_A =$ 0.797 ft

$W_B =$ 3.972 ft

$H_A =$ 0.466 ft

$H_B =$ 1.261 ft

$H_{B1} = 0.292$ ft

$H_{B2} =$ 0.662 ft

$H_{B3} =$ 0.307 ft

Insulation Path Results

Similar to the Rtot = 30 case, the thermal resistance of A and B are:

$R_A = \frac{H_A}{k_{insul}} = 14.546$ hr-ft^2-F/Btu

$R_B = \frac{H_B}{k_{insul}} = 39.346$ hr-ft^2-F/Btu

The heat transfer rates are:

$$Q_A = \frac{W_A * \Delta T}{R_A} = \frac{0.797 * 100}{14.546} = 5.48$$

$$Q_B = \frac{W_B * \Delta T}{R_B} = \frac{3.972 * 100}{39.346} = 10.095$$

$Q_{framingpath} = Q_A + Q_B =$ 15.57 Btu/hr-ft

Framing path results

The thermal resistance of A, per foot of roof edge perpendicular to the section:

$R_A = \frac{H_A}{k_{wood}} = 5.55$ hr-ft^2-F/Btu

The thermal resistance of path B is the sum of layer resistances. k = 0.084 hr-ft-F/Btu is assumed.

$R_B = \frac{H_{B1}}{k_{wood}} + \frac{H_{B2}}{k_{insul}} + \frac{H_{B3}}{k_{wood}}$ =hr-ft^2-F/Btu

$= 3.472$ + 20.66 + 3.66 = 27.79

The sum of the heat transfers in this case is:

$$Q_A = \frac{W_A * \Delta T}{R_A} = \frac{0.797 * 100}{5.55} = 14.36$$

$$Q_B = \frac{W_B * \Delta T}{R_B} = \frac{3.972 * 100}{27.79} = 14.29$$

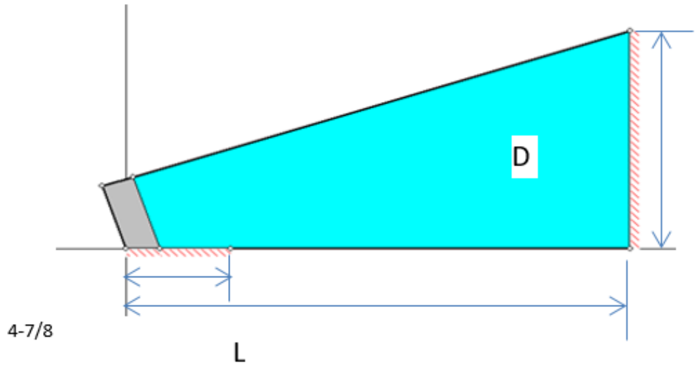
$Q_{framingpath} = Q_A + Q_B =$ 28.65 Btu/hr-ft

2.2.3.3 2-D Model, Rtot = 30, Y = 4-inches

Insulation Path

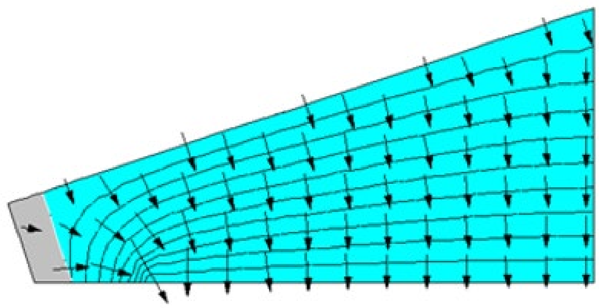
The Figure 26 case is modeled with the simplified geometry of Figure 34, shown for a ceiling insulation of R30. The top of the plate capping the vertical wall is assumed to be adiabatic. The tilted block assumed to be wood, exposed to ambient conditions on its outside sides. The outside of the wood and insulation assumed to be at a uniform 100F. The ceiling side of the insulation is set to at 0 F. The same material properties were used as in the 1-D model.

Figure 34: Standard Truss, Insulation Path, 2-Dimensional Heat Transfer Model Geometry



The resulting isotherms and heat transfer vectors are shown in Figure 35.

Figure 35: Standard-Heel, Insulation Path, 2-Dimensional Heat Transfer Isotherms and Heat Transfer Vectors



The overall heat transfer, per foot of perimeter, for this case was determined (RUN std30.FET) to be:

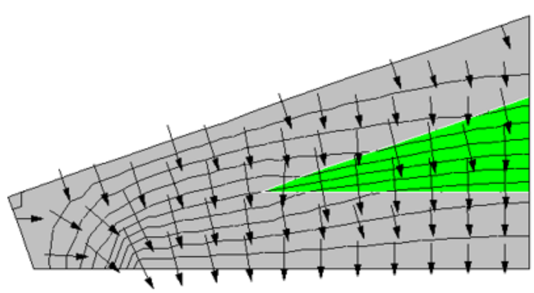
$$Q = 9.67 \text{ Btu/hr-ft}$$

Equation 229

Framing Path

The frame path was modeled similarly, with the Figure 36 graphic results.

Figure 36. Standard-Heel, Frame Path, 2-Dimensional Heat Transfer Isotherms and Heat Transfer Vectors



The overall heat transfer, per foot of perimeter, for this case was determined (RUN std30F.FET) to be:

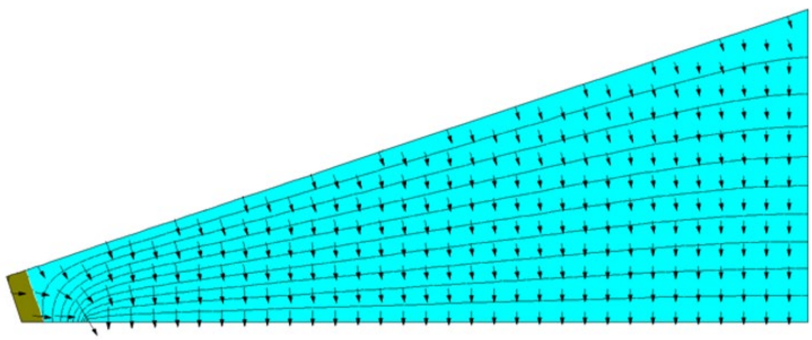
Q = 21.94 Btu/hr-ft

Equation 230

2.2.3.4 2-D Model, Rtot = 60, Y = 4-inches

Similar to the R30 case above, Figure 37 and Figure 38 show the insulation and framing path 2-D results.

Figure 37: 2-D Results for Insulation Path of R-60 Standard-Heel

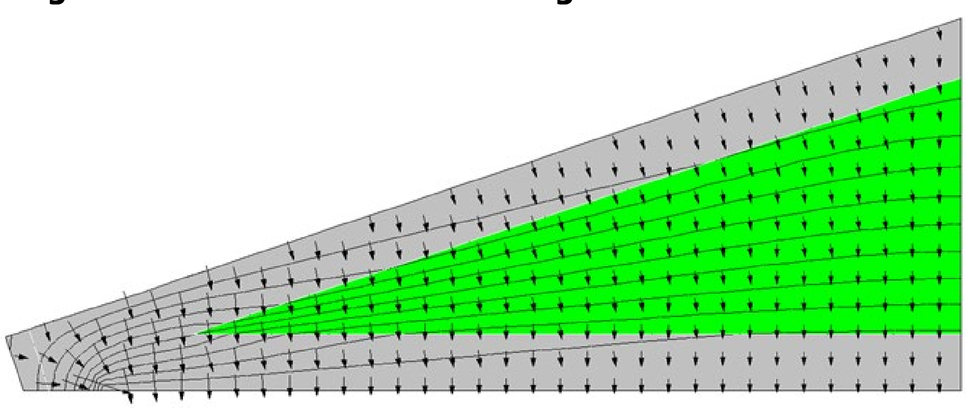


The overall heat transfer, per foot of perimeter, for this case was determined (RUN: std60.fet) to be:

Q = 16.342 Btu/hr-ft

Equation 231

Figure 38: 2-D Results for Framing Path of R-60 Standard-Heel



The overall heat transfer, per foot of perimeter, for this case was determined (RUN: std60F.FET) to be:

Q = 31.543 Btu/hr-ft

Equation 232

2.2.3.5 Comparison of 1-D and 2-D results

The above 2-D results are compared with the simplified 1-D model in Table 8.

Table 8: Comparison of 1-D and 2-D Results

	R-30 Ceiling Insulation Path	R-30 Ceiling Framing Path	R-60 Ceiling Insulation Path	R-30 Ceiling Framing Path
Q_{1D}	9.94	22.86	15.57	28.65
Q_{2D}	9.67	21.94	16.34	31.543
Q_{1D} is	$3\% > Q_{2d}$	$4\% > Q_{2d}$	$5\% < Q_{2d}$	$9\% < Q_{2d}$

Source: NORESCO for California Energy Commission

Because the 2-D model used is itself of limited accuracy considering the numerous approximations made, the above results are not considered to be definitive. However they do indicate that a number of the assumptions made in the 1-D model are reasonably accurate. While this comparison is limited to steady state heat transfer performance, mass effects are expected to have comparable accuracy.

2.3 How to Build an Airnet

2.3.1 Background

2.3.2 Approach

IZXFER is the building block input for an Airnet. There will be many IZXFERs in an input file, each representing a single air transfer object (leak, vent, window, fan, duct leak). Each IZXFER needs a unique name if detailed reports on its activity are needed. IZXFER is a command at the same level as HOLIDAY.

MATERIAL, CONSTRUCTION, METER, ZONE and REPORT which means that it can be located anywhere except inside another object (like a zone).

The main objects in the Airnet are:

- Infiltration
- Window ventilation
- IAQ ventilation
- Mechanical cooling ventilation
- Duct leakage

Units are ft^2.

CBECC inputs to add for Airnet:

Input	Description
WinHHTop	Head height of the highest windows in the zone. Used to get the vertical location of the window ventilation holes. In the development program this was done on a building wide basis: #define WnHeadHeight 7.67 // Average head height above the floor of operable windows
Ventilation Height Difference	This rule needs to be changed to refer to Zone instead of Building: "The default assumption for the proposed design is 2 feet for one story buildings and 8 feet for two or more stories. Greater height differences may be used with special ventilation features such as high, operable clerestory windows. In this case, the height difference entered by the user is the height between the average center height of the lower operable windows and the average center height of the upper operable windows. Such features shall be fully documented on the building plans and noted in the Special Features Inspection Checklist of the CF-1R." (2008 RACM pp 3-9)
Floor Height	The height of each floor over outdoors, crawl or garage is needed to set the Z dimension of the hole in the floor.
Soffit height	The height of the attic floor. Probably can be determined by the height of the ceiling below attic. Trouble for Split level?
Interzone Door	May need input for whether an interzone door exists between each 2 conditioned zones. Assuming it for now.
ReturnRegister	The conditioned zone(s) where the return/exhaust register is located. Make this an input on the HVAC System Data screen

2.3.2.1 Problems

- The window scheme doesn't work for 3 story zones!!!
- The Econ and NightBreeze cooling ventilation systems are multizone and use ducts. I suggest we set them up as part of the duct system.

2.3.3 Inputs

Input	Description
ACH50	7.6 (Air Changes per Hour at 50 Pascals pressure difference that leak through the envelope of the conditioned zones)
Avent	1/300 (ratio of "free area of attic vents to AceilGross)
Fraction High	0.3 (fraction of the attic vent area located in the upper part of the attic, check precise definition)

1. *Infiltration Setup.* Infiltration is uncontrolled air leakage through the cracks and intentional vents in the building. The first step is to determine the total size of the openings and then distribute them over the conditioned zones in proportion to surface areas.

   It is modeled in a single conditioned zones with 8 holes (IZXFERs) to represent the leakage in vertical walls and 1 hole each in the floor and ceiling.

   Calculate:

   a. For conditioned zones the total Effective Leakage Area ELAtot = CFA*ACH50/(2*10000) (CFA is conditioned floor area)
   b. Determine Envelope Areas
      1. ExCeiltotSF =sum (AceilGross + area of exterior ceilings) (exterior ceilings are surfaces in conditioned zones of type ceiling whose outside condition is Ambient, Ignore Knee walls for infiltration (walls between the conditioned zone and the attic)
      2. ExWalltotSF =sum (Gross Area of Exterior Walls) (walls in conditioned zones whose outside condition is Ambient)
      3. ExFloortotSF =sum (Gross Area of Exterior floors) (floors in conditioned zones whose outside condition is Ambient, Crawl or GROUND)
      4. ExFloorSlabSF =sum (Gross Area of Exterior slab on grade floors) (slab on grade floors in conditioned zones)
      5. SlabRatio =ExFloorSlabSF/ExFloortotSF
      6. GaragetotSF =sum (Gross Area of Surfaces to Garage) (walls and floors in conditioned zones whose outside condition is Garage)
   c. Determine leakage distribution:
      1. ELAceilsf = ELAtot* (.4+.1*SlabRatio)/(AceilGross + area of exterior ceilings)
      2. ELAraisedFloorsf = ELAtot* (.2* 1-SlabRatio)/(ExFloortotSF-ExFloorSlabSF)

   #If there is a garage zone

      1. ELAGaragesf = ELAtot* 0.1/GaragetotSF
      2. ELAwallsf = ELAtot* (.3 + .1*SlabRatio)/ExWalltotSF

      #Else

      3. ELAGaragesf = 0
      4. ELAwallsf = ELAtot* (.4 + .1*SlabRatio)/ExWalltotSF

   #endif

2. *Cooling Ventilation Setup:* Four types: Windows only (all types have windows for some part of the year), Whole house fan, Smart Vent, NightBreeze

   Set up seasonal window control

   #if Smart Vent or NightBreeze //Windows are on in Winter, but off in summer when mechanical ventilation is on

   #redefine Windowmode select(@weather.taDbAvg07 >60., 0.00001,default 1.)

   #define VentDiffMult select(@top.tDbOSh < (@znRes[Single].prior.S.tAir-VentDiff), 1,default 0.000001) //Vent off if Tin-Vendiff > Tout

   #Else //everything but Econ and NightBreeeze Windows are on year round

   #reDefine Windowmode 1.//Always available

   #Define VentDiff 0 // Differential. No differential for windows or WWF

   // multiplier for window and whole house fan vent availability, .00001 is proxy for Off Revised to start at dawn end at 11 PM.

   #redefine Win_hr select($hour < 24, select($radDiff <1., select($hour>12,1.0, default .00001), default 1.0), default .00001)

3. *Airnet for Each Conditioned Zone:*
   a. Calculate

      ELA_Aceil(zone) = ELAceilsf * AceilGross(zone)

      ELA_Xceil(zone) = ELAceilsf * (AEdge(zone) + area of exterior ceilings(zone)) //AEdge is determined in the Ceiling Surface setup BAW 120517

      ELAXwall(zone) = ELAwallsf * Gross Area of Exterior Walls(zone)

      ELAGwall(zone) = ELAGaragesf * Gross Area of walls and floors next to the Garage(zone)

      ELAfloor(zone) = ELAraisedFloorsf * AreaExtfloor(zone) (gross area of floors whose outside condition is Ambient, Crawl)

      ZoneBotZ = Bottom(zone) - height of the lowest floor in the zone

      ZoneTopZ = ZoneBotZ + FloortoFloor(zone)*NumofStories(zone)

      ZoneHeightZ = ZoneTopZ - ZoneBotZ

      WinHHTop = ZoneBotZ + FloortoFloor(zone)*(NumofStories(zone)-1) + Window head height

b. Exteror wall of conditioned zones infiltration objects Calculate height of bottom and top holes.

// All infiltration leaks in walls are assumed to be spread uniformly over the exposed wall surfaces areas. There are no LEAKS associated with windows, doors etc.

//8 Wall Holes in each zone to Outdoors 1 upwind, 2 side walls, 1 downwind. Sidewalls are identical so combine them into 1 hole with 2*area

// Low is at 1/4 of wall height, high is at 3/4 of wall height

// izCpr (default = 0) = Wind Coef Upwind wall +0.6 Side walls -0.65 Downwind Wall -0.3

ELAXwall(zone) = ELAwallsf * Gross Area of Exterior Walls(zone)

WH = ELAXwall(zone)*1.45/8 //Wall Hole size. Conversion from ELA to airnet infiltration opening is 1.45*

Write Airnet Objects to CSE Input WlLU stands for Wall Low Upwind etc.

IZXFER (ZoneName)WlLU izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = WH izHD = ZoneBotZ + (0.25 * ZoneHeightZ) izNVEff = 1 izExp=0.65 izCpr=0.6

IZXFER (ZoneName)WlLS izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = 2*WH izHD = ZoneBotZ + (0.25 * ZoneHeightZ) izNVEff = 1 izExp=0.65 izCpr=-.65

IZXFER (ZoneName)WlLD izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = WH izHD = ZoneBotZ + (0.25 * ZoneHeightZ) izNVEff = 1 izExp=0.65 izCpr=-0.3

IZXFER (ZoneName)WlHU izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = WH izHD = ZoneBotZ + (0.75 * ZoneHeightZ) izNVEff = 1 izExp=0.65 izCpr=0.6

IZXFER (ZoneName)WlHS izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = 2*WH izHD = ZoneBotZ + (0.75 * ZoneHeightZ)izNVEff = 1 izExp=0.65 izCpr=-.65

IZXFER (ZoneName)WlHD izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = WH izHD = ZoneBotZ + (0.75 * ZoneHeightZ) izNVEff = 1 izExp=0.65 izCpr=-0.3

c. Windows

// Operable window openings for ventilation. Assumes effect of screens is included in open area Revised 120409 BAW

// IZXFER izALo and izAHi are the min and max vent areas. Both are hourly.

//8 Window Holes in zone Single to Outdoors Assumes no orientation so 1/4 each orientation, 1/8 low and 1/8 high. Sidewalls are identical so combine them into 1 hole with 2*area

// high is at 1/2 default Hdiff below Window WinHHTop, Low is at WinHdiff below.high

//Note that this scheme doesn't work for 3 story zones!!!

Inputs

WnVentArea	// ft2, Nonzero - operable window open area. Default is 10 percent of the window area. Assume a single window is 4 feet high with openings centered at -1 and -3' from the top
WnVentHDiff 2.0	// Window vent height difference between center of high opening and low opening
WinHHTop	// Head height of highest windows in the zone

Calculate

WnHole = 0.5*(WnVentArea/8.)*Win_hr*Windowmode // 1/8th in each hole, ft2. 1/2 of nominal area to account for screens etc. Hourly and seasonal availability

Write Airnet Objects to CSE Input WnLU stands for Window Low Upwind etc

IZXFER (ZoneName)WnLU izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = WnHole izHD = WinHHTop -(3+ WnVentHDiff) izNVEff =.5 izCpr=0.6

IZXFER (ZoneName)WnLS izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = 2*WnHole izHD = WinHHTop - (3+WnVentHDiff) izNVEff =.5 izCpr=-.65

IZXFER (ZoneName)WnLD izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = WnHole izHD = WinHHTop - (3+WnVentHDiff) izNVEff =.5 izCpr=-0.

IZXFER (ZoneName)WnHU izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = WnHole izHD = (WinHHTop-1) izNVEff =.5 izCpr=0.6

IZXFER (ZoneName)WnHS izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = 2*WnHole izHD = (WinHHTop-1) izNVEff =.5 izCpr=-.65

IZXFER (ZoneName)WnHD izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo=.00001 izAHi = WnHole izHD = (WinHHTop-1) izNVEff =.5 izCpr=-0.3

d. Ceiling

Calculate

If ceiling below attic

ELA_Aceil(zone) = ELAceilsf * AceilGross(zone) //knee walls to attic not included in determining the conditioned to attic leakage distribution of

If Whole House fan, Ceiling leak through WWF when off

If Improved WHFela = .05 // Average of Motor Damper Models

else WHFela = .11 // Average of Gravity Damper Models

If ceiling to outside

ELA_Xceil(zone) = ELAceilsf * AEdge(zone) + area of exterior ceilings(zone)

CeilHole = (ELA_Aceil(zone) + WHFela)*1.45//Ceil Hole size. Conversion from ELA to airnet infiltration opening is 1.45*

CathCeilHole = ELA_Xceil(zone) * 1.45 //Cathedral Ceil Hole size. Conversion from ELA to airnet infiltration opening is 1.45*

Write Airnet Objects to CSE Input

IZXFER (ZoneName)xAttic izNVTYPE = AirNetIZ izZN1=(ZoneName) izALo=CeilHole izHD = ZoneTopZ izNVEff=1. izExp=0.65 izZN2 = Attic

IZXFER (ZoneName)CC izNVTYPE = AirNetExt izZN1=(ZoneName) izALo=CathCeilHole izHD = ZoneTopZ izNVEff=1. izExp=0.65

e. Floor over outside

For each floor over outside calculate:

ELAfloor(Name) = ELAraisedFloorsf * AreaExtfloor * 1.45 (floors whose outside condition is Ambiant)

Write Airnet Object to CSE Input

IZXFER (Name) izNVTYPE = AirNetExt izZN1 = (ZoneName) izALo = ELAfloor(Name) izHD = Floor Height izNVEff = 1 izExp=0.65 izCpr=0. // located at the Extfloor elevation, no wind effect

f. Floor over Crawl

For each floor over outside calculate:

ELAfloor(Name) = ELAraisedFloorsf * AreaCrawlfloor * 1.45 (floors whose outside condition is Crawl)

Write Airnet Object to CSE Input

IZXFER (Name)xCrawl izNVTYPE = AirNetIZ izZN1=(ZoneName) izALo=ELAfloor(Name) izHD = Floor Height izNVEff=1. izExp=0.65 izZN2 = Crawl

g. Floor over Garage

For each floor over garage calculate:

ELAfloor(Name) = ELAGaragesf * AreaGarfloor * 1.45 (floors whose outside condition is Garage)

Write Airnet Object to CSE Input

IZXFER (Name)xGarage izNVTYPE = AirNetIZ izZN1=(ZoneName) izALo=ELAfloor(Name) izHD = Floor Height izNVEff=1. izExp=0.65 izZN2 = Garage

h. Garage wall

Calculate:

GWH	= ELAGaragesf * Gross Area of walls next to the Garage(zone)/2 // size of the 2 holes (high and low) betwen zone and garage
GWalltopZ	= Min(ZoneTopZ(zone),(ZoneTopZ(Garage)) //The top of the shared wall
GWallBotZ	= Max(ZoneBotZ(zone),(ZoneBotZ(Garage)) //The bottom of the shared wall
GwallH	= GWalltopZ - GWallBotZ // Height of shared wall
GWHhZ	= GwallBotZ + .75 GwallH // Height of top hole
GWHlZ	= GwallBotZ + .25 GwallH // Height of bottom hole

Write Airnet Objects to CSE Input

IZXFER (ZoneName)xGarageH izNVTYPE = AirNetIZ izZN1=(ZoneName) izALo=GWH izHD = GWHhZ izNVEff=1. izExp=0.65 izZN2 = Garage

IZXFER (ZoneName)xGarageL izNVTYPE = AirNetIZ izZN1=(ZoneName) izALo=GWH izHD = GWHlZ izNVEff=1. izExp=0.65 izZN2 = Garage

4. Airnet for Each Unconditioned Zone:

a. Attic

If Ventilated attic Calculate (4 soffit vents at attic floor elevation plus sloped deck vents at 2/3 of Attic high if frac high > 0

// Pitch types for roof wind pressure coeffs: 0 deg, <10deg, <15 deg,<25, <35 ,all the rest. Flat same as low slope.

#define PitchType select(Pitch <= 0, 1,Pitch <= 0.18, 1,Pitch <= 0.27, 2,Pitch <= 0.47, 3,Pitch <= 0.7, 4,default 5)

AventTot = AceilGross * AVent

SoffitVent 0.5*0.25 *(1.-FracHigh)*Max(AventTot, AtticRelief) //Attic relief is minimum vent needed to vent mechanical cooling air dumped to attic

Deckvent 0.5*0.25*FracHigh*Max(AventTot, AtticRelief)

If sealed attic [to be developed]

Write Airnet Objects to CSE Input

IZXFER AtticSU izNVTYPE = AirNetExt izZN1 = Attic izALo = SoffitVent izHD = SoffitHeight izNVEff = .6 izExp=0.65 izCpr=0.6

IZXFER AtticSS izNVTYPE = AirNetExt izZN1 = Attic izALo = 2*SoffitVent izHD = SoffitHeight izNVEff = .6 izExp=0.65 izCpr=-.65

IZXFER AtticSD izNVTYPE = AirNetExt izZN1 = Attic izALo = SoffitVent izHD = SoffitHeight izNVEff = .6 izExp=0.65 izCpr=-0.3

IZXFER AtticDU izNVTYPE = AirNetExt izZN1 = Attic izALo = DeckVent izHD = 0.67 * AtticHeight + SoffitHeight izNVEff=.6 izExp=0.5 izCpr=testx*choose(Pitchtype,-.5,-.8,-.5,-.3,.1,.3)

IZXFER AtticDS izNVTYPE = AirNetExt izZN1 = Attic izALo = 2*DeckVent izHD = 0.67 * AtticHeight + SoffitHeight izNVEff=.6 izExp=0.5 izCpr=testx*choose(Pitchtype,-.5,-.5,-.5,-.5,-.5,-.5)

IZXFER AtticDD izNVTYPE = AirNetExt izZN1 = Attic izALo = DeckVent izHD = 0.67 * AtticHeight + SoffitHeight izNVEff=.6 izExp=0.5 izCpr=testx*choose(Pitchtype,-.5,-.3,-.5,-.5,-.5,-.5)

b. Garage – Assume California garage with a water heater and combustion air vents so it is pretty leaky Guess 1 ft2 of free area. Ignore other infiltration

Calculate

Gvent = 1/4

Write Airnet Objects to CSE Input

IZXFER GarageU izNVTYPE = AirNetExt izZN1 = Garage izALo = Gvent izHD = GarageBotZ +1 izNVEff = .6 izExp=0.65 izCpr=0.6

IZXFER GarageS izNVTYPE = AirNetExt izZN1 = Garage izALo = 2*Gvent izHD = GarageBotZ +1 izNVEff = .6 izExp=0.65 izCpr=-.65

IZXFER GarageD izNVTYPE = AirNetExt izZN1 = Garage izALo = Gvent izHD = GarageBotZ +1 izNVEff = .6 izExp=0.65 izCpr=-0.3

c. Vented crawl space [To Be Developed]
d. Sealed crawl space [To Be Developed]
e. Basement [To Be Developed]

5. Interzone Holes – Assume an open door or stair between any twp conditioned zones with common surfaces, except between units in multi-family

If 2 or more conditioned zones

Error if not at least one common surface for every conditioned zone (a surface in zone A whose outside condition is another conditoned zone)

Door calculation for each pair of zones with a common wall surface (zoneA<>zoneB, zoneB<>zoneC, zoneA<>zoneC, etc)

DoortopZ = Min(ZoneTopZ(zone A),(ZoneTopZ(zone B)) //The top of the shared wall

DoorBotZ = Max(ZoneBotZ(zone A),(ZoneBotZ(zone B)) //The bottom of the shared wall

DoorH = DoortopZ - DoorBotZ // Height of shared opening

DH = 20/ // Area of half of assumed door

DHhZ = GwallBotZ + .75 GwallH // Height of top hole

DHHlZ = GwallBotZ + .25 GwallH // Height of bottom hole

For each zone pair write Airnet Objects to CSE Input

IZXFER (ZoneNameA)DHx(ZoneNameB)DH izNVTYPE = AirNetIZ izZN1=(ZoneNameA) izALo=DH izHD = DHhZ izNVEff=1. izExp=0.5 izZN2 = (ZoneNameB)

IZXFER (ZoneNameA)DLx(ZoneNameB)DL izNVTYPE = AirNetIZ izZN1=(ZoneNameA) izALo=DH izHD = DHlZ izNVEff=1. izExp=0.5 izZN2 = (ZoneNameB)

Stair calculation for each pair of zones with only a floor/ceiling surface (zoneA<>zoneB, zoneB<>zoneC, zoneA<>zoneC, etc)

StairZ = Max(ZoneBotZ(zone A),(ZoneBotZ(zone B)) //The height of the stair hole is at the upper floor

For each zone pair write Airnet Objects to CSE Input Note that izZN1 MUST be the lower of the 2 zones or the model doesn't work

IZXFER (ZoneNameA)Sx(ZoneNameB)S izNVType = AIRNETHORIZ izZN1=(ZoneName of lowerzone) izZN2 = (ZoneName of upper zone) izL1=3 izL1=10 izHD =StairZ

6. *IAQ ventilation*

Inputs for each zone

IAQVentCFM // CFM of IAQ vent

IAQfanWperCFM // W/CFM of IAQ vent

Type IAQExhaust // "IAQExhaust", "IAQSupply", "IAQBalanced" "NoIAQVent"

IAQVentHtRcv 0.0 // Heat recovery efficiency of Balanced type, frac

Write Airnet Objects to CSE Input

If Exhaust

IZXFER (Zone)IAQfan izNVTYPE = AirNetExtFan izZN1 = (Zone) izVFmin=-IAQVentCFM izVFmax=-IAQVentCFM izFanVfDs=IAQVentCFM izFanElecPwr=IAQfanWperCFM izFanMtr=IAQventMtr

If IAQSupply

IZXFER (Zone)IAQfan izNVTYPE = AirNetExtFan izZN1 = (Zone) izVFmin=IAQVentCFM izVFmax=IAQVentCFM izFanVfDs=IAQVentCFM izFanElecPwr=IAQfanWperCFM izFanMtr=IAQventMtr

If IAQBalanced // Needs heat recovery

IZXFER (Zone)IAQfanS izNVTYPE = AirNetExtFan izZN1 = (Zone) izVFmin=IAQVentCFM izVFmax=IAQVentCFM izFanVfDs=IAQVentCFM izFanElecPwr=IAQfanWperCFM izFanMtr=IAQventMtr

IZXFER (Zone)IAQfanE izNVTYPE = AirNetExtFan izZN1 = (Zone) izVFmin=-IAQVentCFM izVFmax=-IAQVentCFM izFanVfDs=IAQVentCFM izFanElecPwr=IAQfanWperCFM izFanMtr=IAQventMtr

7. *Mechanical Cooling Ventilation* // The following does not work for multi-zone systems with Econ, NightBreeze. Revise along with ducts model

For each Cooling Ventilation System

Inputs

CoolVentType //type of MECHANICAL cooling ventilation, Choice of WHF, Econ, NightBreeze

CoolVentCFM //Rated air flow of the mechanical cooling system

CoolVent W/CFM //

ReturnRegister // If WHF the conditoned zone where it is located

Calculate

Relief = CoolVentCFM/750 // The minimum size of the attic vents required to let the WHF flow out of the attic

If WHF // Whole House Fan

Calculate

Relief = CoolVentCFM/750 // The minimum size of the attic vent required for this fan to let the WHF flow out of the attic

Write Airnet Objects to CSE Input

IZXFER (Zone)WHF izNVTYPE=AirNetIZFan izZN1=(Zone) izVFmin=0. izVFMax=-CoolVentCFM*Win_hr izFanVfDs=CoolVentCFM izZn2=Attic izFanElecPwr=CoolVentWperCFM izFanMtr=CoolVentMtr

If Econ // Economizer ventilation option on the Central Forced Air System such as Smartvent

Calculate

Relief = CoolVentCFM/750 // The minimum size of the attic vent required for this fan to let the WHF flow out of the attic

Write Airnet Objects to CSE Input

ZXFER Econ# izNVTYPE=AirNetExtFan izZN1=(zone) izVFmin=0. izVFMax=CoolVentCFM*Coolmode*VentDiffMult izFanVfDs=CoolVentCFM izFanElecPwr=CoolVentWperCFM izFanMtr=CoolVentMtr //!! 110413

IZXFER Relief# izNVTYPE=AirNetIZFlow izZN1=ReturnRegister izZn2=Attic izVFmin=0 izVFmax=-CoolVentCFM*Coolmode*.9*VentDiffMult

If NightBreeze //Model for NightBreeze variable flow night ventilation system !!needs lower limit @ CFA<1000/unit and multiple systems @ CFA> 3333 ft2

Calculate

Relief = CoolVentCFM/750 // The minimum size of the attic vent required for this fan to let the WHF flow out of the attic

Write Airnet Objects to CSE Input

IZXFER NightBreeze izNVTYPE=AirNetExtFan izZN1=(zone) izVFmin=0. izFanMtr=CoolVentMtr

izFanVfDs=CoolVentCFM * CFA //CoolVentCFM = CFM/CFA for NightBreeze. Default is 0.6

izFanElecPwr = (616.47-0.6159*CFA + .000246 *CFA*CFA)/(CoolVentCFM * CFA) //W/CFM DEG 9/29/2010 Equation 1

izVFMax=CoolVentCFM*Coolmode*VentDiffMult*CFA / max((17.91554 - 3.67538 * logE(@weather.taDbPvPk)),1)//DEG 9/29/2010 Equation 3 110411

izFanCurvePy = 0, -0.026937155, 0.187108922, 0.839620406, 0 //Fit to DEG flow^2.85

IZXFER NBRelief izNVTYPE=AirNetIZFlow izZN1=ReturnRegister izZn2=Attic izVFmin=0 izVFmax=-CoolVentCFM * CFA * Coolmode*.9 *VentDiffMult

Next Zone

Calculate

AtticRelief = Sum(CoolVentCFM)/750 // The sum of all zonal cool vent CFM determines the minimum size of the attic vents required to let the vent air out of the attic

//Used in Attic Zone AirNet above

//Min Attic Vent area for relief Tamarac http://www.tamtech.com/userfiles/Fan%20size%20and%20venting%20requirements(3).pdf

7. *Duct system leaks and pressurization.*

These are generated automatically by CSE based on the duct system inputs.

2.4 How to Create CSE Conditioned Zone Internal Mass Inputs

2.4.1 Background

2.4.2 Approach

Internal mass objects are completely inside a zone so that they do not participate directly in heat flows to other zones or outside. They are connected to the zone radiantly and convectively and participate in the zone energy balance by passively storing and releasing heat as conditions change. For now only in Conditioned Zones.

The main internal mass objects in the are:

- Interior walls
- Interior floors
- Furniture
- Cair
- Specific masses (for addition later)

CBECC inputs to add:

- Specific masses (for addition later)

2.4.3 Inputs

Floor Area of zone

For each Conditioned Zone

1. Interior Floor Setup. Input for inside the conditioned zone interior floors as mass elements.

   Calculate:

   a. Xflr = sum of the area of floors to ground, crawl space, exterior or other zones
   b. IntFlr = Floor Area-Xflr

2. Interior Wall Setup. Input for inside the conditioned zone interior walls as mass elements.

   Calculate:

   a. IZwall = sum of the area of interior walls to other conditioned zones
   b. Intwall(zone) floor area - .5 * IZwall

3. Write objects to the CSE input

Light stuff

1. znCAir=floor area * 2
2. Interior wall if Intwall(zone) > 0

   SURFACE IntWallC(zone) sfType=Wall sfArea=0.75*Intwall(zone) sfCon=IntwallCav; sfAZM=0 sfExCnd=ADJZN sfAdjZn=(zone)

   SURFACE IntWallF(zone) sfType=Wall sfArea=0.25*Intwall(zone) sfCon=IntwallFrm; sfAZM=0 sfExCnd=ADJZN sfAdjZn=(zone)

3. Furniture

SURFACE Furniture(zone) sfType=wall sfArea= Floor Area * 2.; sfCon=FurnCon; sfAZM=0 sfExCnd=ADJZN sfAdjZn=Zone

Interior Floor if IntFlr(zone) >0

// floor construction for interior mass. Assumes 2x10 @ 16" OC. Both floor and ceiling are in the conditioned zone

SURFACE IntFlrFrm sfType=Floor sfCon=IntFFrm2x10 sfArea=0.1 * RaisedFlr; sfExCnd=ADJZN sfAdjZn=(Zone)

SURFACE IntFlrCav sfType=Floor sfCon=IntFCav2x10 sfArea=0.9 * RaisedFlr; sfExCnd=ADJZN sfAdjZn=(Zone)

4. Constructions

CONSTRUCTION FurnCon // 2.5" wood Revised Layers

Layer lrMat="SoftWood" lrThk=2.5/12

CONSTRUCTION IntwallCav // 2x4 Revised Layers

Layer lrMat="Gypsum Board"

Layer lrMat="Gypsum Board"

CONSTRUCTION IntwallFrm // 2x4 Revised Layers

Layer lrMat="Gypsum Board"

Layer lrMat="SoftWood" lrThk=3.5/12.

Layer lrMat="Gypsum Board"

CONSTRUCTION IntFFrm2x10 // 9.25" (2x10)

Layer lrMat="Carpet"

Layer lrMat="Wood layer"

Layer lrMat="SoftWood" lrThk=9.25/12.

Layer lrMat="Gypsum Board"

CONSTRUCTION IntFCav2x10 // 9.25" (2x10)

Layer lrMat="Carpet"

Layer lrMat="Wood layer"

Layer lrMat="Carpet" // Air space with 1 psf of stuff (cross bracing wiring, plumbing etc) approximated as 1" of carpet

Layer lrMat="Carpet" // Air space with 1 psf of stuff (cross bracing wiring, plumbing etc) approximated as 1" of carpet

Layer lrMat="Gypsum Board"

2.5 Appliances, Miscellaneous Energy Use, and Internal Gains

2.5.1 Background

This model is derived from the 2008 HTM (California Energy Commission, HERS Technical Manual, California Energy Commission, High Performance Buildings and Standards Development Office. CEC-400-2008-012). This is a major change from the 2008 RACM in that internal gains are built up from models for refrigerator, people, equipment and lights instead of the simple constant plus fixed BTU/ft^2 used there. The HTM derived model has been used in the 2013 Development Software throughout the 2013 revision process.

This model has another significant change beyond the HTM model with the addition of latent gains required as input for the new CSE air conditioning model. There was no information on latent gains in either the 2008 RACM or the HTM. The latent model here was created by applying the best available information on the latent fraction of internal gains to the HTM gains model.

2.5.2 Approach

The approach here is to calculate the Appliances and Miscellaneous Energy Use (AMEU) for the home and use that as the basis for the internal gains. This will facilitate future expansion of the procedure to calculate a HERS Rating.

2.5.2.1 Problems

The procedure here (also used in the 2013 development program) does not work correctly for multifamily buildings unless all of the units are the same (CFA and number of bedrooms). I don't believe this problem was considered in developing the HTM. I believe that the only exactly correct solution involves simulating each unit as a separate zone with a different internal gain. For now we will ignore this problem and assume that average values are OK.

The HTM equations do not work if there is a gas range and electric oven.

The allocation of internal gain to zones is not specified in either the RACM or the HTM. A proposed approach is presented here.

2.5.3 Inputs

Units	Number of dwelling units in the building.
BRperUnit	Bedrooms/DwellingUnits rounded to an integer

CFA Conditioned Floor Area in the building

CFAperUnit CFA/DwellingUnits

New CBECC input at the building level: an Appliances Input Screen (for a single conditioned zone, most of these default, we are assuming that MF buildings will be done as one zone):

Input	Description
Refrigerator/Freezer	Efficiency (Choice of Default = 669 kWh/year, no other choices at this time), Location (Choice of zones if multiple conditioned zones). // HTM assumes all Dwelling units have refrigerators. Different for additons and alterations when we get to them.
Dishwasher	Efficiency (Choice of Default, no other choices at this time), Location (Choice of zones if multiple conditioned zones). // HTM assumes all Dwelling units have refrigerators. Different for additons and alterations when we get to them.
Clothes Dryer	Location (Choice of zones if multiple zones, No Dryer space or hookup provided) Dryer power (Choice Electric, Gas or other) //Assuming gas for now
Clothes Washer	Location (Choice of zones if multiple zones), No Washer space or hookup provided)
Range/Oven	Location (Choice of zones if multiple conditioned zones, No Range/Oven space and hookup provided) Range/Oven power (Choice Electric, Gas or other) Assumes gas for now.

Assumes CSE Meters are set up elsewhere:

Mtr_Elec

Mtr_NatGas

Mtr_Othewr //PropaNE

Write Constants to the CSE input:

#redefine Intgain_mo choose1($month, 1.19,1.11,1.02,0.93,0.84,0.8,0.82,0.88,0.98,1.07,1.16,1.21) //The monthly internal gain multiplier (same as 2008 RACM).

#redefine Lights_hr hourval(0.023,0.019,0.015,0.017,0.021,0.031,0.042,0.041,0.034,0.029,0.027,0.025,\

0.021,0.021,0.021,0.026,0.031,0.044,0.084,0.118,0.113,0.096,0.063,0.038) // Changed 0.117 to 0.118 to add to 1

#redefine OutdoorLights_hr hourval(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0.25,0.25,0.25,0.25) //

```
    #redefine People_hr
hourval(0.035,0.035,0.035,0.035,0.035,0.059,0.082,0.055,0.027,0.014,0.014,0.014,\
            0.014,0.014,0.019,0.027,0.041,0.055,0.068,0.082,0.082,0.070,0.053,0.035)

      #redefine Equipment_hr
hourval(0.037,0.035,0.034,0.034,0.032,0.036,0.042,0.044,0.037,0.032,0.033,0.033,\
            0.032,0.033,0.035,0.037,0.044,0.053,0.058,0.060,0.062,0.060,0.052,0.045)
```

1. Setup the gains that are distributed across the zones per CFA of the zone and write to CSE input: Calculations are generally more complicated in future for HERS
   a. //Lights Returns Btu/day-CFA - based on ElectricityInteriorLights = (214+ 0.601×CFA)×(FractPortable + (1-FractPortable)×PAMInterior) //HTM Eqn 11, p. 30

      #define FractPortable .22 //fixed for now, variable later for HERS

      #define Paminterior 0.625 //fixed for now, variable later for HERS

      #Redefine LightsGainperCFA (((214. + 0.601 * CFAperUnit) * (FractPortable + (1-FractPortable) * Paminterior) * 3413. / 365) * DwellingUnits /CFA)

   b. People Returns BTU/day-CFA - 100% is internal gain 57.3% sensible, 42.7% latent Based on HTM and BA existing bldgs Sensible 220, Latent 164 BTU

      #Redefine PeopleperUnit (1.75 + 0.4 * BRperUnit)

      #Redefine PeopleGainperCFA ((3900/0.573) * PeopleperUnit * DwellingUnits / CFA)

   c. Misc Electricity Returns BTU/day-CFA - 100% is internal gain

      #Redefine MiscGainperCFA ((723. + (0.706 * CFAperUnit))* DwellingUnits * 3413. / 365.)/CFA

2. Setup the gains that are point sources located in a particular zone and write to CSE input. Calculations are generally more complicated in future for HERS
   a. Refrigerator. In the HTM all Standard Design refrigerators use the same amount of electricity (669 kWh/year) regardless of the size of dwelling unit or number of bedrooms. The proposed use is based on the energy label of the actual refrigerator installed or if that is not available the default. For existing home HERS calculations the default is (775 kWh/year). Refrigerators run at a constant power 24 hours per day, regardless of the interior air temperature or number of times the door is opened.

Returns BTU/day - 100% is internal gain. Installed refrigerator rating is input for proposed in HERS later

#Redefine RefrigeratorGain (DwellingUnits * 669. * (3413. / 365.))

b. Dishwasher. 0 based choose returns BTU/day // uses Table based in INTEGER bedrooms per dwelling.

```
#Redefine DishwasherGain (choose
        (BRperUnit,90,90,126,126,126,145,145,174,174,174,default 203) *
        DwellingUnits * 3413. / 365.)
```

c. Stove and Oven – Assumes both are gas with electonic igniter Returns BTU/day - Full Energy Use, 90% is internal Gain

```
define CookGain (((31. + (.008 * CFAperUnit))* 0.43* 0.9)* DwellingUnits * 100000. /
        365.) //Added the 0.43 for the electronic ignition 12/4 BAW
```

d. Clothes Washer - // Returns BTU/day

```
#Redefine WasherGain ((-64 + 0.108 * CFAperUnit) * DwellingUnits *
    3413. / 365.)
```

e. Clothes Dryer - Assumes gas with electonic igniter Returns BTU/day - Full energy Use, 30% is internal gain

```
define DryerGAin (13. + (.01 * CFAperUnit))* DwellingUnits * 100000. / 365. //Added
        the 0.43 for the electronic ignition //120831
```

f. Exterior Lights Returns Btu/day - based on HTM Eqn 14

```
#define PamExterior 0.49    //fixed for now, variable later for HERS

#Redefine ExtLightGain (-81+ 0.152 × CFA)×PAMExterior * 3413. / 365)
```

3. For each conditioned zone: //Write GAIN objects inside each conditioned zone

```
GAIN Lights(zone) gnPower=
LightsGainperCFA*CFA(Zone)*Lights_hr*Intgain_mo gnFrRad=0.4
gnEndUse=Lit gnMeter= Mtr_Elec

GAIN People(zone) gnPower=
PeopleGainperCFA*CFA(Zone)*People_hr*Intgain_mo gnFrRad=0.3
gnFrLat=0.427 // Free Energy so not metered

GAIN Misc(zone) gnPower=
MiscGainperCFA*CFA(Zone)*Equipment_hr*Intgain_mo gnFrRad=0.3
gnFrLat=0.03 gnEndUse=Rcp gnMeter= Mtr_Elec
```

Write any of the following if the source is located in this zone:

```
GAIN Refrigerator gnPower= RefrigeratorGain/24 gnFrRad=0 gnEndUse=Refr
gnMeter= Mtr_Elec // No *Intgain_mo, change fro 2013 DevProg

GAIN Dishwasher gnPower= DishwasherGain*Equipment_hr*Intgain_mo
gnFrRad=0 gnFrLat=0.25 gnEndUse=Dish gnMeter= Mtr_Elec //
```

GAIN Cooking gnPower= CookGain*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.67 gnEndUse=Cook gnMeter= Mtr_NatGas gnFrZn=.9 //

GAIN Washer gnPower= WasherGain*Equipment_hr*Intgain_mo gnFrRad=0 gnEndUse=Wash gnMeter= Mtr_Elec //

GAIN Dryer gnPower= DryerGAin*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.5 gnEndUse=Dry gnMeter= Mtr_NatGas gnFrZn=.3 //

Write the following to the 1st zone only (one gain per building):

GAIN ExtLights gnPower= ExtLightGain*OutdoorLights_hr gnFrZn=.0 gnEndUse=Ext gnMeter= Mtr_Elec // outside lights, no internal gain

4. For each unconditioned zone write the following if the source is located in this zone: //Garage or Basement Maybe 2nd refrigerator in garage later?

   GAIN Washer gnPower= WasherGain*Equipment_hr*Intgain_mo gnFrRad=0 gnEndUse=Wash gnMeter= Mtr_Elec //

   GAIN Dryer gnPower= DryerGAin*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.5 gnEndUse=Dry gnMeter= Mtr_NatGas gnFrZn=.3 //

2.6 Seasonal Algorithm

These are constant control rules. You could substitute values for defined terms in some cases like Winter_Vent Winter_Cool Summer_heat and Sumr_Vent_Temp

//Thermostats and associated controls

//Heat Mode

#redefine SZ_Heat_hr hourval(65,65,65,65,65,65,65,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,65)

#redefine Liv_Heat_hr hourval(65,65,65,65,65,65,65,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,65)

#redefine Slp_Heat_hr hourval(65,65,65,65,65,65,65,68,65,65,65,65,65,65,65,65,65,65,65,65,65,68,68,65)

#redefine Winter_Vent 77

#redefine Winter_Cool 78

//Cool Mode

#redefine SZ_Cool_hr hourval(78,78,78,78,78,78,78,83,83,83,83,83,83,82,81,80,79,78,78,78,78,78,78,78)

#redefine Liv_Cool_hr hourval(83,83,83,83,83,83,83,83,83,83,83,83,83,82,81,80,79,78,78,78,78,78,78,83)

```
#redefine Slp_Cool_hr
hourval(78,78,78,78,78,78,78,83,83,83,83,83,83,83,83,83,83,83,83,83,83,78,78,78)

#redefine Summer_Heat 60

#redefine Sumr_Vent_Temp 68      //

//  Summer Winter mode switch based on 7 day average temp.  Winter<=60>Summer

#redefine Coolmode select( @weather.taDbAvg07 >60., 1,default 0)

#redefine HeatSet select( @weather.taDbAvg07 >60., Summer_Heat, default
SZ_Heat_hr )

#redefine CoolSet select( @weather.taDbAvg07 >60., SZ_Cool_hr, default Winter_Cool
)

#redefine Tdesired select( @weather.taDbAvg07 >60., Sumr_Vent_Temp, default
Winter_Vent)

// Window interior shade closure

#define SCnight 0.8    //  when the sun is down.  80%

#define SCday 0.5      //  when the sun is up  50%

#define SCcool 0.5     //  when cooling was on previous hour.  50%?
```

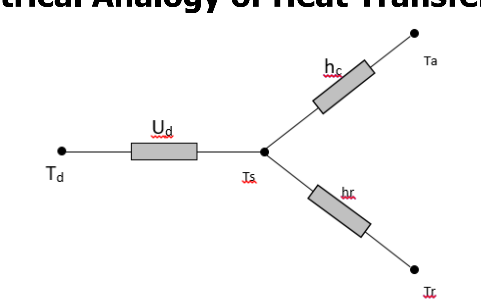
TECHNICAL APPENDICES

Appendix A. Derivation of Duct Loss Equations Using Heat Exchanger Effectiveness and Y-Delta Transformations

This derivation is for one zone only, and the nomenclature is specific to this appendix alone.

Heat transfer through the duct walls can be illustrated in the electrical analogy in Figure A-1. The first node on the left represents the temperature of the air in the duct (T_d) and is connected to the temperate on the surface of the duct (T_s) by the conductance through the duct wall (U_d). The convective heat transfer coefficient (h_c) connects the surface temperature to the duct zone air temperature (T_a). The radiation heat transfer coefficient (h_r) connects the surface temperature to the duct zone radiant temperature (T_r).

Figure A-1: Electrical Analogy of Heat Transfer through a Duct Wall



The temperatures of the duct zone are assumed to be constant; the duct surface temperature is not. The duct surface temperature can be removed from the analysis by using a Y-Δ transform. Figure A-2 shows the result of this transformation with direct connections between the duct air temperature, the duct zone radiant and air temperatures through combined coefficients defined in Equation A- 1.

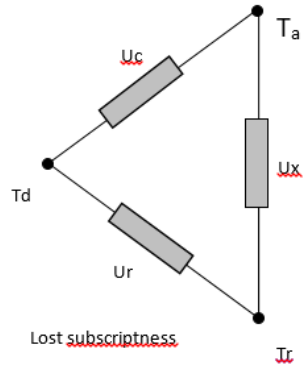
$$U_r = \frac{U_d h_r}{D} \qquad U_c = \frac{U_d h_c}{D} \qquad U_x = \frac{h_c h_r}{D}$$

Equation A- 1

where

$$D = U_d + h_c + h_r$$

Figure A-2: Heat Transfer through a Duct Wall with Surface Temperature Removed



Using an energy balance, the rate of change of heat flow along the length (x) of duct must equal the heat flow through the duct wall, or

$$-mc_p \frac{dT_d(x)}{dx} = U_c P(T_d(x) - T_a) + U_r P(T_d(x) - T_r)$$

Equation A- 2

where

mc_p = capacitance flow rate of the air in the duct

T_d = temperature of air in the duct

U_c = equivalent heat transfer coefficient (see Equation A- 1)

P = perimeter of duct

T_a = temperature of air in duct zone

U_r = equivalent heat transfer coefficient (see Equation A- 1)

T_r = radiant temperature in duct zone

Regrouping by temperature terms

$$mc_p \frac{dT_d(x)}{dx} = -(U_c P + U_r P) T_d(x) + U_c P T_a + U_r P T_r$$

Equation A- 3

and dividing through by the quantity $(U_c P + U_r P)$ gives

$$\frac{mc_p}{(U_c P + U_r P)} \frac{dT_d(x)}{dx} = -T_d(x) + T_{amb}$$

Equation A- 4

where

$$T_{amb} = \frac{U_c P}{(U_c P + U_r P)} T_a + \frac{U_r P}{(U_c P + U_r P)} T_r$$

Equation A- 5

Let $y(x)$ be

$$y(x) = T_{amb} - T_d(x)$$

Equation A- 6

The derivative of which is

$$dy = -dT_d$$

Equation A- 7

Substituting Equation A- 6 and Equation A- 7 into Equation A- 4 gives

$$-\frac{mc_p}{(U_c + U_r)P} \frac{dy}{dx} = y(x)$$

Equation A- 8

Rearranging

$$\frac{1}{y(x)} dy = -\frac{(U_c + U_r)P}{mc_p} dx$$

Equation A- 9

and integrating from entrance ($x = 0$) to exit ($x = L$)

$$\int_0^L \frac{1}{y(x)} dy = \int_0^L -\frac{(U_c + U_r)P}{mc_p} dx$$

Equation A- 10

Gives

$$\ln y(L) - \ln y(0) = -\frac{(U_c + U_r)PL}{mc_p}$$

Equation A- 11

Recalling the definition in Equation A- 6 and replacing the product of the perimeter and length with the surface area (A) of the duct, and a bit of manipulation yields the following relationships

$$\frac{y(L)}{y(0)} = \frac{T_d(L) - T_{amb}}{T_d(0) - T_{amb}} = \exp\left(-\frac{(U_c + U_r)A}{mc_p}\right)$$

Equation A- 12

Let

$$\beta = \exp\left(-\frac{(U_c + U_r)A}{mc_p}\right)$$

Equation A- 13

Then

$$\frac{T_d(L) - T_{amb}}{T_d(0) - T_{amb}} = \beta$$

Equation A- 14

Solving for the exit temperature gives

$$T_d(L) = \beta(T_d(0) - T_{amb}) + T_{amb}$$

Equation A- 15

The temperature change in length L of duct is

$$T_d(0) - T_d(L) = -\beta(T_d(0) - T_{amb}) - T_{amb} + T_d(0)$$

Equation A- 16

This can be rewritten as

$$T_d(0) - T_d(L) = (1 - \beta)(T_d(0) - T_{amb})$$

Equation A- 17

Let ε be the sensible heat exchanger effectiveness

$$\varepsilon = (1 - \beta)$$

Equation A- 18

Then the conduction loss from the duct to the duct zone can then be written as

$$Q_{loss} = mc_p(T_d(0) - T_d(L)) = \varepsilon\, mc_p(T_d(0) - T_{amb})$$

Equation A- 19

Appendix B. Screen Pressure Drop

NOTE: The following algorithms are not currently implemented in the code, but are here for future code use, and in the interim are useful to manually determine the effects of screens on window ventilation flow pressure drop.

The references cited are a few of the papers reviewed to ascertain state of the art regarding screen pressure drop. In one of the more recent papers, Bailey et al. (2003) give the pressure drop through a screen as:

$$\Delta p = K\frac{\rho w^2}{2g_c} = K\frac{m^2}{2g_c\rho A^2}$$

Equation B- 1

where,

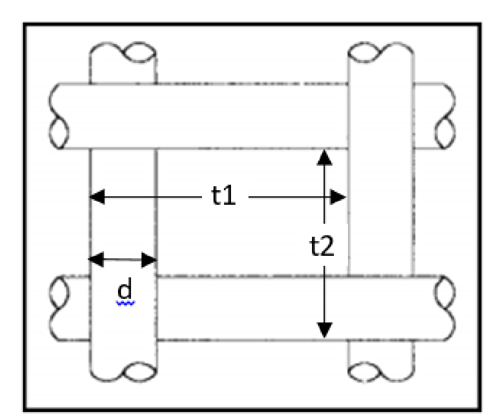
$$K = \left(\frac{1}{\beta^2} - 1\right)\left[\frac{18}{Re} + \frac{0.75}{log(Re+1.25)} + 0.055\,log(Re)\right]$$

Equation B- 2

and,

β = screen porosity = open area/total area perpendicular to flow direction.

$$\beta = \left(1 - \frac{d}{t1}\right)\left(1 - \frac{d}{t2}\right)$$



$Re = \frac{wd}{\nu} = \frac{md}{\rho A\nu}$ = Renolds number.

w = face velocity = $\frac{m}{\rho A}$, ft/sec.

m = mass flow rate, lb_m/sec.

d = wire diameter, ft.

ν = viscosity ≈ 1.25E-4 + 5.54E-07T(degF); ft^2/sec. = 1/6100 ft2/sec at 70-F.

ρ = air density, lb_m/ft^3.

g_c = 32.2 $lb_m ft/lb_f\text{-}sec^2$.

The first term, intended for portraying Re < 1 pressure drops, is the dominate term. The third term, intended for Re > 200, is relatively negligible, and the second term is a bridge between the first and third terms.

The Reynolds number for the screen flow $Re = \frac{wd}{\nu}$ is roughly 5 times the face velocity in ft/sec. For a velocity of 1 ft/sec, Re ~ 5. For the expected range of wind speeds of concern for ventilation (see note #1), and with the motive of making the partial derivatives simple (see below), Equation B- 2 is approximated as

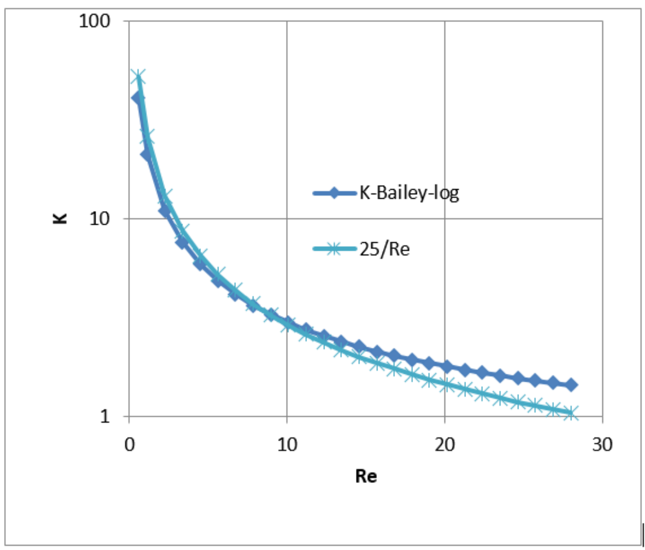
$$K = \left(\frac{1}{\beta^2} - 1\right)\frac{25}{Re}$$

Equation B- 3

[note #1: California CZ12 ave yearly Vmet ≈ 11 ft/sec. Correcting for height and shielding gives Vlocal ≈ 11*0.5*0.32 ≈ 1.8 ft/sec. For max flow case of windows on windward and leeward walls, with typical wall wind pressure coefficients, w ≈ 0.5*Vlocal. Thus, the maximum window velocity expected for the annual average wind velocity of 11 ft/sec is w ≈ 0.5*1.8 = 0.9 ft/sec. In a building with windows in multiple directions, the average *w* is expected to be much lower, perhaps 0.5 ft/sec. *Stack Effect:* Using old ASHRAE equation, $w(fpm) = 9\sqrt{H[ft](\Delta T[F])} =$ $9 * \frac{\sqrt{10*10}}{60} = 1.5\frac{ft}{sec}$ together, the wind and stack may be on the order of 1-ft/sec].

The constant 25 in this approximate formula was determined by forcing Equation B- 2 and *Equation B- 3* to match when the window air velocity is at the characteristic value $w_c = 21\psi\nu C_d^2$, defined below. As discussed there, at this velocity the pressure drop through the screen is equal to that through the window orifice.

Figure B-1: Screen Pressure Drop



Equation B- 3 can be written as

$$K = \frac{25\psi\nu}{w}, \text{or alternately} \frac{25\psi\rho A\nu}{m}$$

Equation B- 4

where, as a result of the approximation *Equation B- 3*, the screen inputs can be combined into one characteristic screen parameter ψ (of dimension ft^{-1}):

$$\psi = \frac{1}{d}\left(\frac{1}{\beta^2} - 1\right)$$

Equation B- 5

ψ encapsulates all that needs to be known about the screen for pressure drop purposes. This is only true when *K* varies in the form assumed by *Equation B- 3*.

The flow rate through a screenless window is modeled by Airnet as a sharp edged orifice of opening area A.

$$m = C_d A(2\rho g_c \Delta p)^{\frac{1}{2}}$$

Equation B- 6

[Idelchik says this is valid for Re > 10^4].

At the equal pressure point the window orifice Reynolds number is $\mathrm{Re_{wdw}} = (\mathrm{D_h}/\mathrm{d})25\psi \mathrm{d}\mathrm{C_d^2}$.

$\mathrm{w_c}$ =1.89 ft/sec for std 14x18x0.011 screen &Cd=0.6; 14&18 are wires/inch.

$\mathrm{Re_c}$ = 10.6 for std 14x18x0.011 screen &Cd=0.6

$\mathrm{Re_{wdw}}$= (~1.5*12/0.011)*(10.6)=1,7345 >10^4.

Thus Re is not > 10^4 when w < ~1 ft/sec. But this is when the pressure drop starts to be dominated by the screen, so the orifice drop accuracy is not so important.

Solving for Δp,

$$\Delta \mathrm{p} = \frac{1}{\mathrm{C_d^2}} \frac{\rho \mathrm{w}^2}{2\mathrm{g_c}} = \frac{1}{\mathrm{C_d^2}} \frac{\mathrm{m}^2}{2\mathrm{g_c}\rho \mathrm{A}^2}$$

Equation B- 7

Adding Equation B- 1 and Equation B- 7 gives the total pressure drop for a window and screen in series:

$$\Delta p = \left(K + \frac{1}{C_d^2}\right) \frac{m^2}{2 g_c \rho A^2}$$

Equation B- 8

Solving for mass flow rate,

$$\mathrm{m} = \mathrm{AC_d} \left(\frac{1}{1 + \mathrm{C_d^2 K}}\right)^{\frac{1}{2}} (2\rho \mathrm{g_c} \Delta \mathrm{p})^{\frac{1}{2}}$$

Equation B- 9

or,

$$m = AC_d S(2\rho g_c \Delta p)^{\frac{1}{2}}$$

Equation B- 10

where S is the ratio of the flow with a screen to the flow rate without a screen, as a function of velocity *w*, viscosity, and screen and window orifice parameters.

$$S = \left(\frac{1}{1 + C_d^2 K}\right)^{\frac{1}{2}} = \left(\frac{1}{1 + C_d^2 \frac{25\psi v}{w}}\right)^{\frac{1}{2}}$$

Equation B- 11

Equating Equation B- 1 and Equation B- 7 shows that the velocity when the screen and window pressure drops are equal is given by:

$$\mathrm{w_c} = 25\psi\nu \mathrm{C_d^2}$$

Equation B- 12

The corresponding Reynolds number is $Re_c = 25\psi d C_d^2$.

Substituting Equation B- 12 into Equation B- 11shows that for this condition,

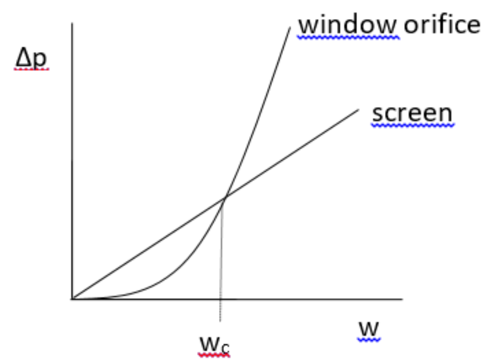
$$S_c = \frac{1}{\sqrt{2}} = 0.707$$

Equation B- 13

Equation B- 12 and Equation B- 13 show that w_c, which, besides viscosity, only depends on the screen constant ψ and window-orifice coefficient C_d, can be considered a "characteristic" velocity, the velocity at which the flow is reduced by (1 - 0.707) ~ 29.3% by the addition of a screen to the window.

Figure B-2 shows that the typical Δp vs. flow curves for a screen and an orifice separately, not in series. The curves cross at velocity w_c. To the left of w_c, the laminar flow pressure drop dominates the window orifice pressure drop; to the right the orifice pressure drop progressively dominates. Screens give a greater flow reduction at low wind speeds than at high wind speeds.

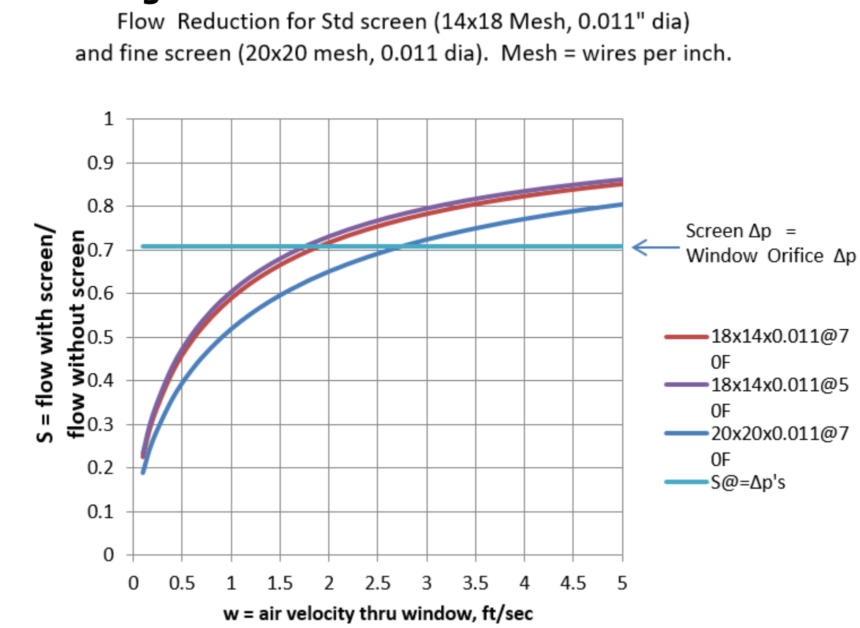
Figure B-2: Pressure vs. Flow Characteristics



In Figure B-2, to the left of w_c the laminar-flow screen pressure drop is higher, and to the right the orifice pressure drop dominates.

Figure B-3 shows S as a function of air velocity w for two common screen sizes. For the Standard screen, w_c is 1.9-ft/sec. [At w = ~ 1-ft/sec taken as typical according to note #1, S = 0.6, corresponding to a 40% reduction in flow].

Figure B-3: Standard Screen Flow Reduction



Partial Derivatives for use in Airnet:

From Equation B- 4 and Equation B- 8,

$$\Delta p = \left(\frac{25\psi\rho A v}{m} + \frac{1}{C_d^2}\right)\frac{m^2}{2g_c\rho A^2}$$

Equation B- 14

This can be written in the quadratic form for m:

$$m^2 + bm - a\Delta p = 0$$

Equation B- 15

Where,

$$a = 2g_c\rho C_d^2 A^2$$

$$b = 25\psi\rho v C_d^2 A$$

The single real root of the quadratic Equation B- 15 gives the mass flow rate through a screen in series with a window-orifice as a function of screen and window properties and overall pressure drop:

$$m = \frac{b}{2}\left\{\left(1 + \frac{4a\Delta p}{b^2}\right)^{\frac{1}{2}} - 1\right\}$$

Equation B- 16

If Δp is taken as $\Delta p = P_1 - P_2$, then the partial derivative of m with respect to P_1 is

$$\frac{\partial m}{\partial P_1} = \frac{a}{b\sqrt{1 + \frac{4a\Delta p}{b^2}}}$$

Equation B- 17

$$\frac{\partial m}{\partial P_2} = -\frac{\partial m}{\partial P_1}$$

Equation B- 18

These derivatives are needed in the Newton-Raphson procedure. The derivatives Equation B- 17 and Equation B- 18 do not become unbounded when $\Delta p = 0$, as does the orifice Equation B- 6, so that no special treatment is needed near $\Delta p = 0$.

But the derivatives do become a little peculiar near zero Δp as shown in Figure B-4 and Figure B-5. The value of $\frac{a}{b} \approx 25$, and $\frac{4a}{b^2} \approx 88$ for thse plots for the standard screen of Figure B-3. It is possible this could cause problems in the N-R method, but testing AirNet with this type of element is the easiest way to find out.

Figure B-4: For Small Δp

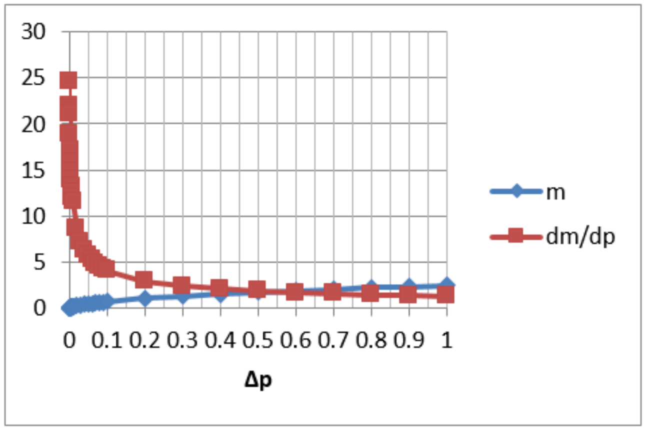
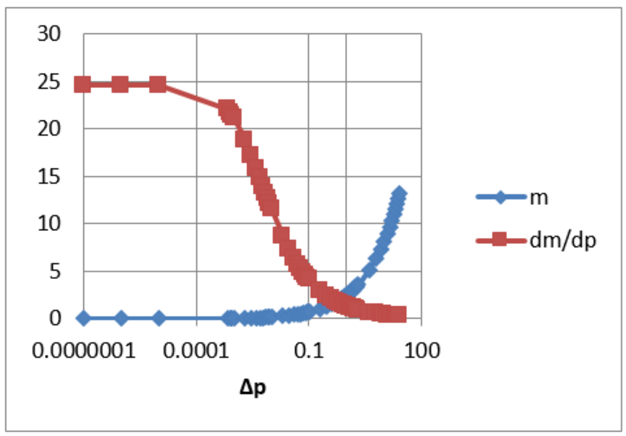


Figure B-5: For Large Δp



Appendix C. Exact Longwave Radiation Model

Figure C-1 shows the standard Heat Transfer Engineering method of determining the long wavelength radiation exchange between black-body surfaces at uniform temperatures (Oppenheim(1956), Mills(1992)). The areas need not be equal, or symmetrically disposed, but are drawn that way for simplicity. The surfaces are assumed to be isothermal, and each surfaces temperature node is connected to all other surface temperature nodes via conductances $h_b A_i F_{ij}$.

The following methodology is referred to as the "exact" solution in the discussions of Section 1.6. However, it is recognized that it still is an idealization. For instance, surfaces are generally not isothermal. Although the heat transfer q_{ij} [Btu/hr], of Equation C- 2 is accurate if surfaces i and j are isothermal, the *local* surface heat transfer $q_{ij}^{'}$ [Btu/hr-ft^2] on the surfaces is nonuniform because the local view factors are different than the integrated value F_{ij}. For example, if the two surfaces are connected along a common edge, then near the edge $q_{ij}^{'}$ will be higher than the average $\frac{q_{ij}}{A_i}$, which will tend to change the temperatures of each wall near the edge faster than away from the edge. For the same reason, the radiation intensities are also non-uniform over a surface, which affects the accuracy of the treatment of the emissivity effects by the Oppenheim surface conductance term, which assumes uniform irradiation.

From the Stefan-Boltzmann equation, the net heat transfer rate between surfaces i and j is:

$$q_{ij} = h_b A_i F_{ij}(T_i - T_j)$$

Equation C- 1

where,

$h_b = 4\sigma\bar{T}^3$ = black body radiation coefficient; Btu/(hr-ft^2-F).

$\sigma = 0.1714x10^{-8}$ Btu/hr-ft^2-R^4, the Stefan-Boltzmann constant.

$\bar{T}^3 \approx \frac{T_i+T_j}{2}$; degrees R.

The F_{ij} term is the standard view factor, equal to the fraction of radiation leaving surface *i* that is intercepted by surface *j*. F_{ij} depends on the size, shape, separation, and orientation of the surfaces, and at worst requires a double integration. Reciprocity requires that $A_i F_{ij} = A_j F_{ji}$.

Equation (C-1) is in the linearized form of the Stefan-Boltzmann equation, where for small temperature differences, $(T_i^4 - T_j^4)$ is approximated by $4\bar{T}^3(T_i - T_j)$.

Figure C-1: View-Factor Method's Radiant Network for Black-Body Surfaces

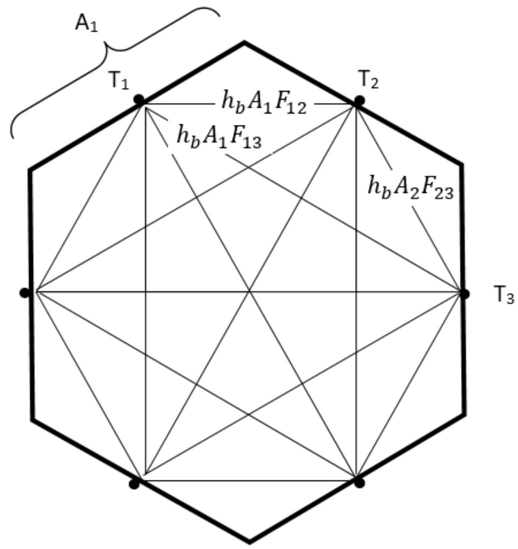
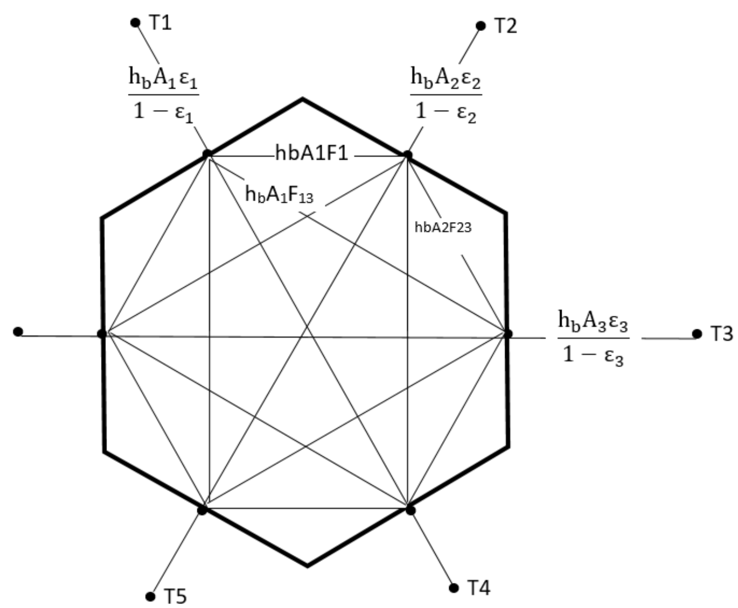


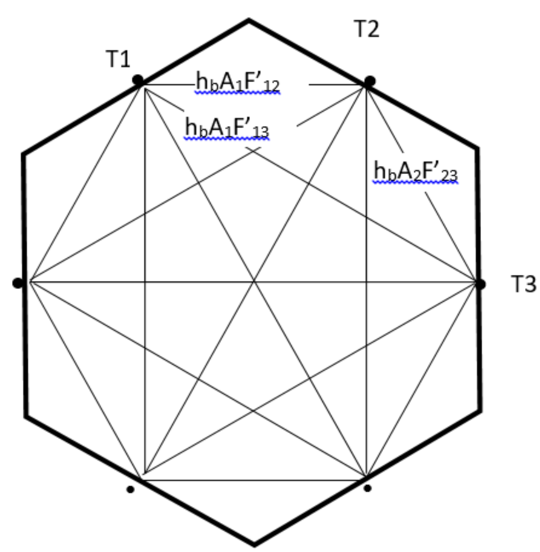
Figure C-2 shows the Figure C-1 black surface case extended to handle diffuse gray surfaces (ε = α = constant over temperature range of interest) with emissivities ε_i, by adding the Oppenheim radiant surface conductances $\frac{A_i\varepsilon_i}{1-\varepsilon_i}$ between the surface temperature nodes and the black body network. (Figure C-2 also represents the un-linearized Stefan-Boltzmann circuit if the surface temperatures are replaced by the emissive power of the surfaces. In this case the surface radiosities are the potentials at the floating nodes.)

Figure C-2: View-Factor Method's Network for Grey Surfaces



By dissolving the radiosity nodes using Y-delta transformations, Figure C-2 converts into Figure C-3 showing the same circuit form as the black surface circuit of Figure C-1. The transformation provides the conductances $A_i F_{ij}^{'}$ implicit in the conductances of Figure C-2.

Figure C-3: View-Factor Method's Network for Grey Surfaces Reduced to Star Network



F'_{ij} are the 'radiant interchange factors'. As with the black surfaces view factors, reciprocity holds: $A_i F'_{ij} = A_j F'_{ji}$. The net heat transfer between surface *i* and *j* (both directly and via reflections from other surfaces) is given by:

$$q_{ij} = h_b A_i F'_{ij} (T_i - T_j)$$

Equation C- 2

The total net heat transfer from surface *i* (i.e., the radiosity minus the irradiation for the un-linearized circuit) is given by summing Equation C- 2 for all the surfaces seen by surface *i, j≠i*:

$$q_i = \sum_{j=1}^{n} h_b A_i F'_{ij} (T_i - T_j)$$

Equation C- 3

The above methodology is referred to as the "exact" solution in the discussion of Section 1.6.1. However, as discussed by Carroll, it is recognized that it is still an idealization. For instance, surfaces are generally not isothermal. Although the heat transfer, q_{ij} [Btu/hr], of Equation C- 2 is accurate if surfaces i and j are isothermal, the *local* surface heat transfer q'_{ij} q' [Btu/hr-ft^2] on the surfaces is nonuniform because the local view factors are different than the integrated value F_{ij}. For example, if the two surfaces are connected along a common edge, then near the edge $q'_{ij} q'$ will be higher than the average $\frac{q_{ij}}{A_i}$, which will tend to change the temperatures of each wall near the edge faster than away from the edge. For the same reason, the radiation intensities are also non-uniform over a surface, which affects the accuracy of the treatment of the emissivity effects by the Oppenheim surface conductance term, which assumes uniform irradiation.

Appendix D. Determining the Form of the Self-weighting Term $\mathrm{F_i}$

Consider a flat black surface of area A_1 and temperature T_1 viewing the rest of the room of area A_s and surface temperature T_s, with the view factor $F_{1s} = 1$. By Equation C- 1 of C, the net q from surface A_1 is given by:

$$q_1 = h_b A_1 F_{1s} (T_1 - T_s) = h_b A_1 (T_1 - T_s)$$

Equation D- 1

With Carroll's model applied to this geometry,

$$q_1 = h_b A_1 F_1 (T_1 - T_r)$$

Equation D- 2

where

$$T_r = \frac{A_1 F_1 T_1 + A_s F_s T_s}{A_1 F_1 + A_s F_s}$$

Equation D- 3

Equating Equation D- 1 and Equation D- 2 and solving for F_1 gives:

$$F_1 = \frac{1}{1 - \frac{A_1 F_1}{A_1 F_1 + A_s F_s}}$$

Equation D- 4

The net heat transfer rate from surface 1 is $q_1 = h_b A_1 F_1 (T_1 - T_r)$, with similar expressions for F_s and q_s. This is then generalized to the form of Equation 78 of Section1.6.1.

REFERENCES

Anderson, J.V. and K Subbarao, "Spectral Analysis of Ambient Weather Patterns, " Annual System Simulation Conference, Reno, American Society of Mechanical Engineers, 1981.

ASHRAE, American Society of Heating, Refrigeration and Air-Conditioning Engineers. *1993 ASHRAE Handbook, Fundamentals*, pp 22.1.

ASHRAE. 2010. Thermal Environmental Conditions for Human Occupancy. ANSI/ASHRAE Standard 55-2010.

Bailey, B.J., et al, "Airflow Resistance of Greenhouse Ventilators with and without Insect Screens, "Biosystems Engineering (2003) 86 (2),217–229.

Barnaby, Charles S., J.D. Spitler, D. Xiao, "Updating the ASHRAE/ACCA Residential Heating and Cooling Load Calculation Procedures and Data", ASHRAE 1199-RP, Final Report, Aug. 20, 2004.

Bazjanac V., Huang, J., Winkelmann, F.C., "DOE-2 Modeling of Two-dimensional Heat Flow in Underground Surfaces, prepared for the California Energy Commission, February 2000.

Blocken, Defraeye, Derome,Carmeliet, 2009, “High-resolution CFD simulations for forced convective heat transfer coefficients at the facade of a low-rise building”, Building and Environment.

Brundrett E (1993). Prediction of pressure drop for incompressible flow through screens. Journal of Fluid Engineering, Transactions American Society of Mechanical Engineers, 115, 239–242, June 1, 2010.

Burch, J., Casey, R., “Wind Issues in Solar Thermal Performance Ratings,” Preprint NREL/CP-550-45466, April 2009.

Carroll, J. A., 1980, An ‘MRT Method’ of Computing Radiant Energy Exchange in Rooms, Proceedings of the Second Systems Simulation and Economic Analysis Conference, San Diego, CA.

Carroll, J.A., 1981, A Comparison of Radiant Interchange Algorithms, Proceedings of the ASME Solar Energy Division Third Annual Conference on Systems Simulation, Economic Analysis/Solar Heating and Cooling Operational Results, Reno, Nevada. 132, 133, 165

Carroll, J. A., 1980a, "An MRT method of computing radiant energy exchange in rooms," Proceedings of the 2nd Systems Simulation and Economic Analysis Conference, San Diego, CA.

Carroll J.A., J. R. Clinton, 1980b, "A Thermal Network Model of a Passive Solar House," Proceedings of the 5th National Passive Solar Conference, American Section of ISES.

Carroll J.A., J. R. Clinton, 1982, "Appendix H: A Thermal Network Model of a Passive Solar House," Final Report USDOE Contract DE AC04-79AL10891. July, 1982.

Carroll, J. A., 1981, "A Comparison of Radiant Interchange Algorithms," Proceedings of the 3rd Annual Systems Simulation and Economics Analysis/Solar Heating and Cooling Operational Results Conference, Reno. Solar Engineering, Proceedings of the ASME Solar division.

Carslaw, H.S., J.C. Jaeger, <u>Conduction of Heat in Solids</u>, 2nd Ed., Oxford Press, 1959.

Chirlian, <u>Signals, Systems, and the Computer</u>, Intext Educational Publishers, 1973.

Clarke, J.A., Hensen, J.L.M., "An Approach to the Simulation of Coupled Heat and Mass Flows in Buildings,", 11th AIVC Conference, Belgirate, Italy, Sept. 1990.

Clear, R.D., L. Gartland and F.C. Winkelmann, 2001, "An Empirical Correlation for the Outside Convection Air Film Coefficient for Horizontal Roofs," Lawrence Berkeley National Laboratory, Jan 2001.

Cooper, L.Y., "Calculation of the Flow Through a Horizontal Ceiling/Floor Vent", NISTIR 89-4052, Mar. 1989.

Deru, M., and P. Burns. 2003, "Infiltration and Natural Ventilation Model for Whole Building Energy Simulation of Residential Buildings," NREL/CP-550-33698; ASHRAE preprint, Kansas City, Missouri.

Emmel, Abadie, Mendes, “New external convection heat transfer coefficient correlations for isolated low-rise buildings”, Energy and Buildings 39 (2007).

Energy Plus Engineering Reference, Oct, 2009.

European Convention for Constructional Fieldwork,”Recommendations for the Calculation of Wind Effects on Buildings and Structures”. Technical General Secretary, Brussels, Belgium, September 1978.

Francisco, P.W., and L. Palmiter, 1999, revision 2003, "Improvements to ASHRAE Standard 152P," U.S. DOE Subcontract 324269-AU1.

Goldstein, F. B., Some Analytical Models of Passive Solar Building Performance: A Theoretical Approach to the Design of Energy Conserving Buildings, LBL-7811, Lawrence Berkeley Laboratory, Berkeley, 1978. This was confirmed for winter weather.

Holmes, J. D. , "Wind Loading In Structures," Spon Press, 2003.

Holmes, J.D., " Wind loading and structural response", Lecture 18.

Holmes, J. D. , Wind Loads on low rise buildings - a review. CRISO, Div. of Building Research, Highett, Victoria, Australia, 1993.

Howell, J.R., Radiation Configuration Factors, McGraw-Hill, 1982.

Idelchik, I.E., "Handbook of Hydraulic Resistance", 3rd Ed, Springer-Verlag, Berlin, 1986.

Kusuda, T., P. R Achenbach, "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States," NBS REPORT 42103-12-4210436 June 22, 1965.

Lorrenzetti, D.M.,"Computational Aspects of Multizone Airflow Systems", Building and Environment 37, (2002) 1083-1090.

Martin, Marlo and Berdahl, Paul, "Characteristics of Infrared Sky Radiation in the United States." Solar Energy Vol. 33, No. ¾, pp 321-336, 1984.

McAdams, Heat Transmission, McGraw-Hill, 3rd Ed., 1954.

McAdams eq. (7-8) for horizontal plates with heat transfer down from a cold plate, or up from a hot plate, for the turbulent case: $\mathrm{Nu} = 0.14\mathrm{Ra}^{\frac{1}{3}} \ (2 * 10^{7} < \mathrm{Ra} < 3 * 10^{10})$]

Mills, A.F. , 1992, "Heat Transfer," Irwin Press, Boston.

Churchill, S. W., and Chu, H. H. S., "Correlating equations for laminar and turbulent free convection from a vertical plate," *Int. J. Heat Mass Transfer*, 18, 1323-1329 (1975).

Niles, P., L. Palmiter, B. Wilcox, and K. Nittler, "Unconditioned Zone Model", PIER Research for the 2008 Residential Building Standards. PIER Contract 500-04-006. See http://www.energy.ca.gov/title24 /2008standards/documents/2006-03-28_workshop/2006-03-27_UZM_MODEL.PDF.

Oppenheim, A.K., "Radiation Analysis by the Network Method," Trans of the ASME, May 1956.

Palmiter, L. and T. Bond. 1992, "Impact of Mechanical Systems on Ventilation and Infiltration in Homes," ACEEE.

Palmiter, L., and T. Bond. 1991a, "Modeled and Measured Infiltration: A Detailed Case Study of Four Electrically Heated Homes, " Electric Power Institute report CU-73227, Palo Alto, California.

Palmiter, L., E. Kruse, and P. Francisco, 2004, "Duct Efficiency Under Full-load or Modulating Conditions: Implications for Heat Pump Performance," ACEEE.

Palmiter, L., and T. Bond. 1991b, "Interaction of Mechanical Systems and Natural Infiltration, " AIVC, Ottawa, Canada.

Palmiter, L., and T. Bond. 1991a, "Modeled and Measured Infiltration: A Detailed Case Study of Four Electrically Heated Homes, " Electric Power Institute report CU-73227, Palo Alto, Calif.

Palmiter, L., and T. Bond. 1991b, "Interaction of Mechanical Systems and Natural Infiltration, " AIVC, Ottawa, Canada.

Palmiter, L. and P.W. Francisco, 1996, "Modeled and Measured Infiltration: Phase III-A detailed Study of Three Homes". TR-106228, EPRI WO3512-12.

Palmiter, L, and E. Kruse, 2003, "Derivation of Duct Efficiency Equations in ASHRAE Standard 152", ASHRAE Seminar, Feb. 2003. Available from author at Ecotope Inc.

Parker, D.S., P. Fairey and L. Gu, 1993. "Simulation of the Effect of Duct Leakage and Heat Transfer on Residential Space Cooling Use," Energy and Buildings, 20, Elsevier Sequoia, Netherlands.

Parker, D., P. Broman, J. Grant, L. Gu, M. Anello, R. Vieira and H. Henderson, 1999, "EnergyGauge USA: A Residential Building Energy Design Tool." Proceedings of Building Simulation '99, Kyoto, Japan. International Building Performance Simulation Association, Texas A&M University, College Station, TX, September 1999.

Press, H. P., B. P. Flannery, S. A. Teukolsky, W. T. Vetterling, Numerical Recipes, Cambridge University Press, 1986.

Residential Alternative Calculation Method (ACM), Approval Manual For Compliance with California's 2005 Energy Efficiency Standards, Publication Number: 400-03-003F, Dated Published: October 2004, Effective Date: October 1, 2005

Sebald, A. V., 1985," Efficient Simulation of Large Controlled Passive Solar Systems: Forward Differencing in Thermal Networks", Solar Energy Vol. 34, No. 3.

Sharples, S., "Eaves and roof ridge pressure coefficients on an isolated low-rise dwelling: Wind tunnel study", Proc. CIBSEA: Building Serv. Eng. Res. Technol. 18(1) 59-61 (1997).

Sherman, M., "The Use of Blower Door Data", LBL #35173, March, 1998. Appendix: Modeling Tools.

Sherman, M.H., Grimsrud, D.T., "Measurement of Infiltration Using Fan Pressurization and Weather Data, Oct 1980, LBL-10852.

Subbarao, K., J. Anderson, "A Frequency-Domain Approach to passive Building Energy Analysis", SERI/TR-254-1544, July 1982.

Teitel, M., A. Shklyar, Pressure Drop Across Insect-Proof Screens, Trans. ASAE, Vol. 41(6), 1998.

Valera, D.L., A.J. Alvarez ad F.D. Molina, "Aerodynamic analysis of several insect-proof screens used in Greenhouses," Spanish Journal of Agricultural Research (2006) 4(4), 273-279.

Walker, Iain, 2005, " REGCAP Model Outline."

Walker. I.S., T.W.Forest, D.J. Wilson,"An attic-interior infiltration and interzone transport model of a house.," Building and Environment 40 (2005) 701-718.

Walker, I.S., T.W. Forest and D.J. Wilson (1995), "A Simple Calculation Method for Attic Ventilation Rates", Proc. 16th AIVC Conference, Vol. 1, pp. 221-232, Air Infiltration and Ventilation Centre, Coventry, UK.

Walker, I.S. and D.J. Wilson. 1994, " Practical Methods for Improving Estimates of Natural Ventilation Rates," Proc. 15th AIVC Conference, Buxton, U.K., 1994: 517-525.

Walker, I.S., and D. J. Wilson, 1990, "The Alberta Air Infiltration Model, AIM-2". The University of Alberta, Dept. of Mechanical Engineering, Tech Report 71.

Wright, J.L., Kotey, N.A., 2006. Solar Absorption by Each Element in a Glazing/Shading Layer Array, ASHRAE Transactions, Vol. 112, Pt. 2. pp. 3-12.

Wright, J.L. 2008. "Calculating Centre-Glass Performance Indices of Glazing Systems with Shading Devices," ASHRAE Transactions, Vol. 114, Pt. 2.

Walton, G.N. , 1983, Thermal Analysis Research Program Reference Manual, NBSSIR 83-2655. National Bureau of Standards.

Walton, G.N., A New Algorithm for Radiant Interchange in Room Loads Calculations, ASHRAE Transactions, 1980, Vol. 86, Pt. 2.

Wallenten, Petter, "Heat transfer coefficients in a full scale room with and without furniture", Lund Institute of Technology, Sweden.

Wallenten, P., 2001. Convective heat transfer coefficients in a full-scale room with and without furniture, Building and Environment 36(6), 743-751.

Woloszyn, M., Rusaouën G., Airflow Through Large Vertical Openings in Multizone Modelling, " Building Simulation '99, vol 6, Kyoto (Japan): IBPSA, 1999 p. 465-471.

Xu, Y.L., G.F. Reardon, "Variations of wind pressure on hip roof with roof pitch", Journal of Wind Engineering and Industrial Aerodynamics, 73 (1998) 267-284)

APPENDIX H – Variable Capacity Heat Pumps

1.1 Ruleset Implementation Tests

1.1.1 Introduction

The California Public Resources Code Section 25402.1(b) requires that the Energy Commission certify calculation methods. California Code of Regulations Title 24, Part 1, Chapter 10, Section 109 requires that the Commission only approve a candidate compliance software if it predicts energy consumption substantially equivalent to that predicted by the public domain compliance manager when it models building designs or features.

The tests in this chapter are intended to verify that the Alternative Calculation Method (ACM) candidate compliance software correctly constructs the standard design model and applies rules of the Nonresidential ACM appropriately to the proposed and standard design models. The ruleset implementation tests cover representative portions of the rules for building envelope, lighting, daylighting, space use data, and HVAC. For each test, a set of three models is defined:

- User Model — The user model contains the user inputs for the as-designed building. In most cases, the values for the proposed design will be taken from user inputs with no modification. However, there are some cases where the building input is prescribed for the proposed design or constrained by mandatory minimums or other rules.
- Proposed Design Model — The proposed model is defined by the rules in the *Nonresidential and Multifamily Buildings ACM Reference Manual*, is created by the vendor ACM candidate compliance software, and is the building modeled for compliance. This model takes user inputs for building geometry, building envelope, space functions, lighting, and HVAC and is used in the compliance simulation.
- Standard Design Model — This is the baseline model defined by the *Nonresidential and Multifamily Buildings ACM Reference Manual* modeling rules. It is used to set the energy budget that is the basis for comparison which determines whether a building passes compliance using the performance method.

These tests do not require that simulation outputs be verified, but they do require that simulation input files for the proposed design and standard design are properly constructed according to the rules in the *Nonresidential and Multifamily Buildings ACM Reference Manual*. Some tests require that sizing runs be performed for HVAC inputs with values that depend on autosized standard design systems.

1.1.2 Overview

The test runs described in this chapter represent the Title 24 Nonresidential and Multifamily ACM code compliance calculation and use the following prototype models:

- small office building
- medium office building

- large office building
- warehouse building
- medium retail building
- small hotel

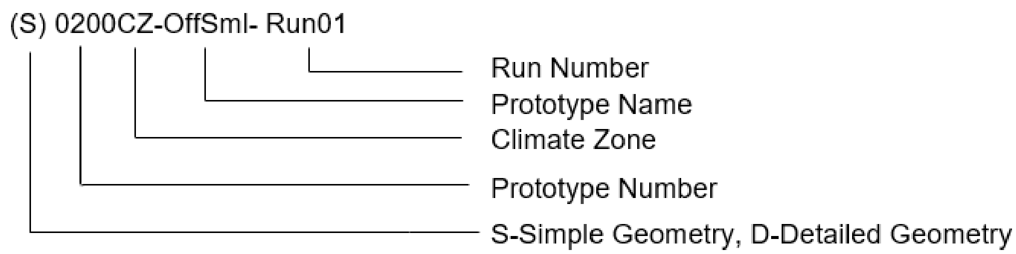
For details on the prototype models, refer to 1.2. Each standard design test case shall be created by modifying the prototype model as described in 1.1.3 of this document. The modified prototype model shall form the proposed case for each test run. The standard design model shall be generated by compliance software as ~~per~~ specified by the rules in the *Nonresidential and Multifamily Buildings ACM Reference Manual*. The standard design and proposed model files for each test case shall then be evaluated to verify that:

- The standard design building envelope constructions are correctly substituted for exterior opaque surfaces and fenestrations.
- The fenestration area in the standard design building is reduced in accordance with the *Nonresidential and Multifamily Buildings ACM Reference Manual* when the proposed design fenestration area is greater than 40 percent of the exterior wall.
- The skylight area in the standard design building is adjusted in accordance with the *Nonresidential and Multifamily Buildings ACM Reference Manual*, when applicable.
- Default schedules of operation are applied for both the standard design building and the proposed design building.
- The proposed and standard design cases use the same defaults, or tailored inputs, for internal loads as required by the *Nonresidential and Multifamily Buildings ACM Reference Manual.*
- The standard design building lighting system is correctly specified.
- Receptacle loads and process loads are modeled according to the rules in the *Nonresidential and Multifamily Buildings ACM Reference Manual.*
- The standard design building uses the correct system types as prescribed in **Error! Reference source not found.** of the *Nonresidential ACM Reference Manual*.
- An economizer (of the right type) is included in the standard design building, if required.
- The primary and secondary standard design building systems are properly specified and sized.
- Fan inputs are correctly specified for the standard design building.
- Prescribed modeling assumptions are applied for both the standard design building and the proposed design building.
- Conditioned, indirectly conditioned, and unconditioned spaces are modeled.
- Other standard design building specifications or modeling assumptions or both are correctly applied.

As the ACM candidate compliance software developer verifies the various test conditions, the input and output files should be annotated with comments or other methods to demonstrate that the modeling rules specified in the *Nonresidential and Multifamily Buildings ACM Reference Manual* are correctly applied. ACM candidate compliance software developers should use the spreadsheets provided by the Energy Commission to report the results of these tests. These annotated files shall then be submitted to the CEC for further evaluation. Any errors discovered shall be corrected by making modifications to the

ACM candidate compliance software, the runs shall be repeated, and the new results shall be annotated for submittal to the CEC.

The standard design tests are labeled using the format:



1.1.3 Ruleset Implementation Tests

The tests provided by the Energy Commission shall be performed to verify that the compliance software correctly creates the standard design model and applies modeling rules as ~~per~~ specified by the requirements of the *Nonresidential and Multifamily Buildings ACM Reference Manual*.

The characteristics of the user model and inputs to be verified in the proposed and standard design models are provided by the Energy Commission.

1.1.3.1 Results Comparison

The applicant shall perform all tests specified in Chapter 3.4: Ruleset Implementation Tests and Chapter 3.5: Software Sensitivity Tests and report the outputs in the forms provided by the Energy Commission. The standard design for some inputs, such as cooling efficiency and pump power, depend upon the autosizing of the HVAC equipment. The ruleset implementation tests do not check that the autosized capacity matches the reference method but that the standard design input is properly defined in relation to the autosized capacity.

1.2 Software Sensitivity Tests

This chapter details the eligibility requirements for a candidate simulation program for use as compliance software. A series of quantitative tests called *software sensitivity tests* shall be performed to measure the change in energy consumption when changing specified input parameters. ACM candidate compliance software results will be compared against predetermined reference results to demonstrate that the ACM candidate compliance software is acceptable for use in code compliance. All the test cases provided by the Energy Commission shall be performed and results summarized in the forms provided by the Energy Commission.

1.2.1 Overview

The ACM candidate compliance software shall perform a suite of software sensitivity tests to demonstrate that the performance is acceptable for code compliance. The ACM candidate compliance software test results shall be compared against a base case called the *reference test case*. The reference test case is the corresponding match of a particular test case simulated already on EnergyPlus engine. The reference test case results are in spreadsheet provided by the Energy Commission.

Test cases specific for simplified geometry are only for software with 2D inputs for building geometry. Software with a 2D geometry approach shall seek certification by submitting the simplified geometry test cases. In addition, they are also required to produce results for HVAC tests that will be compared against the HVAC reference test results that are common for both simplified and detailed geometry.

The test cases will assess the sensitivity of the ACM candidate compliance software to various inputs ranging from envelope thermal conductance to HVAC system performance. Each case tests the effect of the input component on building end-use energy and annual LSC. The following six building components will be tested through a series of tests:

- Opaque envelope
- Glazing
- Lighting
- Daylighting
- Receptacle loads
- HVAC system parameters

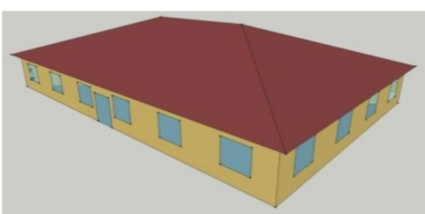
1.2.2 Prototype Models

The software sensitivity tests are performed on four nonresidential and two multifamily prototypes. The nonresidential prototype models are a subset of the U.S. Department of Energy (DOE) prototype building models developed by PNNL for analysis of ASHRAE Standard 90.1. Furthermore, the nonresidential prototype models are EnergyPlus model input files of the DOE prototype building models, modified to comply with the requirements of Title 24. The prototype models will be the reference baseline runs for the test cases. The ACM candidate compliance software shall replicate the building models below using the same inputs as the prototype models. The models so replicated will be the candidate baseline models for the test cases.

A summary of the prototype models is provided by the Energy Commission. Detailed input files of the reference baseline models are available from the CEC's Building Energy Efficiency Software Consortium web page at http://bees.archenergy.com/.

Prototype models used for software sensitivity test cases are:

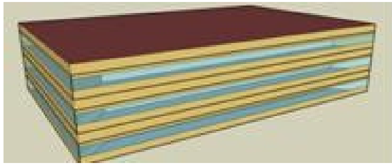
Small Office (02000CZ-OffSml):



Source: California Energy Commission

The small office building model is a single floor rectangular building of 5,500 square feet. It has punched windows and a hipped roof with an attic. There are five zones, each served by packaged single-zone air conditioner units. This prototype is used for simple geometry test cases only.

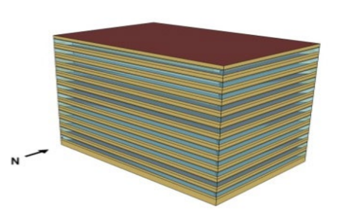
Medium Office Building (0300CZ-OffMed):



Source: California Energy Commission

The medium office building model is a three floor rectangular building with an overall area of 53,600 square feet. It has a window-to-wall ratio of 33 percent with fenestration distributed evenly across all four façades. The zones are served by DX cooling and gas furnace heating with hot water reheat. This prototype is used for both detailed geometry and simple geometry test cases.

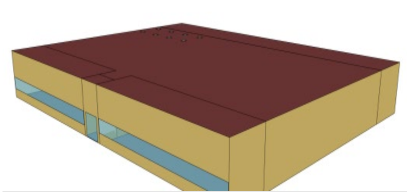
Large Office Building (0400CZ-OffLrg):



Source: California Energy Commission

The large office building has 12 floors and a basement floor with glass windows with a window-to-wall ratio of 40 percent on the above-grade walls. The total area of the building is 498,600 square feet. The HVAC system type used is a variable-air-volume (VAV) system.

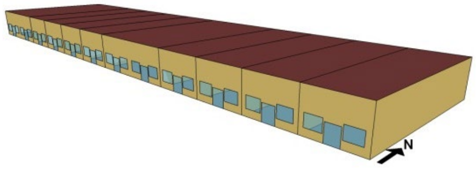
Stand-Alone Retail (0500CZ-RetlMed):



Source: California Energy Commission

The stand-alone retail building is a single floor rectangular building measuring 178 feet by 139 feet. The total area is 24,695 square feet. Windows are located only on the street-facing façade and occupy 25.4 percent of that façade. The building is divided into five thermal zones that are served by packaged single-zone systems. This prototype is used for both detailed geometry and simple geometry test cases.

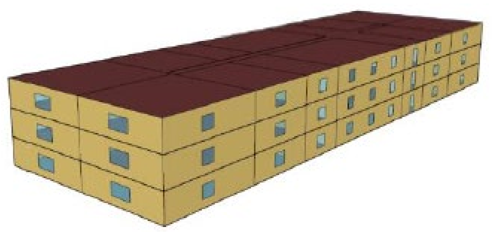
Strip Mall Building Strip Mall-PSZ System (1000CZ-RetlStrp):



Source: California Energy Commission

The strip mall building area is 22,500 square feet. It has 10 zones each with rooftop units. The building has windows in the street-facing façade and has an overall window-to-wall ratio of 10.5 percent.

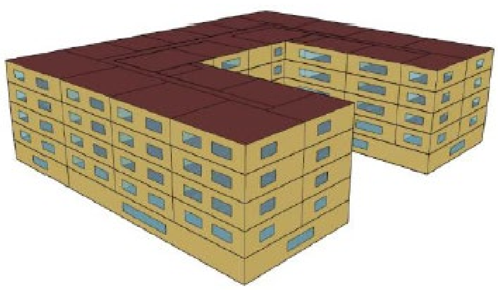
LOADED CORRIDOR MULTIFAMILY BUILDING (MF36UNIT_3STORY):



Source: California Energy Commission

The loaded corridor multifamily building is a three floor residential building with 39,372 square feet of building area, 36 residential units, flat roof, slab on-grade foundation and wood framed wall construction, and a window to wall ratio of 0.25.

MID-RISE MIXED-USE BUILDING (MF88UNIT_5STORY):



Source: California Energy Commission

The mid-rise mixed-use building is a five floor 113,100 square feet mixed use building. The building has one ground floor of nonresidential space and four additional stories of residential space, 88 residential units, flat roof, underground parking garage, concrete podium construction, wood-framed wall construction, and a window-to-wall ratio of 0.10 (ground floor) and 0.25 (residential floors).

1.2.3 Climate Zones

The software sensitivity test cases use building models for 5 of the 16 California climate zones. Most tests are performed with two or three climate zones to capture the sensitivity of the input characteristics to extremes in weather conditions. The test cases are performed in climate zones that represent mild, hot, and cold climates, respectively.

Table 1: Climate Zones Tested

Climate Zone	Example City/Weather File
1	Arcata/ARCATA_725945

Climate Zone	Example City/Weather File
6	Torrance/TORRANCE_722955
7	San Diego Lindbergh/ SAN-DIEGO-LINDBERGH_722900
15	Palm Springs/PALM-SPRINGS-INTL_722868
16	Blue Canyon/BLUE-CANYON_725845

Source: California Energy Commission

1.2.4 Labeling Test Runs

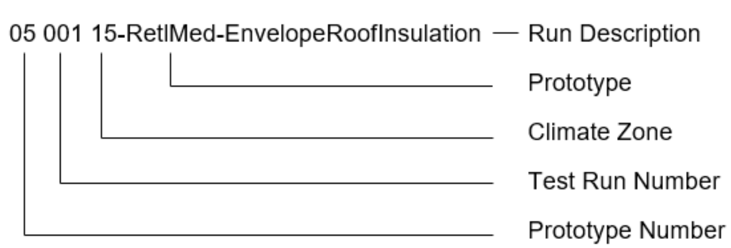
Each test case in the software sensitivity test is labeled uniquely to make it easier to keep track of the runs and facilitate analysis. The following scheme is used:

XXYYYZZ-Prototype-Run Description

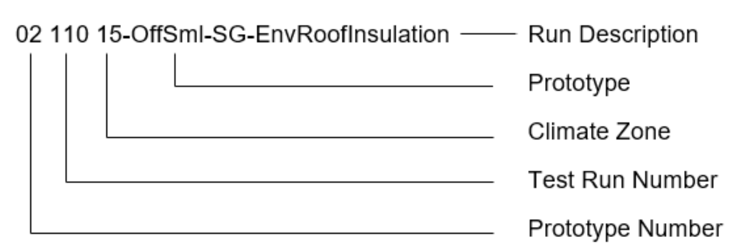
Where:

- XX denotes the Prototype Number
- YY denotes Test Run Number
- ZZ denote Climate zone

Detailed Geometry Example:



Simplified Geometry Example:



1.2.5 Test Criteria

ACM candidate compliance software vendors shall perform a series of computer runs. Each of these runs shall be a systematic variation of the candidate base case model as described in 1.2.7. The applicant test case results will be compared to the reference results to verify that ACM candidate compliance software meets the requirements of the *Nonresidential and Multifamily ACM Reference Manual*.

Simulation results for each test case will be compiled in forms provided by the Energy Commission. Compiled results will include annual site energy consumption for each end use, overall site energy consumption, total unmet load hours, annual LSC and percentage variation of annual LSC, annual Source Energy and percentage variation of annual Source Energy, and total end-use site energy.

The annual LSC percentage variation shall be calculated using the formula:

$LSC_{\%} = (LSC_b – LSC_n)/LSC_b$

Where, $LSC_{\%}$ is the LSC percentage variation,

- LSC_n is the annual LSC for test case number n and
- LSC_b is the annual LSC for the base case run.
- The annual Source Energy percentage variation shall be calculated using the formula:
- $\text{Source Energy}_{\%} = (\text{Source Energy}_b – \text{Source Energy}_n)/\text{Source Energy}_b$
- $\text{Source Energy}_{\%}$ is the Source Energy percentage variation,
- Source Energy_n is the Source Energy for test case number n and
- Source Energy_b is the Source Energy for the base case run.

To be accepted, the ACM candidate compliance software should fulfill the passing criteria as determined by the CEC.

For each test case, the change in energy for the test case must be in the same direction as the Reference Method test case result and must be equal to the Reference Method test case percentage change in LSC energy, plus or minus 0.5 percent of baseline LSC energy.

If any of the tests required for the Title 24 compliance feature set fails to meet these criteria, the ACM candidate compliance software will not be accepted for compliance use.

1.2.6 Reporting Test Results

For each test case, the LSC energy use of the modeled building is reported (kBtu/ft^2), along with the LSC energy use attributed to the major fuel types (electricity, gas), site energy use, and energy end-use intensity for the regulated end uses (cooling, heating, lighting, and so forth). The following energy totals are reported:

- Annual LSC EUI (kBtu/ft2)
- Annual Source Energy EUI (kBtu/ft2)
- Annual SiteEUI – Electricity (kWh/ft2)
- Annual SiteEUI – Natural Gas (therm/ft2)
- Annual Total End Use Site Energy EUI – kBtu/ft2

Site Energy End Uses:

- Site Energy: Heating (kBtu/ft2)
- Site Energy: Cooling (kBtu/ft2)
- Site Energy: Interior Lighting (kBtu/ft2)
- Site Energy: Interior Equipment (kBtu/ft2)
- Site Energy: Fans (kBtu/ft2) (Airside Fans, does not include tower fans)

- Site Energy: Pumps (kBtu/ft2)
- Site Energy: Towers (kBtu/ft2) Water heating (kBtu/ft2)
- ~~TDV~~LSC Percentage Variation – this field is used for the compliance test
- Total End Use Site Energy percent - percentage change in site energy use
- Pass/Fail – test fails if it does not meet passing criteria
- Unmet load hours (UMLH) – defined as the zone with the most UMLH
    - Reference Model Occupied UMLH
    - Candidate Model Occupied UMLH
    - Reference Model Number of Zones with excess UMLH (>150)
    - Candidate Model Number of Zones with excess UMLH (>150)

The results spreadsheet provides the results of the reference method for each test and provides a column for the vendor to report the results from the ACM candidate compliance software.

The variation from baseline section of the spreadsheet shows the percentage change in ~~TDV~~LSC energy use (kBtu/ft^2) and source energy from the base case for testing. The percentage must be within the passing criteria for the ACM candidate compliance software to pass this test.

Also reported is the number of UMLH during occupied hours for the building. An UMLH for a specific zone in Energy Code compliance is defined as any hour when the zone has an unmet cooling or heating load. This is typically reported by the ACM candidate compliance software for each zone in the building. For the test case results, two unmet load hour metrics must be reported: the number of UMLH for the zone with the greatest number of UMLH, and the number of zones that fail the *Nonresidential and Multifamily ACM Reference Manual* criteria for acceptable UMLH. (Any zones with greater than 150 hours fail the criteria.)

The spreadsheet where the results are documented indicates whether the ACM candidate compliance software passes or fails a test. The result in column AL of the spreadsheet indicates whether the ACM candidate compliance software passes the test.

1.2.7 Software Sensitivity Test Cases

Test cases assess the energy impact of one or more of the building or system input characteristics on the baseline model. Each test suite consists of a series of unique test cases aimed to test the effect of a specific characteristic on building energy performance. Simulations are grouped according to test criteria and subgrouped based on the reference model type to allow direct comparison of results. For each test case, the ACM candidate compliance software will modify the candidate baseline model with specific inputs as described in the test case description chapter.

The test cases are simulated on multiple California weather files to evaluate the sensitivity of the building or system input to extremes in climate. Results of the test case runs and the ~~TDV~~LSC percentage variation over the baseline run shall be compiled and compared against the reference results.

Detailed descriptions of the standard design models are provided by the Energy Commission. CBECC input files for all baseline and test case models are available from the CEC's, Building Energy Efficiency Software Consortium web page, http://bees.archenergy.com.

1.2.8 Results Documentation

The applicant shall perform simulations for all tests specified above. A detailed description of each test case is provided by the Energy Commission, and report results in the forms provided by the Energy Commission. Some of the prototype models have variants of the baseline model. These include:

- Stand-alone duct loss baseline – a variant of the stand-alone retail model
- StripMall-PTAC model – a variant of StripMall-PSZ model
- StripMall-Fan Coil model – a variant of StripMall-PSZ model

Three test cases are presented here as an example: one for building envelope, one for lighting and daylighting, and one for HVAC. The development of the other required test cases follows the same process.

Example Test Case: 0301315-OffMed-GlazingWindowSHGC

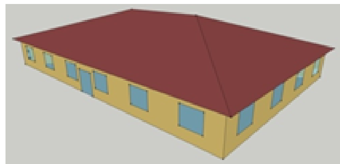
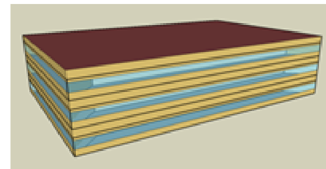
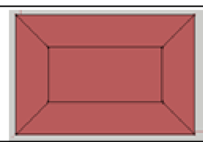
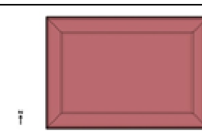
For this test case, the U-factor and solar heat gain coefficient (SHGC) of all vertical fenestration is decreased by 20 percent. The prototype used for this test case is a medium office building.

Before the test cases are run, the first step is to generate the prototype models for the four reference buildings, which are required for all the tests. T (While many of the prototype model inputs are based on Title 24 prescriptive requirements, the prototype models do not exactly conform to minimum Title 24 requirements but are intended to test the sensitivity of the ACM candidate compliance software simulation results to common variations in building inputs.)

Step 1: Generate prototype models

The first step is to generate the prototype building for the medium office building. The detailed specification of the medium office building is provided by the Energy Commission. A portion of the inputs are shown in Figure 1: Prototype Model Definition. The prototypes are defined for the reference models provided by the Energy Commission.

Figure 1: Prototype Model Definition

Prototype Description	Small Office Building	Medium Office Building
Vintage	New Construction	New Construction
Location	CZ-6/15/16	CZ-3/6/15/16
Fuel Type	gas, electricity	gas, electricity
Total Floor Area (sq feet)	5500 (90.8 ft x 60.5ft)	53600 (163.8 ft x 109.2 ft)
Building shape		
Aspect Ratio	1.5	1.5
Number of Floors	1	3
Window Fraction (Window-to-Wall Ratio)	24.4% for South and 19.8% for the other three orientations (Window Dimensions: 6.0 ft x 5.0 ft punch windows for all façades)	33% (Window Dimensions: 163.8 ft x 4.29 ft on the long side of facade 109.2 ft x 4.29 ft on the short side of the façade)
Window Locations	evenly distributed along four façades	evenly distributed along four façades
Shading Geometry	none	none
Azimuth	non-directional	non-directional
Thermal Zoning	Perimeter zone depth: 16.4 ft. Four perimeter zones, one core zone and an attic zone. Percentages of floor area: Perimeter 70%, Core 30%	Perimeter zone depth: 15 ft. Each floor has four perimeter zones and one core zone. Percentages of floor area: Perimeter 40%, Core 60%
		

Source: California Energy Commission

The prototype model definition in the spreadsheet contains links to other input definitions:

Rows 19, 26, 45: Links to layer-by-layer exterior construction assembly definitions in the *Construction Assembly* tab

Row 52: Links to layer-by-layer interior construction assembly definitions in the *Construction Assembly* tab

Step 2: Define base case and variation for test run

The base case is defined as the starting point for each test. In many tests, the base case will be one of the prototype models. However, in some cases, a variation of the prototype may serve as the base case for the test.

Figure 2: Base Case Definition

Y4 | f_x | Decrease U value & SHGC of windows by 20% compared to baseline case

	A	U	V	W	X
2	**Test Run Name**	**20CZ06MediumOffice Envelope FloorslabInsulation**	**21CZ06MediumOffice Envelope Infiltration**	**22CZ06MediumOffice Glazing WindowU**	**23CZ06MediumOffice Glazing WindowSHGC**
3	**Baseline**	CZ06MediumOffice	CZ06MediumOffice	CZ06MediumOffice	CZ06MediumOffice
4	**Test Description**	Change Floor slab F factor to 0.45	Increase Exterior Wall Infiltration by 10% compared to baseline case	Decrease U value of windows by 20% compared to baseline case	Decrease SHGC of windows by 20% compared to baseline case
5	Location	CZ06	CZ06	CZ06	CZ06

Source: California Energy Commission

For this test, the baseline field in row 3 of the *Test Criteria* tab shows that the baseline is *CZ06MediumOffice*, the medium office prototype in Climate Zone 6.

This same *Test Criteria* tab shows the input(s) to be verified, which are highlighted in purple. For this test, the SHGC of all vertical fenestration is reduced by 20 percent, from 0.25 to 0.20.

Figure 3: Input Parameter Variation for Medium Office

A	U	V	W	X
Test Run Name	**20CZ06MediumOffice Envelope FloorslabInsulation**	**21CZ06MediumOffice Envelope Infiltration**	**22CZ06MediumOffice Glazing WindowU**	**23CZ06MediumOffice Glazing WindowSHGC**
Baseline	CZ06MediumOffice	CZ06MediumOffice	CZ06MediumOffice	CZ06MediumOffice
Test Description	Change Floor slab F factor to 0.45	Increase Exterior Wall Infiltration by 10% compared to baseline case	Decrease U value of windows by 20% compared to baseline case	Decrease SHGC of windows by 20% compared to baseline case
Location	CZ06	CZ06	CZ06	CZ06
Dimensions		Refer MediumOffice		
Tilts and orientations				
Window				
Dimensions				
Glass-Type and frame				
U-factor (Btu / h * ft^2 * °F)			0.29	
SHGC				0.2
Visible transmittance				
Operable area				

Source: California Energy Commission

Step 3: Run the base case model and generate test results

Once the base case model is developed, the simulation is run, and the results are recorded onto the spreadsheet of test cases.

The ACM candidate compliance software shall report electricity use by end use, gas use by end use, LSC, and UMLH. For compliance, UMLH are defined at the zone level, and the zone with the greatest number of UMLH must pass the criteria specified in the sizing procedure.

For the reference tests, the capacities and flow rates of the HVAC system are provided by the Energy Commission.

Step 4: Run the test case model (with the reduced SHGC) and report the results

The model is rerun, and the energy results and outputs are reported. The percentage change in energy use is reported.

Step 5: Report the change in regulated LSC and source energy use from the base case as a percentage change

The reported percentage change in energy use from the ACM candidate compliance software must fall within the passing criteria for the reference method.