California Energy Commission

STAFF REPORT

Appendix H: Variable Capacity Heat Pumps

FOR THE 2025 BUILDING ENERGY EFFICIENCY STANDARDS

Energy Conservation Manual

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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:
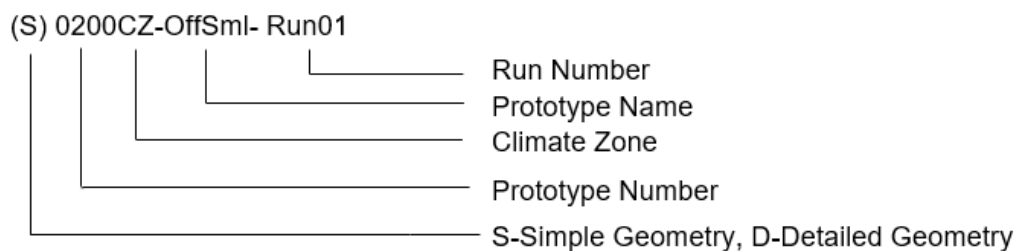
1.1.3 Ruleset Implementation Tests

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):
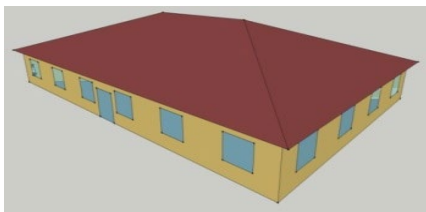
Source: California Energy Commission

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):
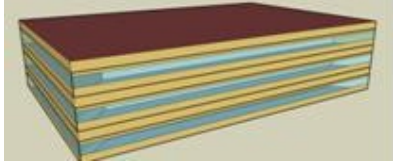
The medium office building model is a three floor rectangular building with an overall area of 53,600 square feet. It has a window-to-wall ratio of 33 percent with fenestration distributed evenly across all four façades. The zones are served by DX cooling and gas furnace heating with hot water reheat. This prototype is used for both detailed geometry and simple geometry test cases.
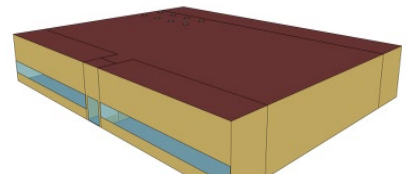
Large Office Building (0400CZ-OffLrg):
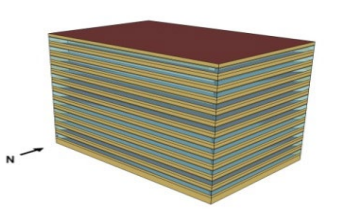
The large office building has 12 floors and a basement floor with glass windows with a window-to-wall ratio of 40 percent on the above-grade walls. The total area of the building is 498,600 square feet. The HVAC system type used is a variable-air-volume (VAV) system.

Stand-Alone Retail (0500CZ-RetlMed):

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.
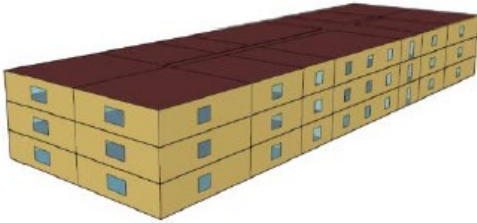
Strip Mall Building Strip Mall-PSZ System (1000CZ-RetlStrp):
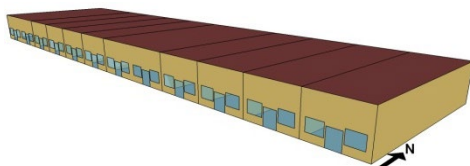
The strip mall building area is 22,500 square feet. It has 10 zones each with rooftop units. The building has windows in the street-facing façade and has an overall window-to-wall ratio of 10.5 percent.

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):
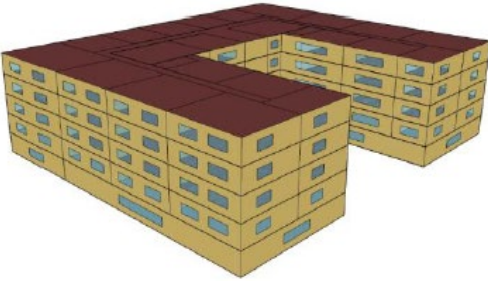
Source: California Energy Commission

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
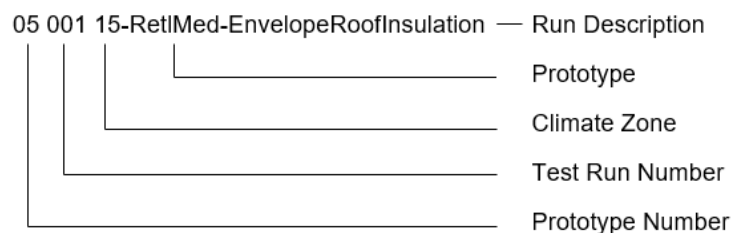
1.2.4 Labeling Test Runs

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:

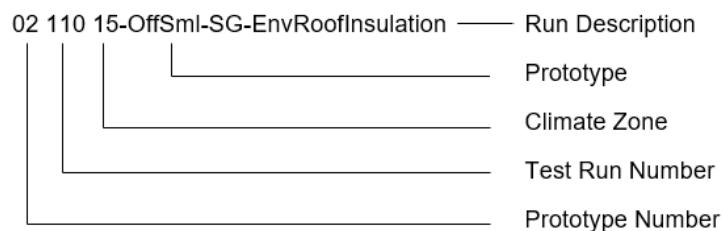XXYYYZZ-Prototype-Run Description

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:
- Source Energy$_\%$ = (Source Energy$_b$ – Source Energy$_n$)/Source Energy$_b$
- 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.

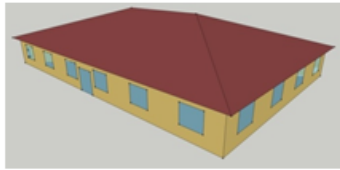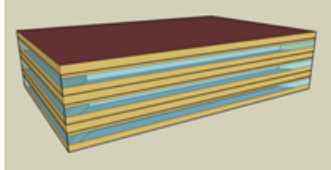Example Test Case: 0301315-OffMed-GlazingWindowSHGC

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	▼	fx	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				
Tilts and orientations		Refer MediumOffice		
Window				
Dimensions				
Glass-Type and frame				
U-factor (Btu / h * ft^2 * °F)			0.29	
SHGC				0.2
Visible transmittance				
Operable area				

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.