Energy Research and Development Division
FINAL PROJECT REPORT

GETTING TO 2020

Two Software Tools to Help Californians Design Zero Net Energy Homes

Prepared for: California Energy Commission
Prepared by: Energy Design Tools Group, UCLA Department of Architecture and Urban Design

MARCH 2013
CEC-500-2013-116

PRIMARY AUTHOR(S):
Murray Milne
Robin Liggett

Energy Design Tools Group
Department of Architecture and Urban Design
UCLA
Los Angeles, CA 90095
310-454-7348
energy.design.tools@ucla.edu

Contract Number: 500-08-029

Prepared for:

California Energy Commission

Dustin Davis
Contract Manager

Virginia Lew
Office Manager
Energy Efficiency Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH ANDDEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

We wish to thank the many people who contributed to this project:

- Bill Beckman, Solar Energy Laboratory, University of Wisconsin and
- David Bradley, TESS Corporation, Madison Wisconsin
- Gail Brager and Ed Arens, University of California, Berkeley
- Tim Kohut, Collaborative Project Consulting, Inc
- John Morton, ZNE Buildings Program, Southern California Edison
- Marc Schiller, Building Science Program, University of Southern California
- Peter Turnbull, ZNE Building Program, Pacific Gas and Electric
- Pablo LaRoche, California Polytechnic University, Pomona
- Alicyn Henkhaus, University of Southern California

… and especially to our software development team:

Carlos Gomez and Don Leeper

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Getting to 2020 is the final report of this project to develop Two Software Tools to Help Californians Design Zero Net Energy Homes (contract number 500-08-029) conducted by Energy Design Tools Group, Department of Architecture and Urban Design, UCLA (www.energy-design-tools.aud.ucla.edu). The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

Home Energy Efficient Design and Climate Consultant are two user-friendly design tools that help Californians create more energy efficient homes that take advantage of their local climate resources. These new tools were developed to help meet the goals of Assembly Bill 32, which calls for substantial greenhouse gas reductions and the California Public Utilities Commission's Big Bold Strategies, which aims for zero net energy new residential construction by 2020. These tools provided Californians a head start at "Getting to 2020". Hundreds of thousands of permits will be issued for new residential construction and for remodeling California's existing housing stock before 2020. The objective of this project was to make it possible for California homeowners, contractors, builders, and architects to become involved from the very beginning of a project in designing comfortable, energy-efficient homes, rather than leaving everything up to an energy consultant at the end of the project who would be focusing on code compliance.

These software tools run on personal or Macintosh computers and emphasize graphic output. Climate Consultant creates various graphic representations of the local climate data and displays a list of the Top 20 Design Guidelines to best use the climate resources of each specific location. Home Energy Efficient Design is a "day one" design tool that lets users quickly create alternative schemes for their home. It uses local climate data to calculate and compare the performance of each new scheme as it evolves toward a zero net energy home. Passive cooling and heating strategies can also be incorporated along with solar hot water and solar photovoltaic systems. The final scheme can be automatically transferred to a certified compliance program to confirm that it meets the California energy building code. Both programs are free and when this report was written they collectively had over 120,000 users.

Keywords: HEED, Climate Consultant, home, energy, design, Zero Net Energy, passive, solar, PV, SHW, California, Energy Code, AB32, 2020

Please use the following citation for this report:

Milne, Murray, Robin Liggett, UCLA Department of Architecture and Urban Design, 2013, ***Getting to 2020: Two Software Tools to Help Californians Design Zero Net Energy Homes***, California Energy Commission, Publication number: CEC-500-2013-116.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ..... **I**

PREFACE ..... **II**

ABSTRACT ..... **III**

TABLE OF CONTENTS ..... **IV**

LIST OF FIGURES ..... **V**

EXECUTIVE SUMMARY **1**

Introduction 1

Project Purpose 1

Project Results 2

Project Benefits 2

CHAPTER 1: INTRODUCTION **5**

1.1 Background 5

1.2 Advancements Produced by this Project 5

CHAPTER 2: WORKED EXAMPLES OF HEED AND CLIMATE CONSULTANT **7**

2.1 HEED Case Study 7

2.2 Climate Consultant Case Study 19

CHAPTER 3: UPDATES TO HEED AND CLIMATE CONSULTANT **29**

3.1 HEED Upgrades, Expanded Development and Validation 29

3.1.1 Year 1 HEED Upgrades 29

3.1.2 Year 2 HEED Upgrades 31

3.1.3 Year 3 HEED Upgrades 33

3.2 Climate Consultant Upgrades 35

3.2.1 Year 1 Climate Consultant Upgrades 35

3.2.2 Year 2: Climate Consultant Upgrades 36

3.2.3 Year 3 Climate Consultant Upgrades 38

CHAPTER 4: DISSEMINATION AND PROJECT OUTREACH **39**

4.1 Energy Design Tools Web Site 39

4.2 Technology Transfer: HEED-Climate Consultant Workshops 41
4.2.1 Year 1: 41
4.2.2 Year 2 42
4.2.3 Year 3: 42
4.3 User Hot Line: Comments on HEED and Climate Consultant 42
4.3.1 HEED User Comments 42
4.3.2 Climate Consultant User Comments 45
4.3.3 Multiplier Effect: User Hot Line Comments from Teachers 46
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS 48
5.1 Project Outcomes: Benefits to California 48
5.2 Recommendations for Future Work 48
REFERENCES 50
GLOSSARY 52
APPENDIX A: HEED VALIDATION TESTS A-1

LIST OF FIGURES

Figure 1: HEED Download and Installation 7
Figure 2: Initial Design Screen 8
Figure 3: Home Energy Rating 9
Figure 4: Home Energy Rating for a Remodeled Home in Sacramento 10
Figure 5: Shadows and Sunlight 11
Figure 6: Energy Costs 12
Figure 7: Energy Efficient Design 13
Figure 8: Basic Design Screens 14
Figure 9: Air Conditioner Output: 3D Results 15
Figure 10: Electric Charges under the Evaluate Icon 16
Figure 11: Climate Specific Design Guidelines 17
Figure 12: Code Compliance using EnergyPro 18
Figure 13: Climate Consultant Download and Installation 19
Figure 14: Temperature Range Plot 20

Figure 15: Monthly Diurnal Averages Plot 21
Figure 16: 3D Chart of Tilted Surface Radiation 22
Figure 17: Psychrometric Chart 23
Figure 18: Design Guidelines for the Full Year 24
Figure 20: Wind Wheel 26
Figure 21: User Help 27
Figure 22: Energy Design Tools web site excerpt 39
Figure 22: Energy Design Tools web site excerpt (continued) 40
Figure 22: Energy Design Tools web site excerpt (continued) 41

EXECUTIVE SUMMARY

Introduction

The "Getting to 2020" program refers to the year when all newly constructed homes should be zero net energy (ZNE) as set forth by the goals of the California Public Utilities Commission (CPUC) Big Bold Strategies program. With these goals fast approaching, Californians need tools to enable designing new or existing homes that maximize energy efficiency and lower energy consumption along with the ability to incorporate on-site renewable energy (solar photovoltaic and solar domestic hot water systems) to reach ZNE annually.

Project Purpose

The goal of this project was to enhance two existing software design tools. Home Energy Efficient Design (HEED) is a popular user-friendly graphic software tool that was first published in 2001. It was intended for intuitive use by architects, contractors, homeowners, and students to help them design more energy efficient homes. Climate Consultant was first published in 1988, and shows users the resources of their local climate, identifies the most appropriate home design resources for passive heating and cooling in that climate, and then gives a list of 20 detailed design guidelines with accompanying sketches.

There were three specific objectives of the project, each of which had numerous tasks associated with it.

1. Enhance HEED to help users:

    - Define any shape home with roofs of any slope and orientation using HEED's simple graphics.
    - Design photovoltaic (PV) and solar domestic hot water (SDHW) systems for their own specific home and to graphically click and drag collectors to fit onto their roof.
    - Easily draw in external shading objects like trees and nearby buildings.
    - See a sun's-eye-view of the building for each hour to check shading from nearby objects.
    - Export a building design file directly into certified code compliance tools such as EnergyPro.
    - Validate HEED against EnergyPlus using the Home Energy Rating System (HERS) Best Protocol.
    - Add various low energy cooling systems such as evaporative cooling and natural or fan-forced ventilation.
    - Add the option of air-to-air heat exchangers such as heat recovery ventilators.
    - Calculate hourly indoor air effective temperatures to evaluate natural ventilation effectiveness.
    - Expand computational capabilities for remodeling older pre-code homes.
    - Upgrade HEED to the 2008 Title 24 Code, the latest gas and electric rates, and the latest greenhouse gas (GHG) emissions coefficients.
    - Offer a Spanish language version of each new release
2. Enhance Climate Consultant to help users:

    - Understand the potential energy and comfort resources of their own local climate.

- Evaluate alternative thermal comfort strategies.
- Obtain a list of the top-20 Design Guidelines for their specific home in its specific climate.
- Have the option of trying a web-based version before they download and install the full version.
- See on a sun-shading plot how nearby objects shade windows or PV or SDHW collectors.

3. Offer nine workshops on HEED and Climate Consultant throughout the state, and maintain user hot lines for each:

    - Conduct workshops for three utilities: Pacific Gas and Electric (PG&E); Southern California Gas (SCG), which is a subsidiary of Southern California Edison; and San Diego Gas & Electric (SDG&E).
    - Conduct a workshop for the American Institute of Architects (AIA).
    - Staff user hotlines for HEED and Climate Consultant and maintain for three years following the completion of this project.

Project Results

Many new features were added to HEED and Climate Consultant, including PV and SDHW systems and new ways to passively create indoor thermal comfort. HEED also was updated to support the 2008 Title 24 Codes and Standards by calculating the energy performance of each scheme compared to a home that meets the 2008 Title 24 code. Technology transfer to the marketplace was aided by offering nine public workshops throughout California in the three major investor-owned utility territories: San Francisco for PG&E, Downey for SCG, and San Diego for SDG&E. This resulted in over 120,000 downloads of the two software programs, 50,000 downloads of HEED and over 70,000 downloads of Climate Consultant. The enhanced versions of HEED and Climate Consultant were designed to be user friendly enough for non-professionals but also to produce sophisticated simulations that were validated by the standards relied upon by energy professionals. These updated tools were compatible with both personal computers (PCs) and Macintosh computers (Macs). Both programs can be downloaded free of charge at: www.energy-design-tools.aud.ucla.edu/.

California energy policy goals are calling for commercial buildings to be much more energy efficient and for new construction to be ZNE by 2030. Additional tools similar to HEED and Climate Consultant that target commercial buildings would be helpful in order to reach energy policy goals without relying solely on energy consultants. HEED and Climate Consultant could also be updated to support the 2013 Title 24 building energy code and comfort criteria.

Project Benefits

The primary benefit of this project was to give California ratepayers two user-friendly tools that will help design more energy efficient or potentially ZNE homes. HEED and Climate Comfort made it possible for all Californians to become involved at the very beginning of their project rather than having to rely solely on energy consultants to design more energy efficient homes. If the use of HEED saved an average of just 25 percent of home energy consumption with only a modest one percent penetration of the new home market, then it would save Californian

ratepayers over $24 million in energy costs by 2020. These tools can also help California achieve its energy policy goals.

CHAPTER 1: Introduction

Getting to 2020 is a program that points to the year when all new homes should be Zero Net Carbon and Zero Net Energy (ZNE). It has been said that we will never get to 2020 without new tools and techniques. The objective of this project was to develop two software tools that can "change the market" with respect to designing homes that maximize energy efficiency. These tools make it possible for all Californians to become involved from "day-one" in the design of their new or existing home, and not just to rely on energy consultants brought in at the end of a project to check code compliance. The goal of this project is to push beyond the current business as usual approaches, to create new alternative paths to show Californians how to lower the end-use energy consumption of their homes, whether new or existing, and how to greatly exceed code standards, and even how to reach zero net energy.

1.1 Background

The two design tools that are being expanded as part of this project have been in development for many years.

HEED (Home Energy Efficient Design) is a popular user-friendly graphic software tool that was first published in 2001 intended for intuitive use by architects, contractors, homeowners, and students, to help them design more energy efficient homes. HEED's advantages have always been speed and ease of use. Inside HEED is a computation engine called Solar-5 that was first published in 1987, and has been under continuous development since. It calculates an hourly heat balance for the building for each of the 8760 hours in a year. It uses standard ASHRAE equations to account for the time lag of heat flow through opaque walls as well as for the time lag of internal thermal mass. It calculates indoor air temperatures that can float within the comfort range. It also integrates loads and energy calculations and in this sense is similar to the EnergyPlus engine. Over the years HEED has been validated using the ANSI/ASHRAE Standard 140-2001 and experimentally against a number of test cells as well as occupied buildings, all of which are documented on the HEED web site (www.energy-design-tools.aud.ucla.edu).

Climate Consultant is the second design tool that was expanded as part of this project. It was first published in 1988, and shows users the resources of their local climate and identifies the most appropriate home design resources for passive heating and cooling in that climate, and then gives a list of 20 detailed design guidelines with accompanying sketches. It can use any of the thousands of EnergyPlus weather files published by the US Department of Energy. It is intended for use at the very beginning of a project, which is the time when design changes are the least expensive to make and when they will have the greatest impact of the final outcome.

1.2 Advancements Produced by this Project

As a result of this project the new releases of HEED and Climate Consultant have added many new features.

These major new advancements have made HEED the first user friendly, whole-building design tool to allow users to specify a building integrated PV or Solar Hot Water System based on the work of Bill Beckman for the CEC. This new version of HEED will let users click and drag collectors/modules onto a 3-D image of their house and pivot it to the eye level of someone standing on the ground in order to evaluate layout and aesthetics. Then a sun's eye view lets them graphically check on shading each hour from nearby buildings or trees. Because HEED runs an hourly energy balance it can calculate how efficiently these on-site generation systems match the building loads. Also incorporated into HEED are a number of new passive heating and cooling options such as various natural and fan-forced ventilation cooling strategies, evaporative coolers, heat recovery ventilators, and detailed shading from trees and neighbors. Each design that HEED generates is complete enough to be directly exported to a certified code compliance tool, such as EnergyPro.

The advancements in the new versions of Climate Consultant incorporate the latest research on human thermal comfort. It has been argued that Californians must get beyond the idea that the only definition of thermal comfort is thermostatically controlled still air between 70 and 75 degrees. Climate Consultant now helps to demonstrate that there are other dimensions of thermal comfort, each of which can be less energy intensive. This is the first design tool to incorporate the work by Gale Brager (on the Adaptive Comfort Model) and Ed Arens (on how air motion impacts thermal comfort). These new advancements in Climate Consultant proceeded in parallel and are nicely cross-linked to HEED, for example, the human thermal comfort calculator developed in Climate Consultant in the first year was incorporated into HEED in the second year.

This Project also produced a number of additional advances to help Californians create zero net energy homes. A web-based version of Climate Consultant, called CClite, was created to allow beginning users to analyze their local climate without having to download and install the full program. Workshops were also offered throughout California to give users a hands-on experience in using these two tools.

All of this was a carefully integrated effort to help Californians understand the resources of their local climate and to implement alternative ways to create more comfortable, more efficient homes. The objective of these new design tools is to help Californians reach well beyond Title 24 minimum performance, and instead to see how they can achieve zero net energy.

The team is pleased to report that these two new versions of HEED and Climate Consultant now have over 120,000 users.

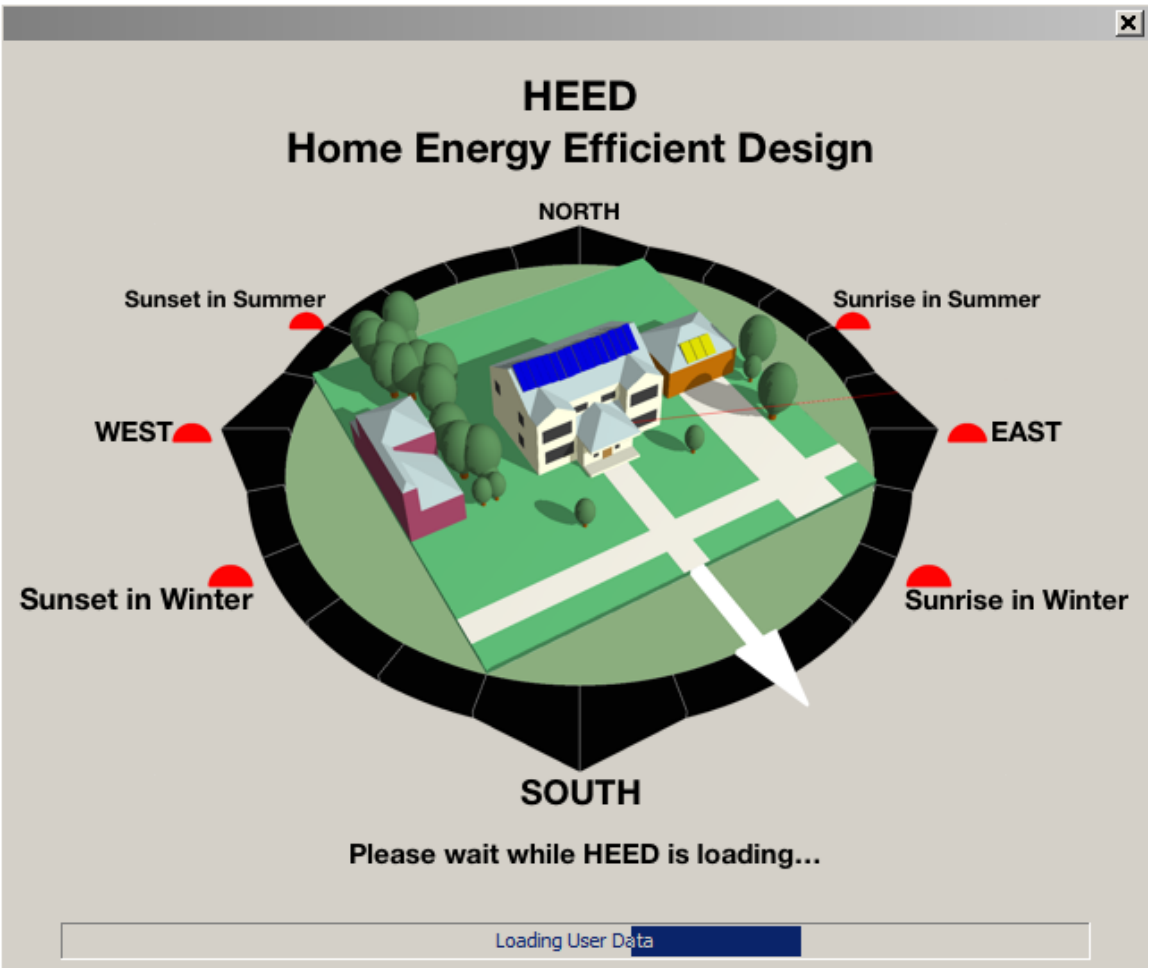
CHAPTER 2:
Worked Examples of HEED and Climate Consultant

These are some examples of selected screens showing HEED and Climate Consultant in action to retrofit a 1960s two-story house in Sacramento. These tools are based on the 2008 Title 24 building energy code, and contain California climate data for all 16 zones.

2.1 HEED Case Study

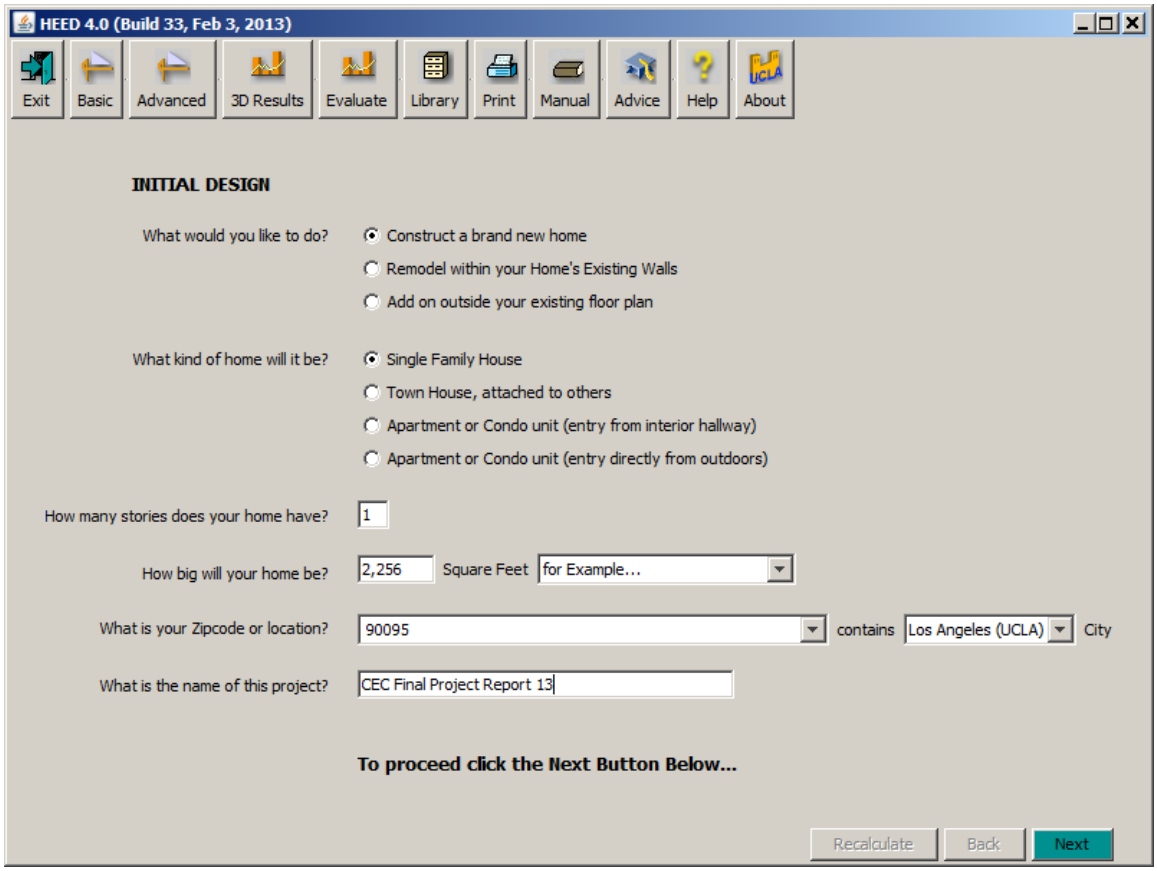
To download HEED go to: www.energy-design-tools.aud.ucla.edu/heed

Figure 1: HEED Download and Installation



HEED is a user-friendly design tool to help Californians design homes that reach zero net energy (ZNE). This image is taken from HEED's Orientation screen. It show a hypothetical house that was created on the Floor Planner screen to show building geometry, plus garages, trees, neighbors, and paving. To further adjust the site layout the user clicks on the arrow head and drags the building to its correct orientation. The objective is to create a model that correctly captures the solar radiation loads on the building's windows and solar collectors.

Figure 2: Initial Design Screen

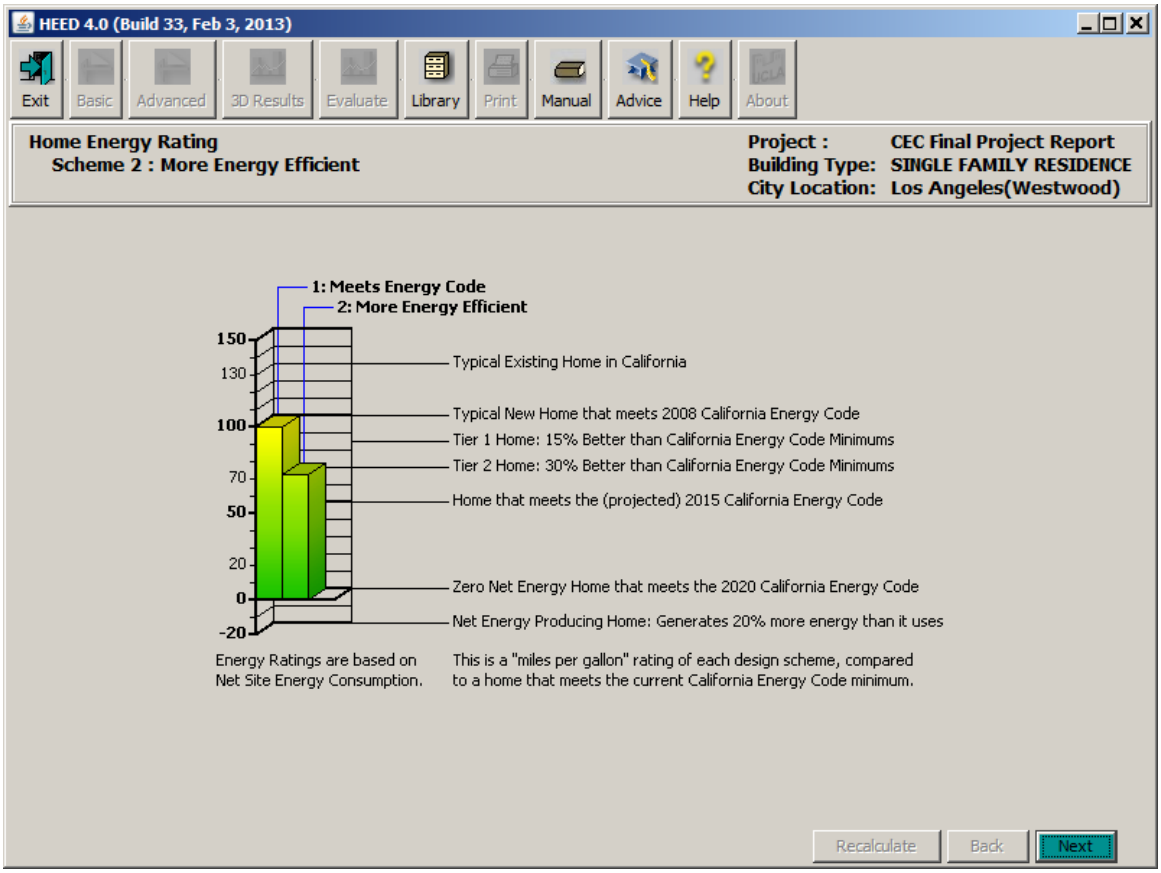


This data input is all that is needed for HEED to generate two homes, in this case for a Brand New Single Family Home in UCLA's zip code in Los Angeles. Scheme 1 is the Standard Design that meets the Title 24 Energy Code, and Scheme 2 is a Proposed Design that HEED's expert system creates that also meets the energy code but is More Energy Efficient. For Location the user can input either a zip code or one of the 16 California Climate Zones, or can download Energy Plus weather (EPW) data for anywhere in the world. HEED also contain gas and electric utility rates for utilities such as San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), and Pacific Gas and Electric (PG&E), and national greenhouse gas production ratios.

To start this day-one design tool the user only enters four facts. In this case the user selected:

1. Building Type: New Construction, Single Family Detached Home
2. Location: Zip code 90095 for UCLA
3. Floor Area: 2256 sq.ft.
4. Number of Stories: 2

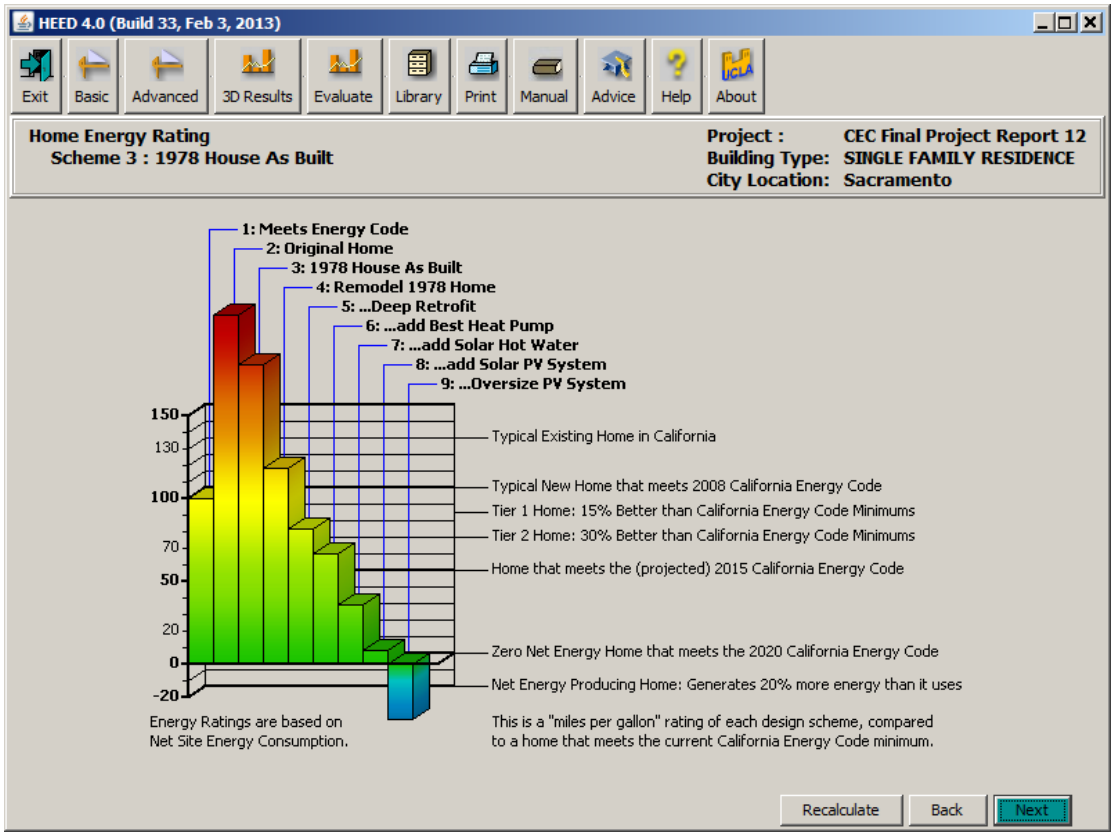
Figure 3: Home Energy Rating



With the data that was input on the Initial Design screen, HEED's expert system first creates Scheme 1 which is a building that meets the 2008 California Energy Code. Then it creates Scheme 2, a proposed building that is more energy efficient than the 2008 California Energy Code as shown above. In this case it is 28 percent better than the code building, which almost meets the Tier 2 reach standard requirements. These two Schemes differ as follows:

Scheme 1 2008 CODE MINIMUM DESIGN	Scheme 2 MORE ENERGY EFFICIENT DESIGN
• Square floor plan • Equal area of glass on each wall • Window tinted as required by code • No window shading • Stud and stucco walls • Raised wood floor over crawlspace • 0.5 Air change infiltration • Lights are mostly incandescent	• Rectangular floor plan facing South • Most glass on South, minimum on East & West • Clear glass on South and North • Overhang shaded South windows • High mass walls with exterior insulation • Slab on Grade floor • Whole House Fan, 10 air changes/hour • Lights are half fluorescent
Both schemes have the same: Floor Area, Window Area, Climate, Occupancy Schedules	

Figure 4: Home Energy Rating for a Remodeled Home in Sacramento



In this example HEED again created Scheme 1, a 2256 sq. ft. home that meets the 2008 California building energy code. Instead of new construction, the user selected "Remodel Your Home within Existing Walls," and then input the year of original construction. HEED's expert system then created Scheme 2 that represents a typical existing Original Home built in 1978.

Scheme 3, the 1978 Home as Built, was a copy of Scheme 2 to which the user adjusted things like moving some windows, creating a pitched gable roof, and adding a porch

Scheme 4, Remodel of 1978 Home, was a copy of Scheme 3, adding attic and underfloor insulation and adding code compliant windows.

Scheme 5, Deep Retrofit, is a copy of scheme 4 but tried super insulating the attic and underfloor, then stripping the exterior walls and adding insulation plus exterior foam.

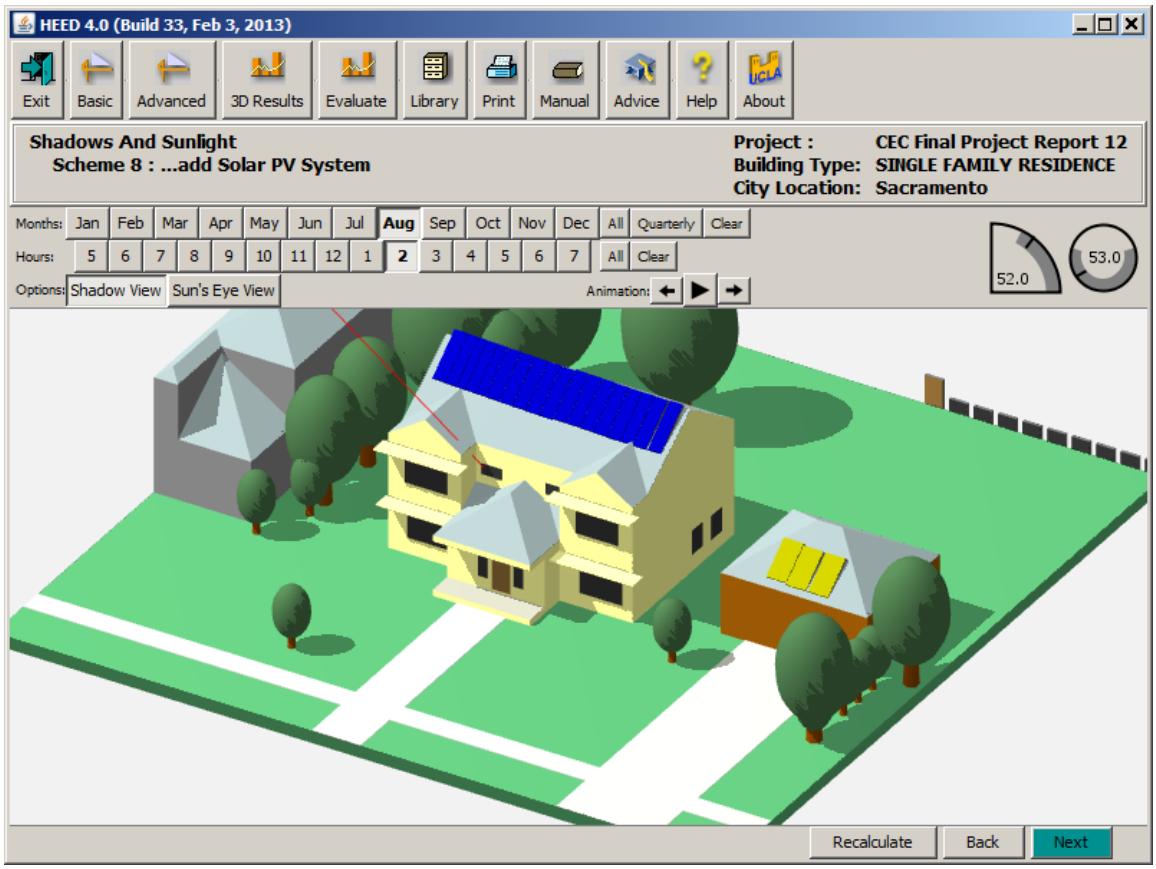
Scheme 6, Best Heat Pump, replaced the older furnace and air conditioner with seasonal energy efficiency ratio (SEER) of 20 and heating seasonal performance factor (HSPF) of 9.5.

Scheme 7 added a Solar Hot Water (SHW) system

Scheme 8 added a Photovoltaic (PV) System with a 3.9 kilowatt (kW) capacity utilizing 18 panels that will fit on the roof and the building has almost reached ZNE.

Scheme 9 added an Oversized PV System (7.9 kW with 36 panels) and the building is a net energy producer, but the floor plan showed that there were too many panels to fit the roof.

Figure 5: Shadows and Sunlight

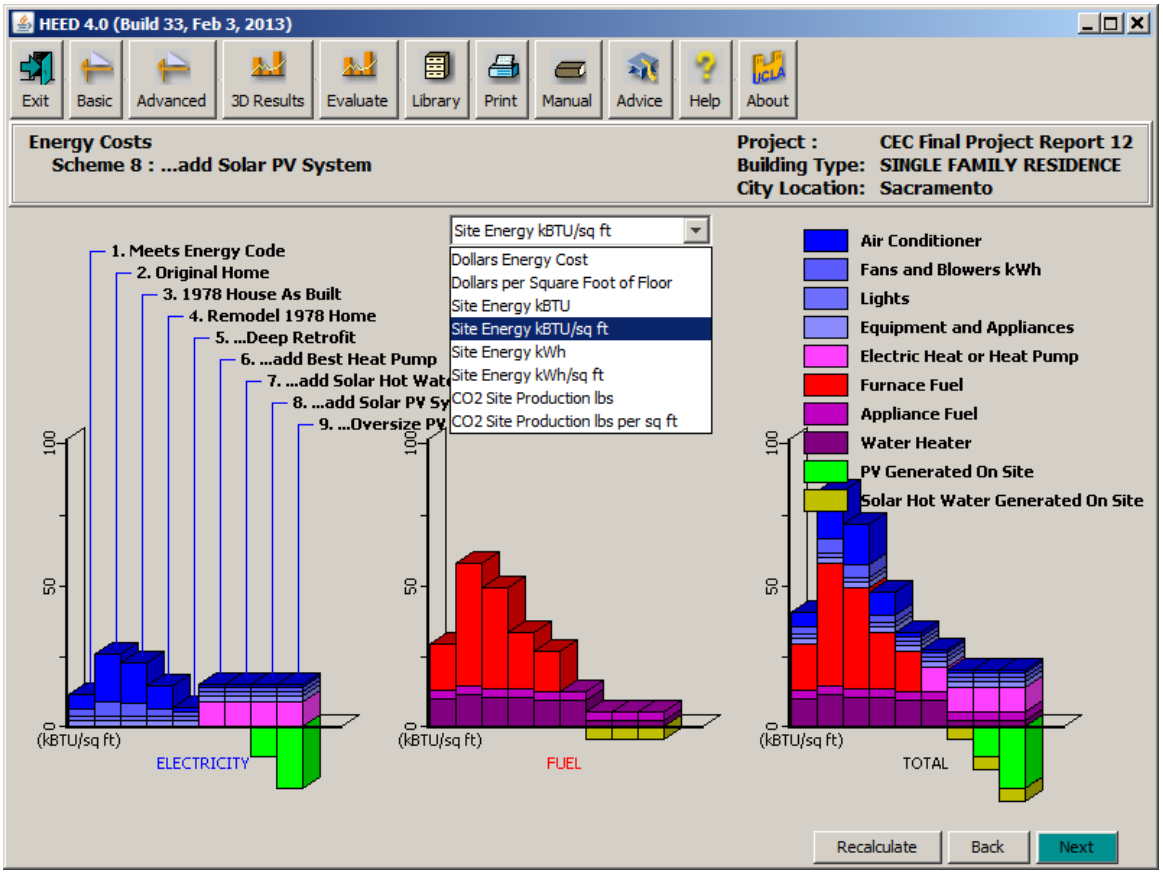


This screen shows how the remodeled home might look after the Solar PV Panels have been added to the roof. The SHW system is mounted on the garage. In this case it shows the shadows at the hottest time of the year, in August at 2p.m. Note that almost all of the windows are fully shaded.

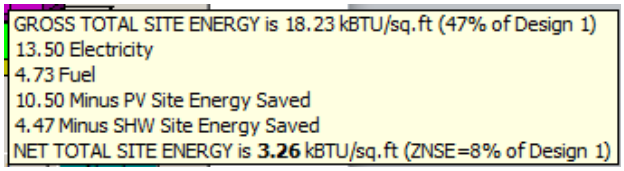
A neighbor was added to the west and paving was added to better define the site. Trees of various heights were added which will affect building performance if they shade windows or solar collectors. Homes with various geometries can be easily input using the fill-in-the-squares technique on the Floor Planner screen. Roof geometry can be automatically created for flat, gable, or shed roofs. The Roof screen lets user choose fan or naturally vented attics with shingles, tiles, or a cool roof.

This example screen also illustrates how windows and doors are initially delivered to the edge of the site. Notice that the north windows and the north door are still lined up along the north curb. If desired the user could have dragged them onto the north wall, however the HEED model calculates building energy performance whether they are left at the curb or placed on the wall. There is an exception if these windows had been placed on a wall where they were shaded by the large tree during some hours, the performance might have been slightly different.

Figure 6: Energy Costs

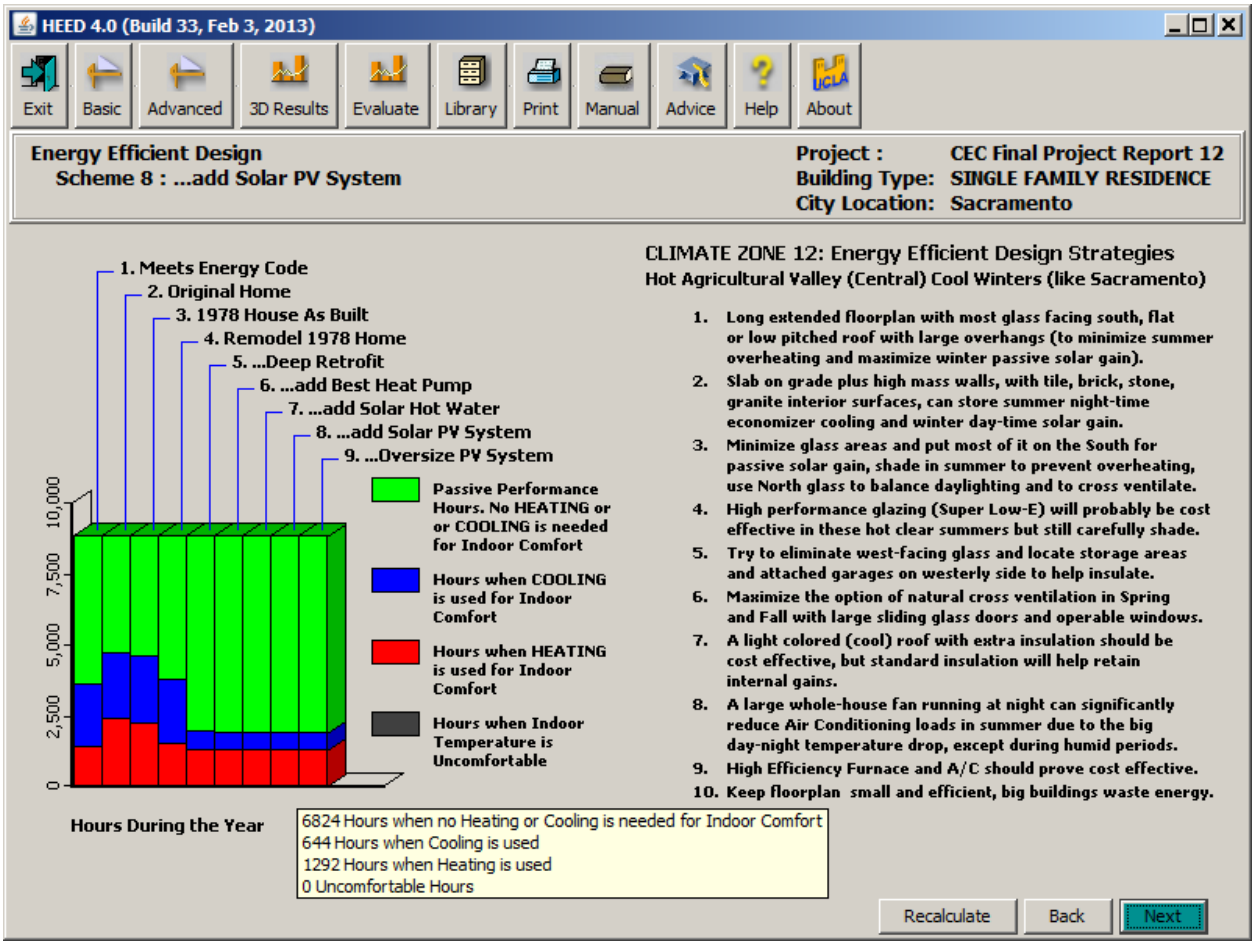


This screen is another way HEED graphically shows the user the comparative performance of various schemes. In this case showing Energy Use Intensity (EUI) in kBTU/sq ft, which is just one of the eight different variables that could be displayed. Notice that in the Total bar chart (right) for Scheme 8 the amount of Electricity and Fuel above the line is roughly equal to the total amount of onsite generated PV and Solar Hot Water below the line. Thus when all these are added together it shows that this Scheme 8 is very close to a Zero Net Energy Home, in this case the Net Total Site Energy consumption is only 3.26 kBTU/sq ft, which is only 8 percent of a home that meets 2008 building energy code (Scheme 1). When the user moves the cursor onto the Scheme 8 bar the following appears:



This chart shows that even though this original 1978 home (Scheme 2) uses double the energy of a home that meets 2008 building energy code (Scheme 1), it could be retrofitted into a home that performs at ZNE using readily available conventional technology. This shows that it's entirely possible for all newly constructed houses to be ZNE by 2020 including existing homes as Scheme 8 depicts.

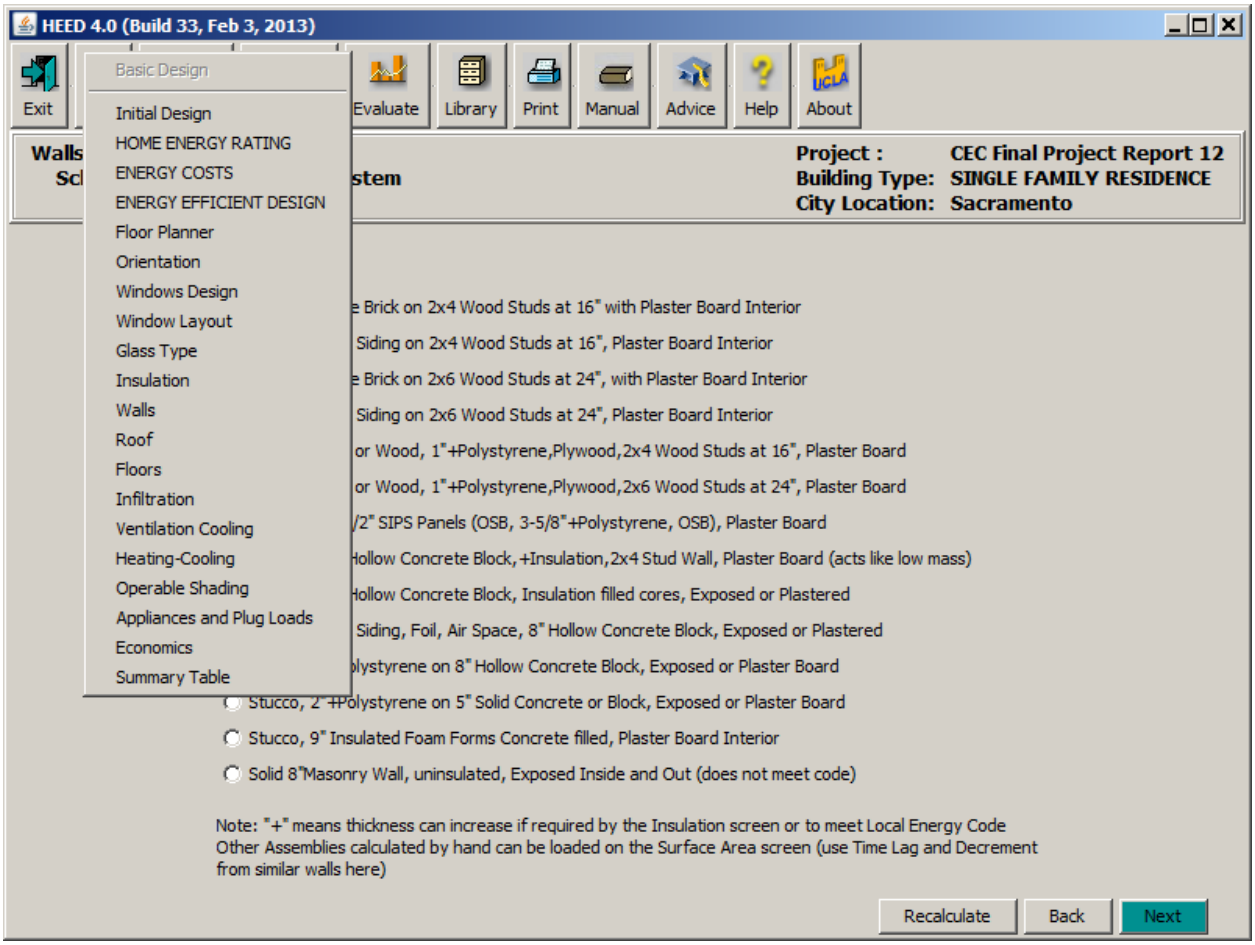
Figure 7: Energy Efficient Design



This screen shows HEED users another type of information about the performance of their various schemes. In this case the green areas show the home's passive performance when the home uses no heating or cooling energy. This screen shows that the occupants are comfortable all year long, because there are no black bars. Notice that for Schemes 5 to 9 the number of red and blue hours when the furnace and air conditioner were used is unchanged, but the prior screens showed that it takes less and less energy to keep the building within the comfort range.

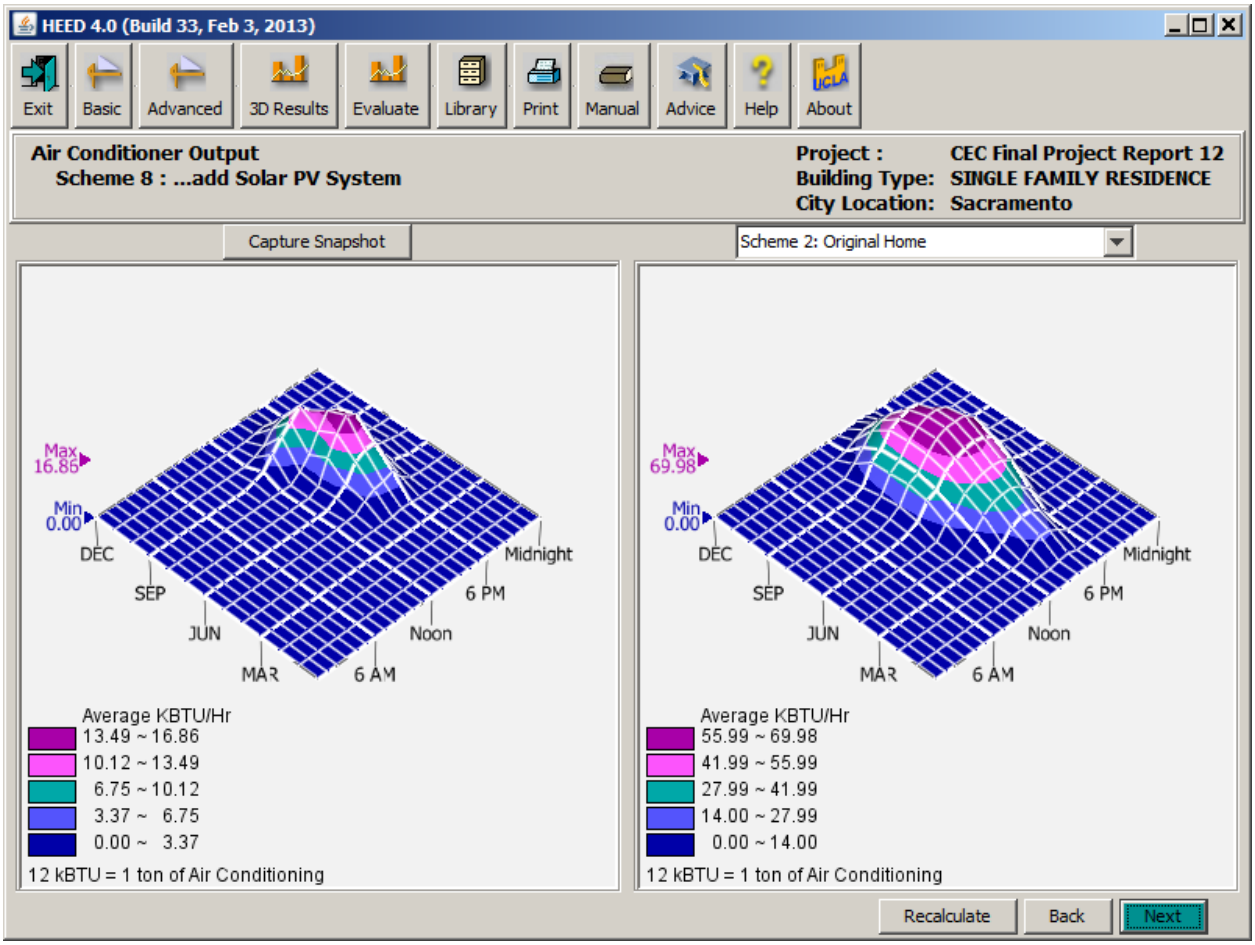
This screen also gives a list of the Energy Efficient Design Strategies, in this case for Sacramento's Climate Zone 12. Notice that all these are met except Strategy 2, because the original 1978 home was assumed to have a raised floor, however the deep retrofit might have added a tile or slate floor or an extra layer of drywall to the ceiling or some other way to add thermal mass to the interior. Strategy 10 is also questionable because this house looks to be rather large, however in this example the square footage was set at the average, 2256 sq ft.

Figure 8: Basic Design Screens



If the user clicks on the Basic Design icon on the top row, this list of options will drop down, and users can select any one of them depending on their decision making process. This list includes various performance graphic screens and various lists of options for Glass Type, Insulation, Walls, Roof, Floors, etc. and even Economic Payoff and Performance Summary Tables. The HEED expert system will have selected appropriate options for all of the variables in each of these screens depending on many different factors including the local code requirements and the local climate. As users become more comfortable with HEED they might elect to change variables on any of the various Basic Design options as shown in the screenshot above. If the user clicked on the Advanced Design icon on the top row, a list of an additional dozen items will appear, which will allow the user to modify the design in more detail by changing specific numeric values of every aspect of the building design. For example the user can change the U-factor for each individual window or each different wall orientation.

Figure 9: Air Conditioner Output: 3D Results

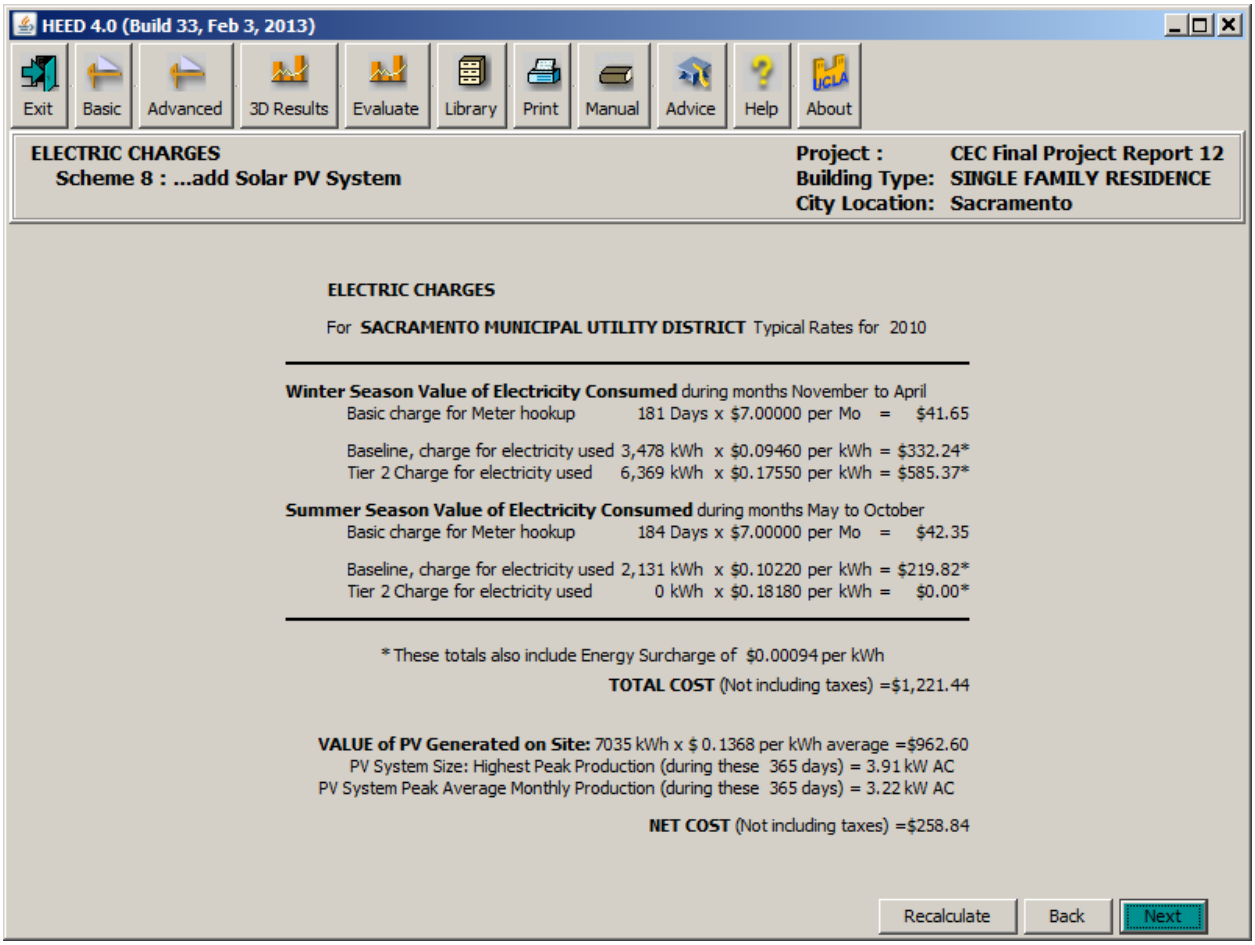


Once advanced users become more familiar and comfortable with HEED there are many more graphic screens available which will help explain building energy performance. In this example, the three-dimensional (3D) results plots shown above highlight the amount of Air Conditioner Output required to maintain indoor comfort conditions, for Scheme 2 the Original Home (on the right) and for Scheme 8 adding Solar PV (on the left). Each of these plots shows the average for every hour of every month. Notice that on the left side of each plot is the Maximum value which shows that the Original 1978 house used almost 70 kBTU of cooling on summer afternoons, while the Scheme 8 design used only about 17 kBTU in July at 5p.m. This plot shows that the air conditioner in Scheme 8 could be much smaller and would run fewer hours.

HEED also plots indoor air temperatures so the user can see how comfort conditions would change if the air conditioner was eliminated, for example.

These plots prove quite useful as the user tries out other design revisions to create a more energy efficient building design.

Figure 10: Electric Charges under the Evaluate Icon

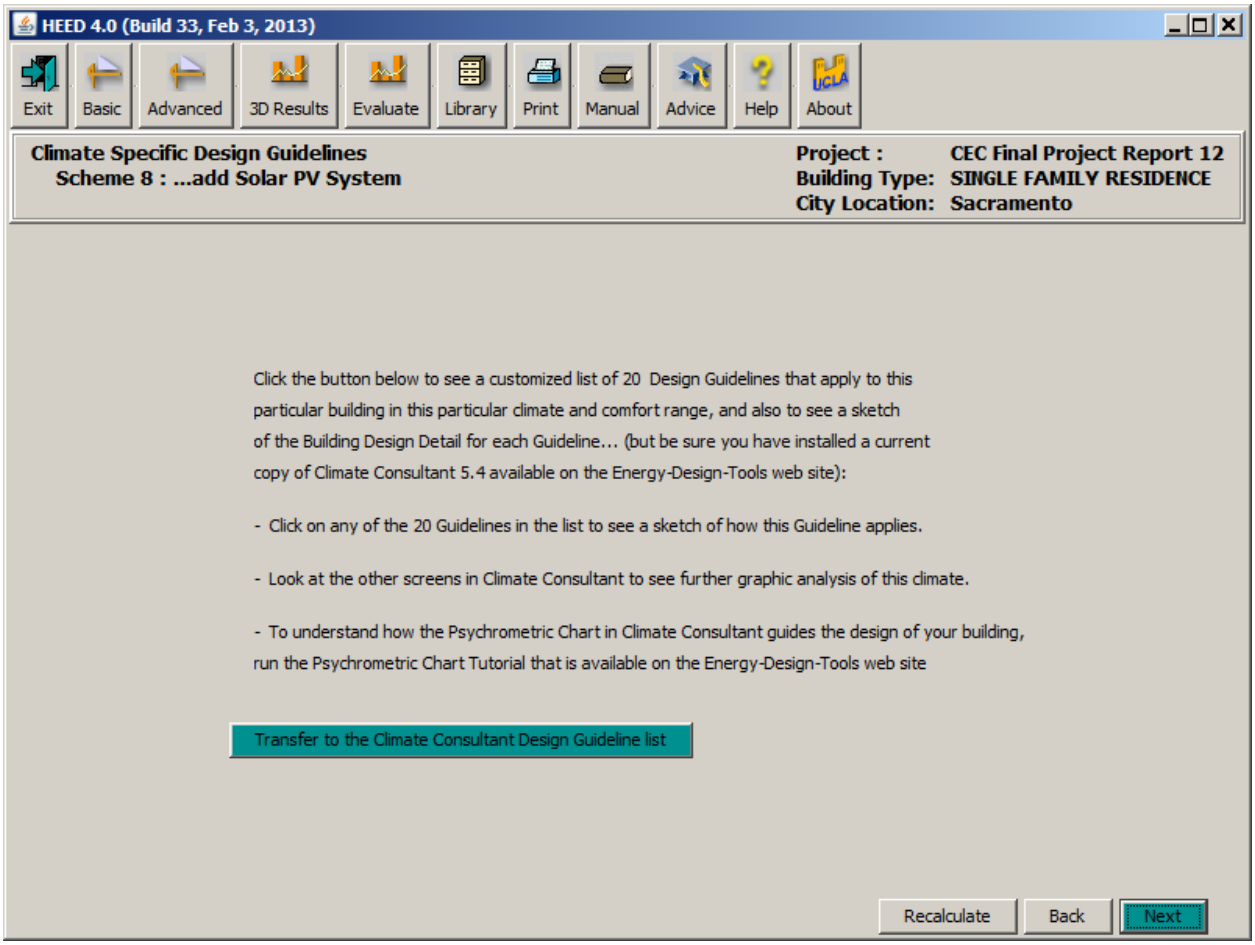


HEED contains residential electric rates for each of California's utilities as shown above. This example for Scheme 8, a very energy efficient building that uses an electric heat pump, has 3.91 kW of PV and so uses very little net electricity in the summer but reaches into Tier 2 in the winter. Notice that the PV system generates onsite power that is worth $962.60, leaving the homeowner with a net cost of only $258.84 per year.

HEED uses the same algorithm to calculate PV performance as used by the New Solar Homes Partnership (CECPV). It also lets users assemble systems with any of the approved inverters or panels. HEED also allows users to modify the electric utility rates if they want to try different energy scenarios.

Similarly, the Fuel Charges screen also shows the value of solar heated domestic hot water that is generated on site, and shows how this would reduce Net Fuel Cost.

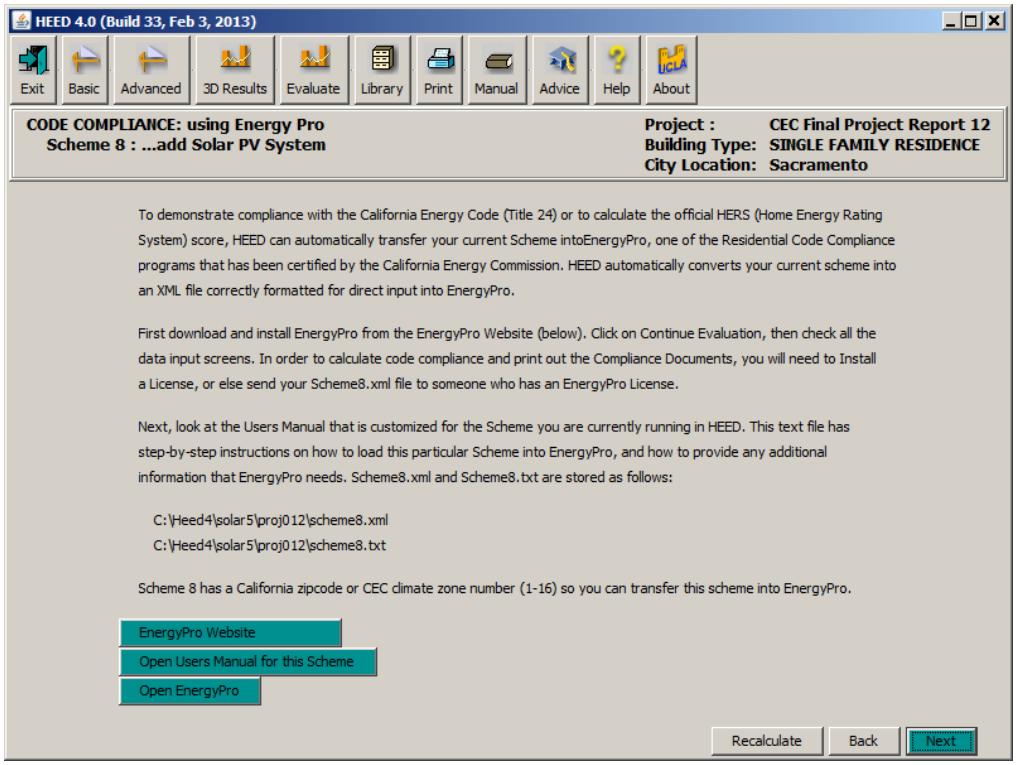
Figure 11: Climate Specific Design Guidelines



This screen provides a direct link between HEED and Climate Consultant. By clicking on the large green button on the bottom of this screen the user will be taken to Climate Consultant which will automatically run an analysis for the same EPW climate data that HEED is using, in this case California's Climate Zone 12.

Climate Consultant will show a list of the top 20 Design Guidelines most appropriate for this climate. If the user clicks on any one of these guidelines a graphic image will appear showing various design options for this guideline. When all 20 images are assembled, a very rough idea will emerge of the kind of house that is most appropriate for this particular climate. This is not a complete building by any means, but is like a set of snapshots of various small scale and large scale aspects of the building (in reality this is still a work in progress, but many users have found all this helpful, surprising, and even insightful).

Figure 12: Code Compliance using EnergyPro



HEED was created to be a day-one design tool that launches with only very minimum information about the project, which is the opposite of a code compliance tool that needs the final fully defined building and only has to output Yes or No, whether or not the building meets the energy code. California currently has three approved residential compliance computer programs. Because one of these, EnergyPro 5.1, accepts input files defining the building that are written in Extensible Markup Language (XML), the team added an automatic feature to HEED that writes out any selected scheme in XML to be directly imported into EnergyPro for a code compliance check.

HEED lets Californians create multiple schemes, graphically displaying whether the design is becoming progressively closer and closer to zero net energy. HEED starts with very little user supplied information about the project, and then its expert system uses the climate data, the energy code, and other architectural design heuristics to fill in everything else. The user can work on up to nine different schemes at the same time, using the design guidelines to try different alternatives and combinations, and can look at HEED's graphic outputs to see if the building's performance is improving. Finally, when the best scheme has been created the user can load it directly into EnergyPro (by selecting the third button on this screen).

Once in EnergyPro, the user can print out code compliance form (form CF-1R) that will show if the building complies and by what margin, give the Home Energy Rating System (HERS) rating, and will calculate the annual Time-Dependent Valuation (TDV) energy usage. Thus HEED can in effect function as a user-friendly front end to this certified code compliance program.

2.2 Climate Consultant Case Study

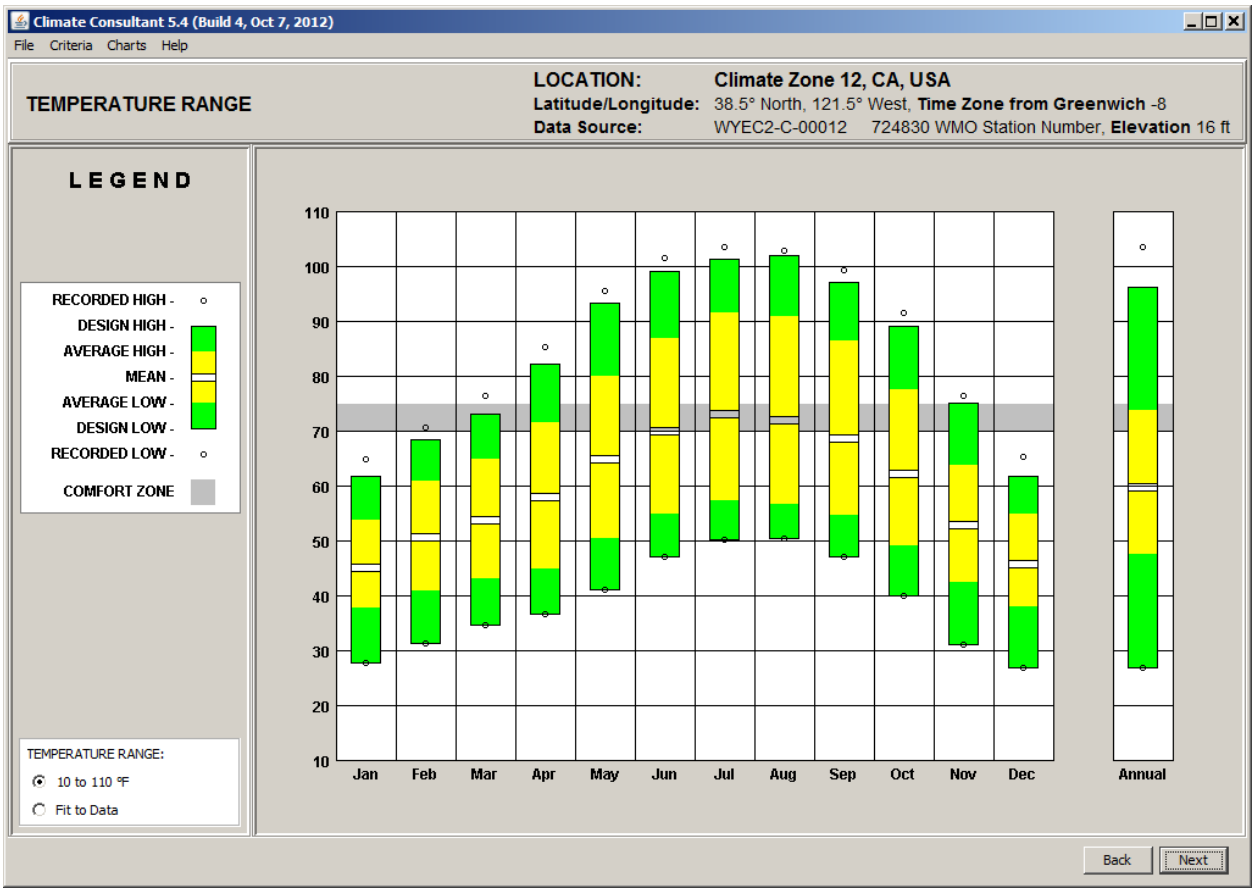
Climate Consultant (CC) is a free user-friendly design tool to help Californians design homes that take advantage of the resources of the local climate.

To download Climate Consultant go to: www.energy-design-tools.aud.ucla.edu

Figure 13: Climate Consultant Download and Installation

The image above is Climate Consultant's first screen that outlines some of the recent features that have been added and explains that when in doubt about what to do next, click the Next button. Data for Climate Consultant in EPW format is provided for California's entire 16 climate zones or else can be downloaded automatically for thousands of other locations around the world from the U.S. Department of Energy Climate Data site.

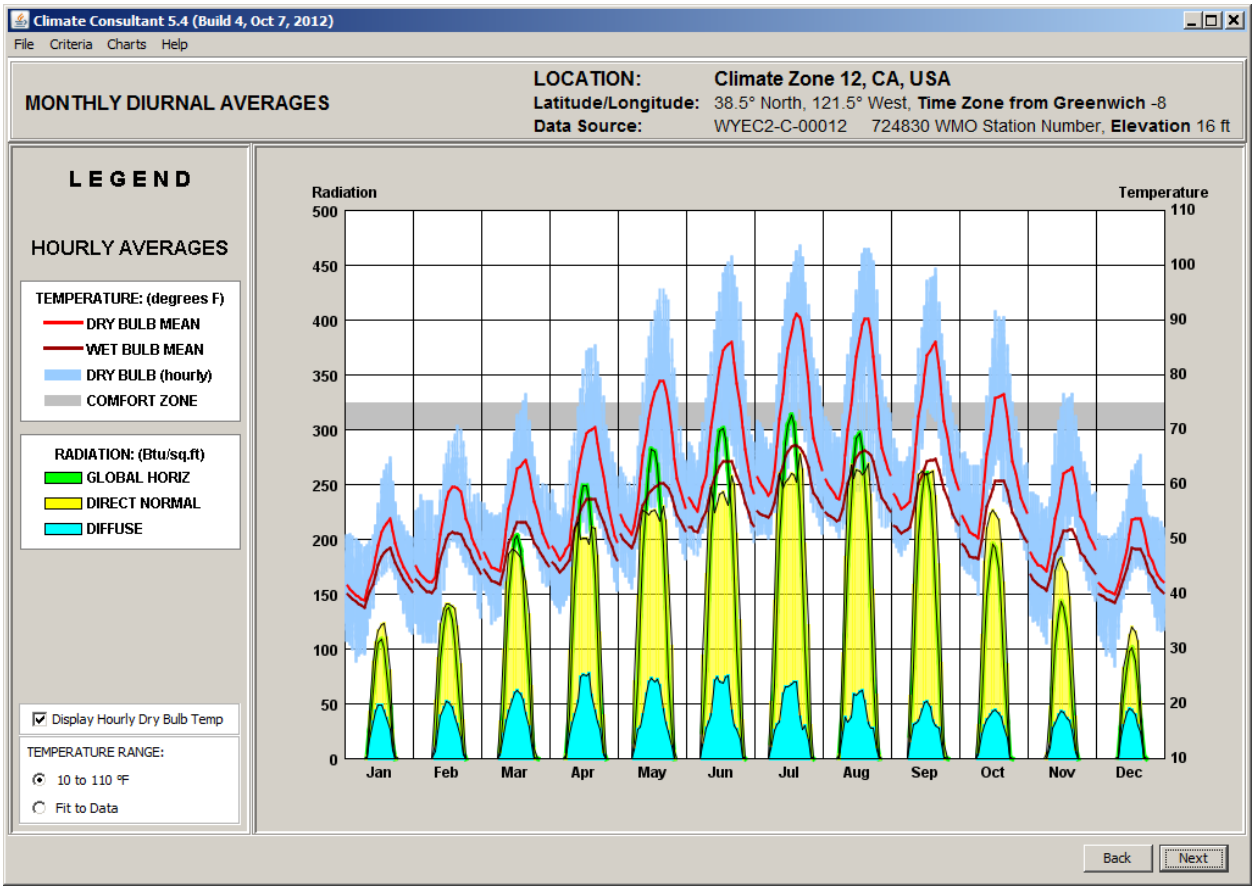
Figure 14: Temperature Range Plot



This is the most basic chart in Climate Consultant and shows us a great deal of information about dry bulb temperatures.

This example for Sacramento shows how Temperature is distributed over the 8760 hours of the year. The California building energy code assumes that the indoor comfort range is between 70° and 75° so it is easy to see that much of time it is uncomfortable outdoors in Sacramento, either too warm or too cool. For example, notice that the highest recorded temperature exceeds 100°F in July. However, the average daily range (yellow) implies that it usually falls below 70°F at night, which means that a home constructed with enough thermal mass and ventilated at night could substantially reduce the cooling load the following day. In winter, the average daily temperature range is only about 15 degrees which implies overcast conditions, thus there will be days when there is not enough passive solar gain to directly heat the building suggesting (as the above chart shows) that supplemental heating will be needed in Sacramento. However, as the Design Guidelines suggests, a compact, well insulated, tightly sealed and carefully ventilated home will minimize the amount of the supplemental heating energy required.

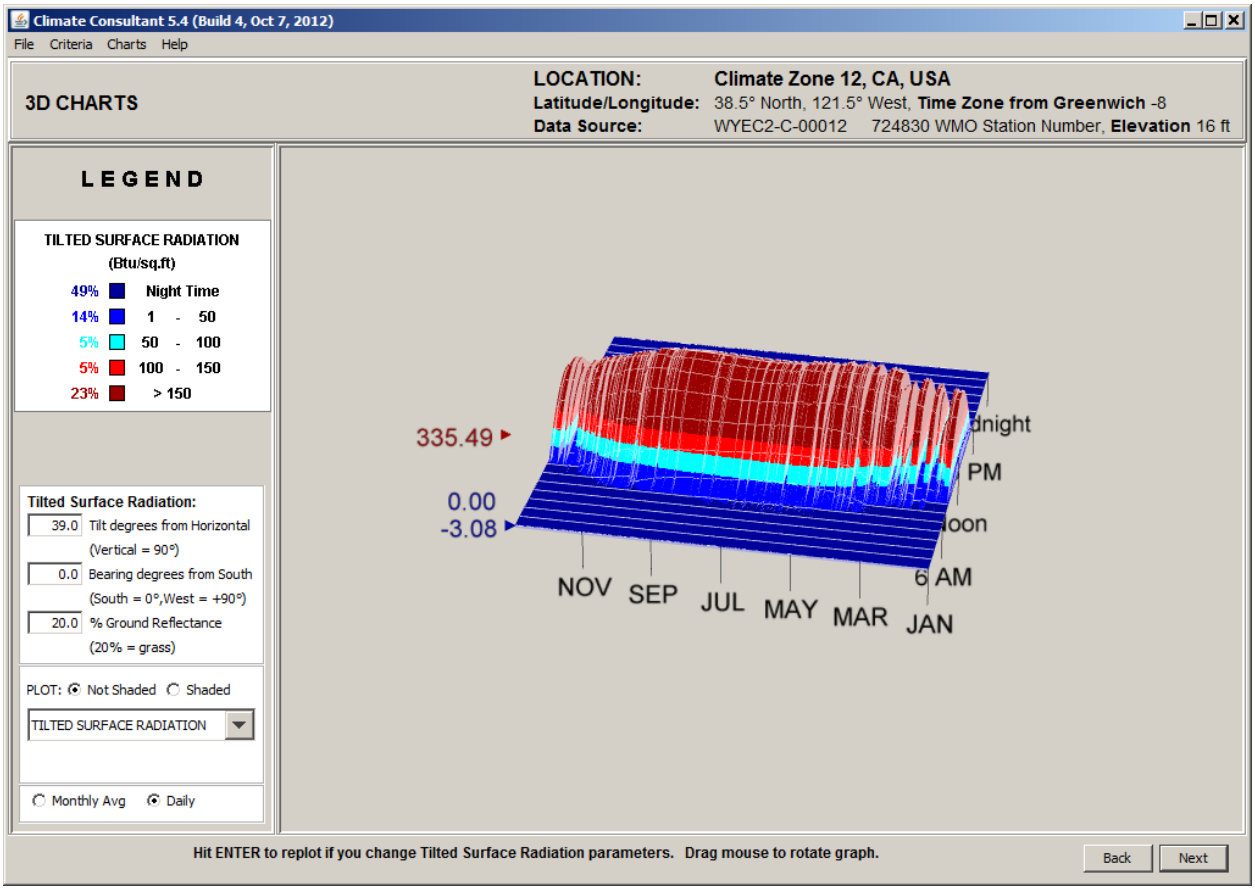
Figure 15: Monthly Diurnal Averages Plot



This is an example of one of the more complex graphic climate analysis plots. It shows how a number of different factors interact and how they change over the 24 hours of each month. The yellow areas show the amount of direct solar radiation peaking at noon for each month in Sacramento. If you were considering adding PV to the roof of your building, this plot shows that most of the PV power output would occur in summer (when air conditioning loads will be the highest).

The red lines are dry bulb temperatures peaking in the afternoon, with the lowest values occurring just before sunrise. The lower dark red lines are wet bulb temperatures. The fact that they are very close together in January means conditions are very humid and probably overcast, but the fact that they are far apart in July means that conditions are dryer with probably clearer skies. The light blue area shows the dry bulb temperatures for every hour of the month, again repeating the same day/night pattern and showing the range of highs and lows.

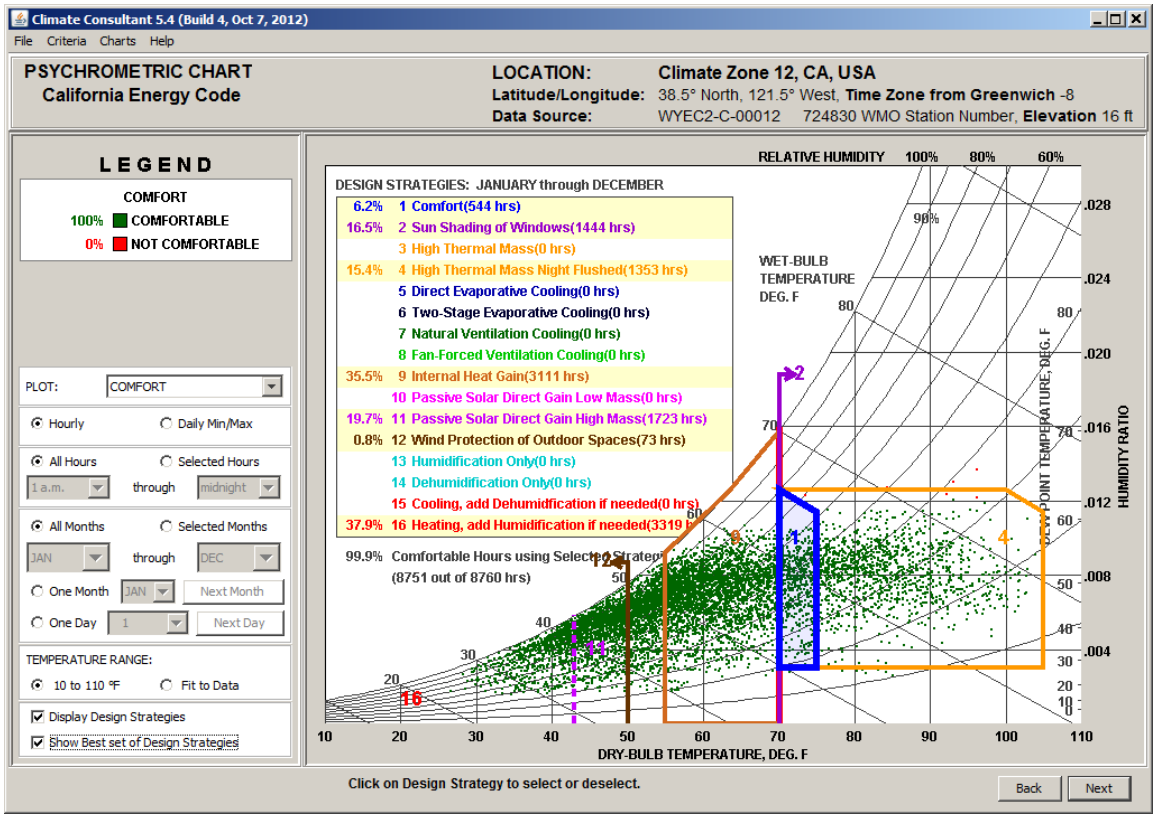
Figure 16: 3D Chart of Tilted Surface Radiation



In Climate Consultant there is a whole set of charts of climate data plotted in 3 dimensions to show the 24 hours of each day for all 365 days of the year. This example is a plot of Total Radiation on a Tilted Surface, such as a solar collector, in this case tilted up at 39 degrees. The radiation would peak in the summer if the surface was lying flat horizontally, but would peak in the winter if the surface was hanging vertically. However, if a surface is tilted up at an angle equal to local latitude, then the radiation on it will be approximately equal all year long. This is true for most of the year for Sacramento, CA, which is depicted in the screen shot above, except in the winter when useful radiation is eliminated for many days (due to stormy and overcast skies).

Other 3D Plots are available including dry bulb temperature, wet bulb temperature, wet bulb depression, relative humidity, wind speed, global horizontal radiation, direct normal radiation, global illumination, direct normal illumination, and sky cover.

Figure 17: Psychrometric Chart



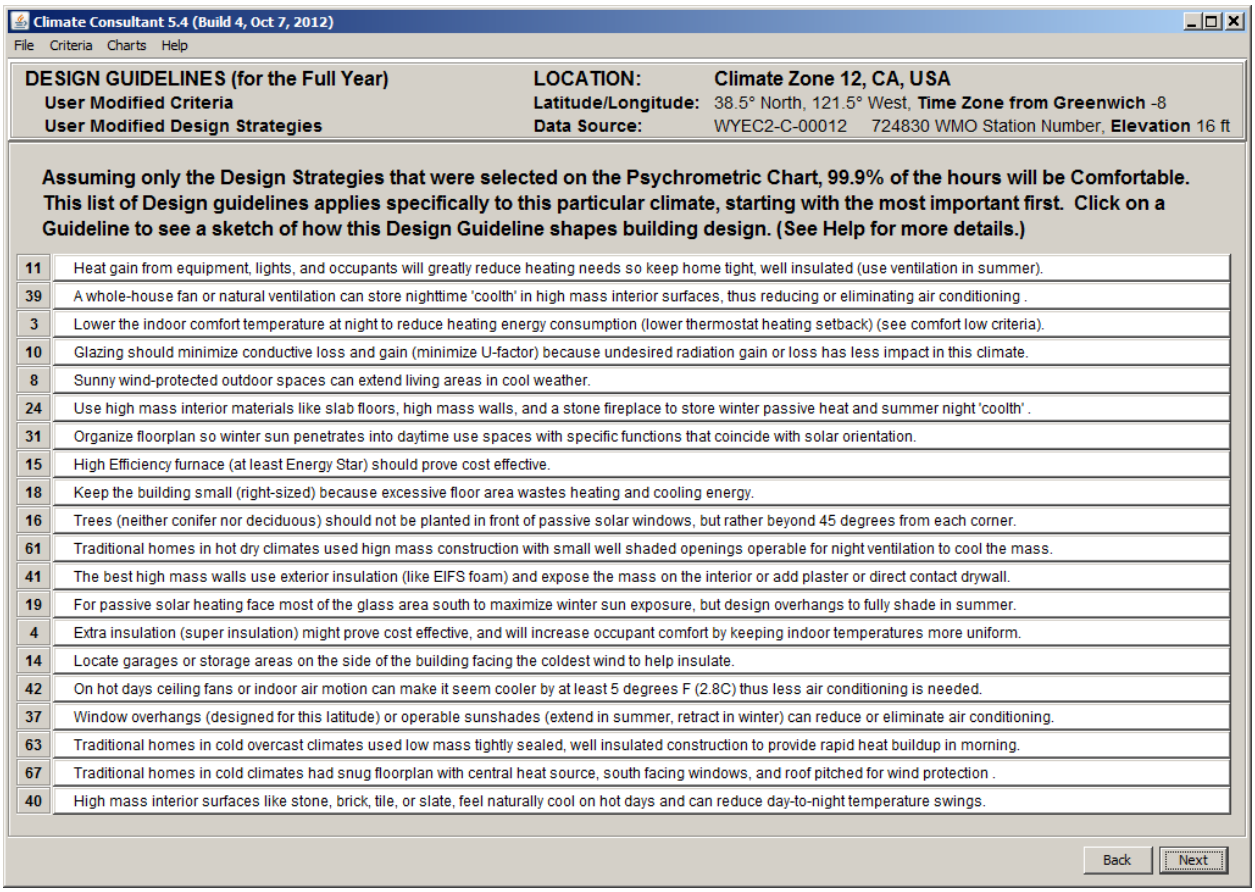
The Psychrometric chart is the most powerful design tool in Climate Consultant. The case above shows one dot for the outdoor temperature/humidity on each hour of the year in Sacramento. The blue outline encloses comfortable conditions. The legend lists various building Design Strategies with the percentage of time they could produce comfortable indoor conditions. This list is automatically generated based on the attributes of this particular climate, but the user can change it if desired. Notice that a High Thermal Mass building with Night Ventilation could produce comfortable conditions for 15.4 percent of the hours when it is too warm outdoors.

When it is too cool outdoors the Design Strategies legend shows that for 35.5 percent of the time Internal Heat Gain from things like lights, appliances, and occupants will be enough to eliminate the need for supplemental heating. However, for 37.9 percent of the time a heating system will be needed.

Note that these numbers are estimated by Climate Consultant based on the assumption of typical home construction that meets the 2008 code. However, the Design Guidelines list (see below) will give other options that can create an even more efficient design, and design tools like HEED will allow these options to be tested in an actual building design, along with a more efficient heating, ventilation, and air conditioning (HVAC) system and onsite generation from PV and SHW.

This screen might look complex but a graphic tutorial has been developed that explains this chart and each of the design strategies. This Flash tutorial is available on the Energy Design Tools web site.

Figure 18: Design Guidelines for the Full Year

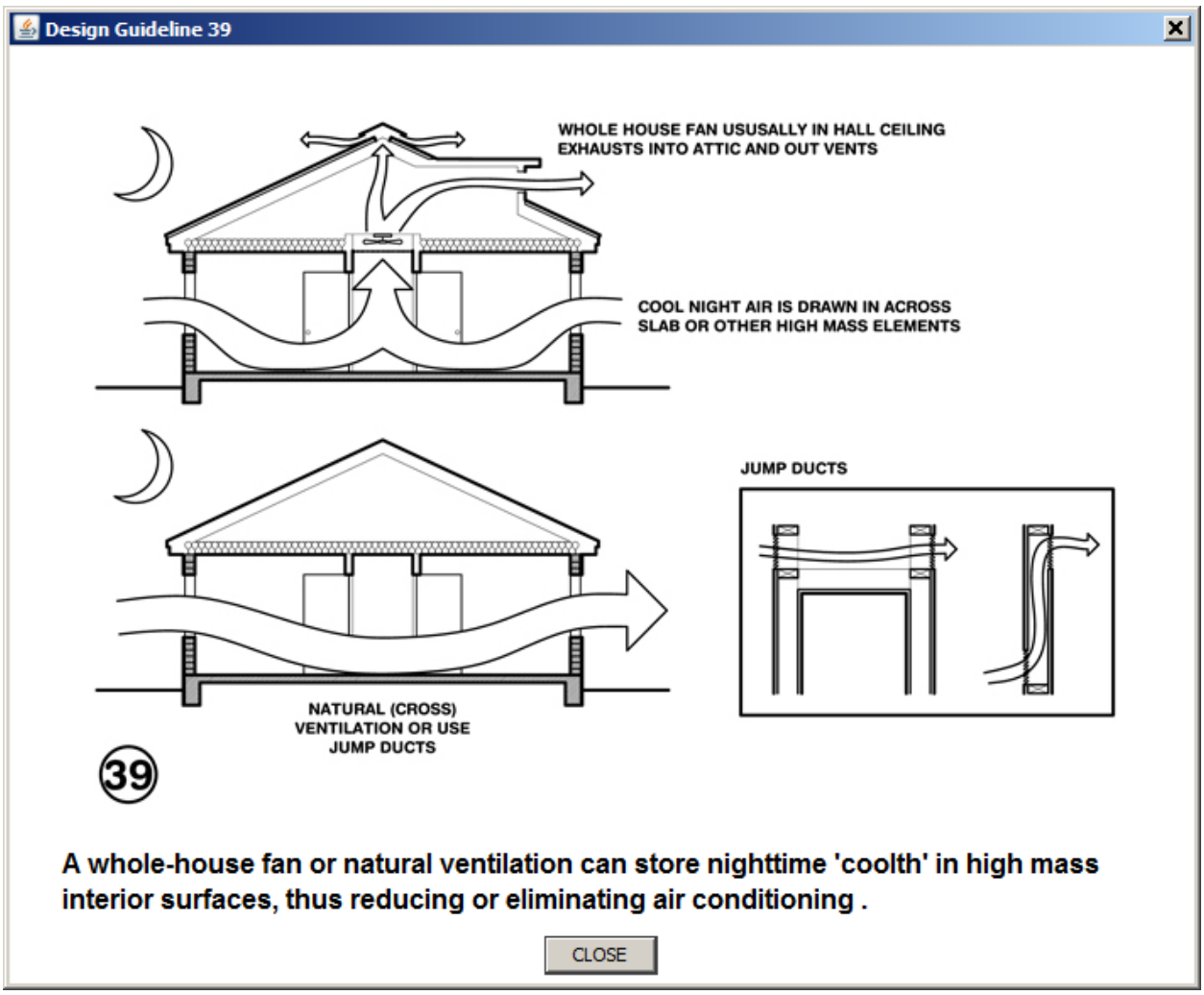


This example shows a set of energy efficiency Design Guidelines. This list was selected based on the attributes of Sacramento's unique climate and the list of Design Strategies describing the building design as given on the Psychrometric Chart. It is organized so that the first items are the most important and have the greatest effect on building performance.

In this case, for a climate responsive residential building in Sacramento, it confirms the value of internal sources of heat gain, night time ventilation, south facing solar windows for solar gain, high mass interior surfaces, high efficiency HVAC equipment, and creating a small compact floor plan.

It should be emphasized that when the climate data for other locations in California are analyzed by Climate Consultant, it could create a totally different list of Design Guidelines, many of which are the exact opposite of the ones on this list.

Figure 19: Example of Sketches for each Design Guideline

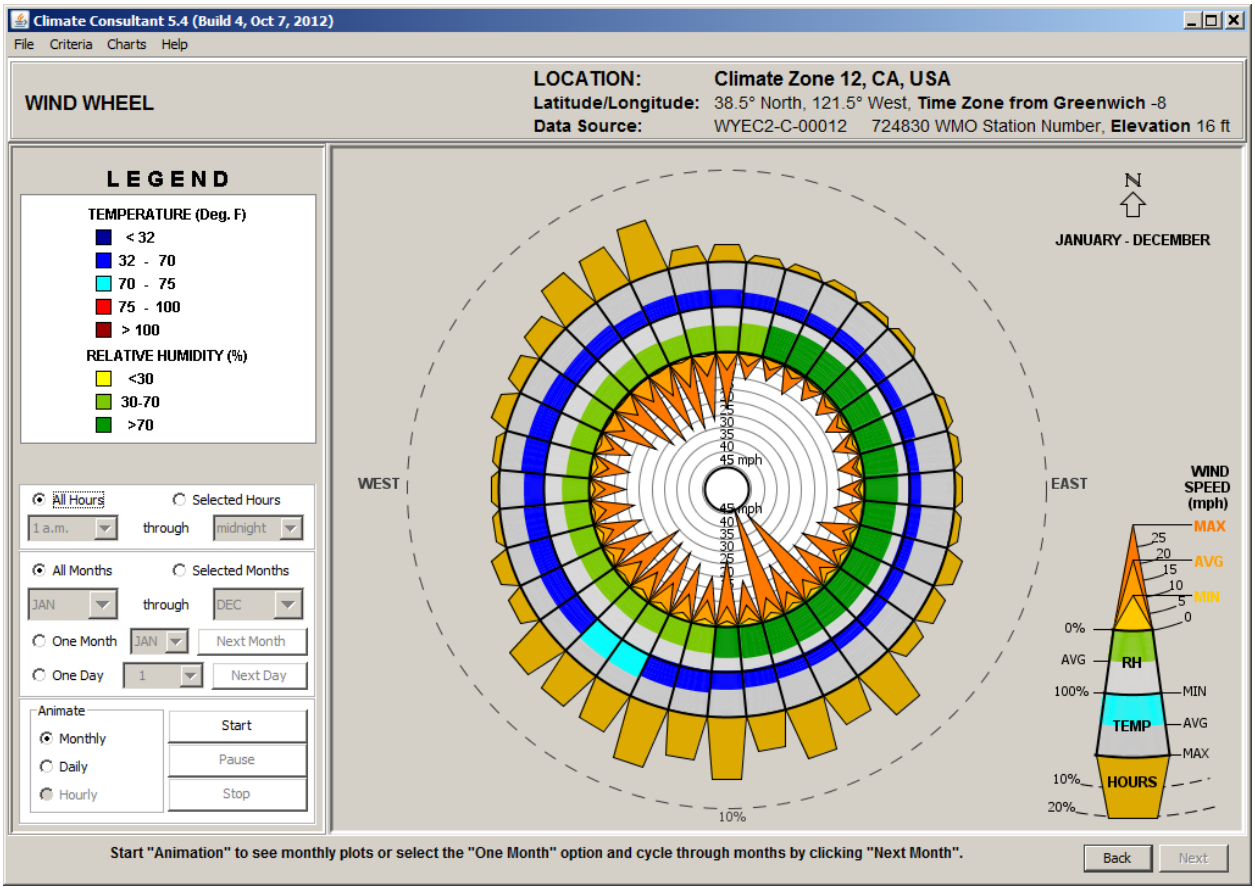


If you click on any one of the design guidelines on the prior list, Climate Consultant will display a sketch or graphic image to help illustrate the application of this guideline and how it might influence building design.

In this case the user clicked on guideline 39, which suggests that in this climate night ventilation will help cool off the house and can store up "cool air" for the next day in high mass surfaces. This cool night air can be brought in by cross ventilation if there is enough wind velocity and if there are openings on adjacent sides of the home, or at least on adjacent walls. However another option would be to install a whole house fan to exhaust air out of the house at night, often into the attic space to help cool this unconditioned zone. There are of course many other ventilation strategies that might include balanced ventilation systems (that insure that inlet and outlet air is equal), heat recovery ventilators (HRV), energy recovery ventilators (ERVs), and traditional stack ventilation (that uses high ceilings and vertical openings with rooftop vents).

Note that in HEED if ventilation cooling is selected, any of these options can be tested in the context of the specific building design and the actual hour by hour climate data.

Figure 20: Wind Wheel

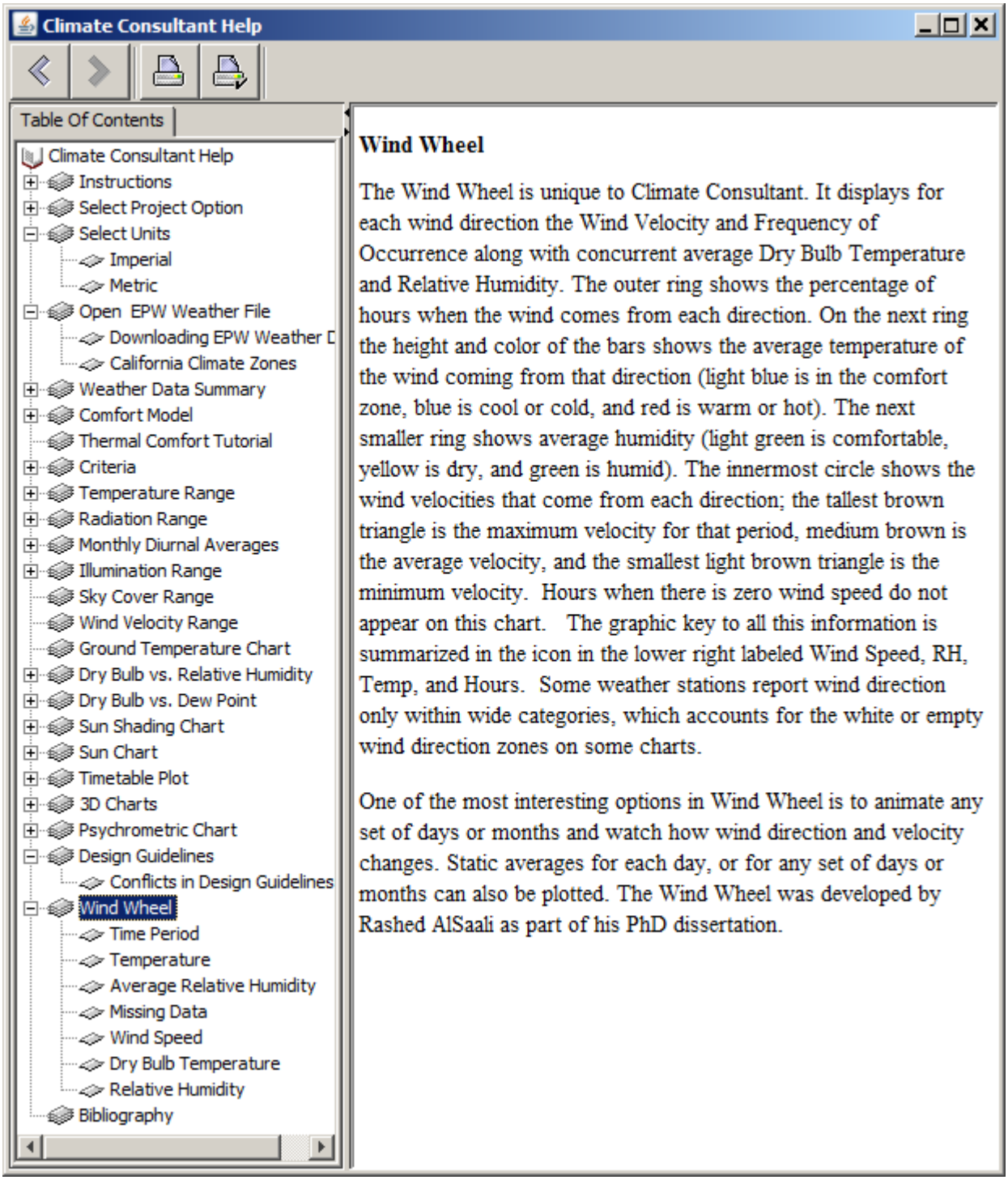


This diagram is unique to Climate Consultant. It shows the correlation of a number of different variables. It displays for each wind direction the wind velocity (triangles), wind frequency of occurrence (brown bars), average dry bulb temperature (red to blue ring), and relative humidity (yellow to green ring). In this example, most of the wind comes from the northwest or generally southerly, but seldom from other directions. However, wind data is notoriously idiosyncratic and is extremely dependent on the specific location where the weather station is located. This is usually at an airport in an open field or on top of a high-rise building, in contrast to the site where the particular home is located that is influenced by nearby structures, trees, or landforms.

Note that this data is for the official California Climate Zone 12 where Sacramento is located, but there are three other EPW climate data sets available for Sacramento, one at the Municipal Airport, one at the Metropolitan Airport, and an older one at Mather Field. The Climate Zone 12 data seems to be based on data taken at the Metropolitan airport. It is reassuring to note that the wind data is very similar for all four locations. The same is true of the psychrometric chart data. Also, the selected list of Best Design Strategies is identical in three of the four data sets, while the fourth set only adds two different design guidelines.

The Wind Wheel also can be animated to show how the data changes hourly over each day or monthly over the full year. Any individual hour, day, or monthly average can be displayed.

Figure 21: User Help



Every screen in Climate Consultant is provided with additional explanations and definitions of terms whenever the user clicks on Help on the top line. The title of every screen is listed and wherever there is a "+" sign the user can click to see additional Help screens. In the case above,

additional screens are shown that offer more information about how to select units, open EPW files, design guidelines, and wind data.

CHAPTER 3:
Updates to HEED and Climate Consultant

This project was made up of separate projects with multiple specific technical tasks.

Note that sections below headed "**In addition**" are the 26 tasks or products that were added above and beyond what were specified in the original contract Scope of Work. Note the word "screen" below refers to the a specific graphic user interface screen in either HEED or Climate Consultant plus the required computational algorithm development and software required to implement this set of graphics or options. (Note also in the following chapter that capitalized phrases are the title of screens in HEED or Climate Consultant or are chapter headings in reference documents.)

3.1 HEED Upgrades, Expanded Development and Validation

This project upgraded HEED to include several new capabilities. As noted above, the functionality for HEED was expanded much more than originally anticipated over a three year period. Upgrades for each year of this effort are highlighted below.

3.1.1 Year 1 HEED Upgrades

Subcontractors Bill Beckman and David Bradley provided the algorithms for calculating the performance of PV systems and SHW systems. Bill Beckman and David Bradley were also the authors of fChart which is used by the California Energy Commission (Energy Commission) for calculating the hourly PV performance in the CECPV software. This software was used to validate HEED's PV performance calculations.

A new PV Power Design screen was added to input PV system parameters.

In addition, a hot link was added to this screen for direct connection to the CECPV web site to encourage users to download and install a current copy of CECPV.

In addition, the capability was added to read and integrate the most recent .LKT files that contain the Energy Commission's current approved lists of Inverters and PV panels (note that HEED has a built-in Example Panel and Example Inverter if the user elects to not download CECPV).

Solar Domestic Hot Water System (SDHW) calculation screen was added (based on algorithms provided by subcontractors Bill Beckman and David Bradley).

In addition, a new Solar Collector Data screen was added with a hot link for direct connection to the Solar Ratings Certification Council (SRCC) web site data base.

In addition, a new Water Heating screen was added under the Advanced Design icon, to allow the design of a Storage Tank or Instantaneous Auxiliary Powered Non-Solar Water Heating

System. This also would be the system that provides the back-up water heating for a SHW systems.

In addition, a new AHRI Water Heater screen has been added, accessible from the Water Heating screen that allows manual input of the eleven different variables required for simulating water heating tank performance using the fChart method. It also contains a hot link to the Air Conditioning Heating and Refrigeration Institute (AHRI) web site where data is available for thousands of water heaters.

On the Floor Planner or the Shadows and Sunlight graphic screens, users can drag and drop PV or SDHW collectors from the curb onto sloped roofs or onto mounting racks on flat roofs, allowing users to visually evaluate the design of roof surfaces and to check if sufficient area is actually available.

Roof Geometry Options were increased in HEED to include graphic representation of various roof shapes, types, slopes, orientations, and materials. For example, the Floor Planner screen now allows users to change roof shape from flat to hip, gable, or shed facing any direction, while the Envelope screen now allows roof slope to be changed to any angle. The Roof Basic Design screen allows ten pre-designed construction options, or the Advanced Surface Area Design screen allows the user to enter any performance data for many other roof options.

In addition, five optional Cool Roofs were added to the Basic Roof Design screen, while Emissivity and Absorptivity can be modified on the Advanced Envelope Design screen.

The new Shadows and Sunlight screen allows users to add a Graphic Representation of Exterior Objects that might shade collectors or windows (such as trees, neighboring buildings, wing walls, porches, balconies, or fins and overhangs), and then to run an hourly time lapse video to see the progress of shading hourly and seasonally across the building and site.

HEED was upgraded to simulate 2008 code compliant homes for each of California's sixteen climate zones and for selecting construction types from the ACM (Alternative Calculation Methods Reference Manual). To minimize download size and increase computational speed, only the most common ACM construction types were included in the Basic Design options. Since HEED is a design tool and not a certified compliance tool, the Ventilated Attic Model from the 2005 ASHRAE Handbook was used in lieu of the Attic Unconditioned Zone Model. Note that the desired technical specifications of any construction type in the 2008 ACM Reference Appendix can be manually input on the Surface Area screen. By using the newly created link to EnergyPro, users can evaluate the performance of their building using the Attic Unconditioned Zone Model if desired, and also in EnergyPro they can test all of the other ACM construction types.

HEED was upgraded with each California utility's gas and electricity rates and carbon dioxide (CO2) emissions coefficients (2010). The option for calculating performance with TDVs was provided by adding the automatic link to EnergyPro.

Note that HEED is a free Design Tool intended to display actual building energy performance, as opposed to EnergyPro which is a commercial Certified Compliance Tool intended to determine compliance with the California Energy Code.

HEED supports the Title 24 "Reach" Standards by taking advantage of HEED's ability to model passive solar gain, night flushing, and building orientation, in addition to new capabilities for calculating PV and SDHW systems. The Energy Cost screen shows how close each building design scheme comes to achieving Zero Net Energy (ZNE).

In addition, a new feature that was requested in HEED is the Home Energy Rating screen, which shows how the energy consumption of each scheme compares to Scheme 1, the Basecase Code Compliant building, (similar to a HERS Rating). This colorful comparison bar chart graphically shows how each scheme ranks according to Tier 1 (15 percent better), Tier 2 (30 percent better), or the Zero Net Energy thresholds.

3.1.2 Year 2 HEED Upgrades

The new Ventilation Cooling Screen added to HEED embodies the PMV Thermal Comfort calculation (that was developed in the Year 1, Tasks 2 to 5, of the Climate Consultant project). This new option includes adding to HEED the evaluation comfort assuming normal occupant clothing and metabolic activity levels (CLO and MET), as well as calculating peak hourly indoor air speed. Hourly Wind Velocities and Wet Bulb Temperature are now read from the EPW climate data file. Thus HEED is now able to test and demonstrate other new approaches to achieving energy efficiency and GHG reductions as a result of this expanded definition of human thermal comfort.

In Addition, in order to supplement the PMV Comfort Calculation, other options have been added to HEED for calculating comfort. First, the Ventilation Cooling screen allows users to specify maximum Indoor Air Velocities for Cooling, and whether this was provided by Natural Ventilation or Fan-Forced Ventilation (either by a Whole-House Fan or by Ceiling Fans). Second, four new graphic screens now show 3-D plots of Outdoor Wind Speed and Indoor Air Velocity, which HEED uses to calculate and plot Indoor Air Temperature (Dry Bulb) as well as Effective Comfort Temperature (that combines the effect of air speed, Clo and Met). Based on this expanded definition of human thermal comfort, HEED can calculate greater energy and carbon savings by using Effective Temperature instead of just Dry Bulb Temperature,

Once work begins on the next Code cycle, HEED is now ready to help the CEC Codes and Standards Division with a free Design Tool that allows development of Title 24 language to include this expanded definition of Human Thermal Comfort

In Addition, this could hopefully allow the 2015 Code to use a wider definition of the current comfort range to account for controlled air motion and seasonal clothing (versus the current 70ºF to 75ºF dry bulb temperature comfort range alone).

Validation of HEED was originally intended to test the CEC's 32 Reference Homes per ACM (16 Zones, 2 Types of Floors), but this dataset is no longer available. Instead ANSI/ASHRAE Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, was used which involved 110 reference building tests. The results show 97 percent pass rate and are published on the Energy-Design-Tools web site (and in the Appendix of this report).

In Addition, other validation tests are also published on the HEED web site (and in the Appendix of this report). Earlier validations tests are published only on the HEED web site including two monitored occupied apartments in Pasadena comparing the HEED model predictions with summer field test measurements. Another experimental study ran for three years comparing full-height test cell performance with HEED model predictions. An earlier published study of 64 Reference Homes (16 California Climate Zones, 2 Types of Floors (high mass versus. low mass), with Whole House Fans or South Window Shading) is also available from the HEED web site.

HEED was also validated against EnergyPlus for all the HERS Best Cases which HEED can model. These validation studies demonstrated that HEED closely matches EnergyPlus performance, in part because HEED and EnergyPlus both are hourly heat balance models. This study showed a 96 percent pass rate. These validation tests compared HEED performance with results published in the EnergyPlus 2010 Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007, and in the HERS BESTEST 1995, Home Energy Rating System Building Energy Simulation Test.

A File Sharing Protocol with EnergyPro has been developed so that any scheme developed by HEED can automatically demonstrate compliance with the California Energy Code using this Approved Compliance Tool. HEED automatically writes a Title 24 XML file that can be a direct import to EnergyPro.

In Addition, a new Code Compliance screen has been added to HEED that contains two hot links, one directly to the EnergyPro web site, and the other to a new customized Tutorial file that HEED writes explaining in detail all the inputs to EnergyPro, most of which HEED generates automatically, but a few of which the user must double check.

The new Design Guidelines screen under the Basic Design icon has a hot link that automatically connects HEED to Climate Consultant. This generates a rank-ordered list of the Top 20 Design

Guidelines based on the climate data analysis capability that was developed in the Climate Consultant project, year 1. This list tells users which building design options are likely to have the highest payoff in energy and GHG savings by utilizing the resources of this specific climate.

In Addition, once inside Climate Consultant the user can click on any one of these 20 Design Guidelines and see a sketch showing various ways to translate it into architectural form or process.

In Addition, once in Climate Consultant the user can go back to the Psychrometric Chart to see which of the sixteen Overall Building Design Strategies have been identified by Climate Consultant as leading to maximum comfort. Also from this point the user can go to any of the other graphic screens in Climate Consultant that apply to this specific building in this specific climate.

The Shadow and Sunlight screen offers a Sun's-Eye-View graphic simulation animation that shows the shading impact of exterior objects like overhangs, trees, and neighboring buildings on windows and on PV and SDHW collectors for each hour of each month of the year. Because this animation can be run from the viewpoint of the moving sun, it allows users to instantly see which objects are casting shadows on which windows or PV panels or Solar Hot Water collectors. HEED computes this shading ratio on each individual window or collector to define actual solar loads which generates more exact energy calculations. Note, however, that Title 24 only allows shading from overhangs and fins (not from trees or neighboring buildings) to be considered for building energy compliance calculations, so HEED has an option allowing these to be turned off.

3.1.3 Year 3 HEED Upgrades

Graphic User Interface improvements were not in the original contract, however innumerable upgrades have been made in graphics, screen layout, and editorial changes, all in the interest of making HEED more user-friendly:

In Addition, a new Color Preference screen has been added at the bottom of the Library icon that lets the user change the color for any of 21 different building and site components of the 3-D Graphic images on the HEED Window Layout, Floor Planner, or Shadows and Sunlight screens.

In Addition, climate data downloading has been greatly simplified by a new Install EPW screen that has been added under the Library icon. It automatically downloads the user's choice of climate data file from the US DoE web site (right click and select Copy Link option). This has virtually eliminated questions to the Email Hot Line about how to get climate data.

In Addition, Archive HEED Data is another new function that was added under the Library icon, to make it possible for people who have difficulties with HEED to automatically collect the log files and project files so they can easily send them to the team for debugging and analysis. This has greatly improved the accuracy of information received via the Email Hot Line so that the team can help people who are having difficulties.

The contract originally budgeted for a consultant to provide functions for calculating the hourly performance of very low energy cooling systems and proprietary economizer systems such as NightBreeze, but the team ended up having to write these in-house as generic algorithms.

The option of an evaporative cooler (swamp cooler) was added to HEED as another alternative to compressor cooling. It was originally hoped that a consultant could be found to write these algorithms, however the team ended up having to write these in-house. This required developing a routine to convert dry bulb and dew point temperature from the EPW climate data file into wet bulb temperature. From this, generic hourly system performance is calculated based on Pad Efficiency as defined on the HVAC Systems screen. The team was unable to acquire performance data specific to proprietary systems such as the OAsys system.

HEED's current generic model for whole-house economizers and night flushing systems was expanded to include economizer for night-flush cooling, and is defined on the Ventilation Cooling screen and on the HVAC Systems screen. The team was unable to acquire performance data specific to proprietary systems such as the NightBreeze System.

Air-to-Air Heat Exchangers and HRVs (Heat Recovery Ventilators) have been added to HEED, using inputs on the HVAC Systems Design screen.

In Addition, this now allows HEED to more accurately model Passiv Haus designs.

HEED's Remodeling and Additions Capabilities have been expanded to automatically define the performance of older homes based on the date when they were built (essential for the CPUC's California Solar Initiative program for vintage homes). The performance of these existing homes is based on Table R3-50 Default Assumptions for Existing Buildings in the ACM. The fact that HEED can now accurately predict the energy consumption of the remodeling and additions to existing homes is critical because this existing homes sector is so large and so inefficient that it will have a huge impact on California's AB 32 GHG reductions, especially when compared to the new homes sector.

HEED works with the new Reach Standards or Green Building Standards by taking advantage of HEED's ability to model the whole building performance of very low energy buildings plus new capabilities for calculating PV and SDHW systems. The Energy Cost screen shows how close each scheme is to Zero Net Energy (ZNE). Added to this is HEED's new Home Energy Rating screen (similar to a set of HERS Ratings). This colorful comparison bar chart graphically

shows how the different schemes rank according to Tier 1 (15 percent Better), Tier 2 (30 percent Better), and the Zero Net Energy thresholds.

Validating HEED's capability of predicting the performance of Zero Energy Buildings is awaiting publication of recorded hourly data from an existing Zero Net Energy Home along with its climate data.

In Addition, a new Performance Data Summary screen has been provided at the bottom of the Evaluation Icon. This provides a link to a detailed spread sheet file (.csv) that contains all of the numerical data displayed graphically in HEED's 3-D Performance Charts.

3.2 Climate Consultant Upgrades

The goal of this project was to upgrade the Climate Consultant Comfort Calculator software by adding the following new features:

3.2.1 Year 1 Climate Consultant Upgrades

Consulting with Gail Brager and Ed Arens (Center for the Built Environment, UC Berkeley) helped us devise ways to translate into Climate Consultant their research on the Adaptive Comfort Model (ACM) and on the effect of Air Motion for Thermal Comfort (ASHRAE Standard 55-2004 applies to Nonresidential settings).

The Adaptive Comfort Model is now programmed into Climate Consultant as one of the four Comfort Model Options. This model applies only to naturally ventilated spaces where occupants can open and close windows. Their thermal response will depend in part on outdoor climates, and may have a wider comfort range than in buildings with controlled HVAC systems. This model assumes occupants adapt their clothing to thermal conditions and are sedentary (1.0 to 1.3 Met). There must be no mechanical Cooling System, and this method does not apply when a Mechanical Heating system is in operation. Climate Consultant calculates the number of hours that fall within the Acceptability Limits for any climate over all 8760 hours of the year (note that all existing Comfort Calculators were originally designed to work only for a single hour).

In Addition a new Comfort Models screen has been added to Climate Consultant which allows users to select which of the four models they prefer. Each model has its own criteria screen and modifies the way the comfort zone is shown on the Psychrometric Chart and other graphs. The comfort models now include:

California Energy Code Comfort Model, 2008 (Default)

ASHRAE Handbook of Fundamentals Comfort Model, 2005

ASHRAE Standard 55-2004 using PMV (Predicted Mean Vote) model

Adaptive Comfort Motel in ASHRAE Standard 55-2004

In Addition, a number of new features were added to the Psychrometric Chart analysis.

Two new Design Strategies have been added to the Psychrometric Chart: Two Stage Evaporative Cooling and Dehumidification.

A fifth new plot option displays whether Indoor Temperature is Comfortable or Not.

As a Design Strategy is added or subtracted from the chart the count of Comfortable hours is updated.

Specific hours during the day can be displayed (e.g. display data from 8 a.m. to 6 p.m. only). Selection of specific hours was also added to the Wind Wheel Chart.

Climate Consultant's Psychrometric Chart Analytic Model was re-programmed to display each of these four different comfort models and their corresponding Design Strategy zones. The number of hours that fall within each of these zones is calculated to show the best way to design a building specifically for that climate. For example, these upgrades now include two options for Air Motion Comfort: Natural Ventilation and Fan-Forced.

The PMV Model of Comfort (as defined in ASHRAE 55-2004) is now programmed into Climate Consultant as one of the four Comfort Model Options. Thermal comfort is defined based on dry bulb temperature, clothing level (Clo), metabolic activity (Met), air velocity, humidity, and mean radiant temperature (MRT). In Climate Consultant it is assumed that indoor MRT is close to dry bulb temperature. The zone in which most people are comfortable is calculated using PMV (Predicted Mean Vote). In residential settings people adapt their clothing to match season and feel comfortable in higher air velocities and so have wider comfort range. On the Psychrometric Chart this model calculates the number of hours that fall within comfort limits for each of the various Design Strategies over all 8760 hours so that the relative comfort of any climate can be evaluated.

The Comfort Model in the ASHRAE Handbook of Fundamentals, 2005, shows two zones, one for summer and the other for winter, thus allowing a full year's actual hourly data to be evaluated so that the relative comfort of any climate can be evaluated (assuming standard MRT, Clo, and Met).

3.2.2 Year 2: Climate Consultant Upgrades

Climate Consultant's ability to identify the Top-20 Design Guidelines that are unique to each climate was expanded to analyze all of these four models of Human Thermal Comfort. Design

Guideline weights were analyzed to make sure they were appropriate for the different Comfort Models and took account of new Design Strategy zones.

In Addition, a new feature was added to the Psychrometric Chart analysis to display hours for a specific day as points in sequence (a daily loop). This allows the user to see in fine grain the daily evolution of temperature and humidity.

In Addition, another feature added to the Psychrometric Chart is the option of letting Climate Consultant calculate and display the Best Subset of Design Strategies. This eliminates all strategies that would be in conflict with other strategies that have a greater impact on comfort in this climate. The Design Strategies that are selected (either automatically or manually by the user) establish a unique set of Top-20 Design Guidelines.

In Addition, another user-requested addition to Climate Consultant was automating the process of downloading EPW Climate Data files from the US DoE site, thus giving users easy access to a thousand or more weather stations around the world.

In Addition, a major enhancement to Climate Consultant in year 2 was the ability to save Project data to files so it would not have to be loaded from scratch each session. Project data is now automatically saved to a file when exiting Climate Consultant and can be recalled automatically at the start of the next Climate Consultant session. The user can also name and save project data to files to be opened at later sessions. Data saved includes the EPW file name, all changes to criteria for Comfort Models used, any obstructions input to the Sun Shading plot as well as information on fins and overhangs and specific plot settings. This is a major increase in the usability of Climate Consultant by the design community.

A new Web Based version of Climate Consultant, called CC-Lite, was developed (it took two years). It is installed on the Energy-Design-Tools web site, and allows users to immediately run any of California's 16 Climate Zones without the need to download and install the full program. CC-Lite includes all of the features of the full downloaded version except it will not allow 3-D plots and is limited to the 16 California Climate Zones.

A modified Sun Shading plot now allows the user to click and drag shading masks for fins and overhangs. A new Shading Obstructions Input screen has been added to allow users to also input distant obstructions such as trees and buildings or nearby objects such as a chimney that shades a window or a solar collector. Based on this input an obstruction graph will be overlaid on the Sun Shading Plot. The number of unshaded hours when shading is needed (red), when solar gain is needed (blue), and when solar gain is not useful (yellow), is now calculated and displayed. Because this chart also allows users to click and drag fins and overhangs onto this Sun Shading chart, users can now quantitatively evaluate Window Shading and PV Placement. This data input and display format is identical to the CECPV Shading Calculator. These changes replace the Fisheye Lens plot as originally proposed.

In Addition, the amount of Tilted Surface Radiation (given the input of tilt degrees, bearing and ground reflectance) can be displayed on the Radiation Range Chart, the Time Table Plot and the 3D Chart.

3.2.3 Year 3 Climate Consultant Upgrades

A hot link was added in HEED to automatically connect it directly to Climate Consultant's list of the Top-20 Design Guidelines, for the specific climate and comfort range defined in HEED. Also by clicking on any of these Guidelines the HEED user can see the Climate Consultant Sketch that illustrates the application of the most appropriate very low energy cooling strategies based on the climate and comfort definition.

In Addition, a great many technical issues had to be solved because many users switched to Windows 7, which required for example the modification of all the 3D Graphic plots.

In Addition, the Sun Shade Chart had to be modified to work in locations in the tropics (between the Tropic of Cancer and Capricorn), because at noon the sun can shine on either the north or south elevation depending on season.

Climate Consultant's User Help function was expanded to include a text-based Tutorial to explain the six factors that define the Expanded Definition of Human Thermal Comfort (based on the local climate developed from the Climate Consultant Psychrometric Chart Analysis).

CHAPTER 4:
Dissemination and Project Outreach

4.1 Energy Design Tools Web Site

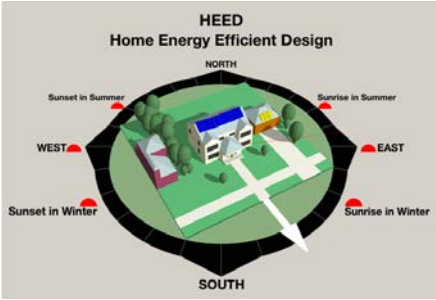
As part of this project, the team developed a web site that has made it possible to disseminate a total of over 120,000 copies of HEED and Climate Consultant. This site also helps facilitate the User Hotline to answer user's questions (usually within 24 hours). Figure 22 below offers an excerpt of the main web page, but there are also three other support pages that manage the downloads and offer additional technical support.

Figure 22: Energy Design Tools web site excerpt

ENERGY DESIGN TOOLS:

All our Energy Design Tools are fast, easy to use, highly graphic, and free. Each has a built in demonstration. Each has an automatic INSTALL routine or a READ.ME file explaining how to use it. You are welcome to publish the output and share copies provided that the Regents Copyright and Terms of Use remain unaltered.

HEED: Home Energy Efficient Design

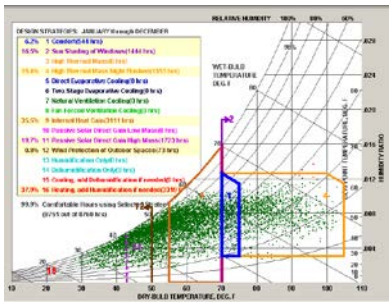


This new easy-to-use version shows you how much energy and money and carbon you can save by making various Design or Remodeling changes to your home. You can easily draw in the floor plan of your house, then click and drag windows to their correct location on each wall. You can add trees and neighboring buildings and see an animation of sun shadows moving across your building. You can select from lists of standard wall and roof construction, and can add high mass to temper indoor temperatures. Various other Passive Heating and Cooling options are available including ventilation, evaporative cooling, and passive solar heating. You can add Photovoltaic Panels and Solar Hot Water Collectors. HEED can automatically download climate data for thousands of locations around the world. Many kinds of Building Energy Performance data is displayed including bar charts that show how close your building is to Zero Net Energy. HEED self-installs on non-networked Windows XP or Mac OS X 10.6 or newer systems. HEED is also available in Spanish.

Go To HEED Page

Figure 22: Energy Design Tools web site excerpt (continued)

CLIMATE CONSULTANT



Climate Consultant is a simple to use, graphic-based computer program that helps architects, builders, contractor, homeowners, and students understand their local climate. It uses annual 8760 hour EPW format climate data that is made available at no cost by the Department of Energy for thousands of weather stations around the world. Climate Consultant translates this raw climate data into dozens of meaningful graphic displays.

The purpose is not simply to plot climate data, but rather to organize and represent this information in easy-to-understand ways that show the subtle attributes of climate, and its impact on built form. The goal is to help users create more energy efficient, more sustainable buildings, each of which is uniquely suited to its particular spot on this planet.

The Psychrometric Chart shown to the left is one of the more advanced features available in Climate Consultant. Each dot on the chart represents the temperature and humidity of each of the 8760 hours per year. Different Design Strategies are represented by specific zones on this chart. The percentage of hours that fall into each of the 16 different Design Strategy Zones gives a relative idea of the most effective passive heating or passive cooling strategies. Climate Consultant analyzes the distribution of this psychrometric data in each Design Strategy zone in order to create a unique list of Design Guidelines for a particular location.

If you wish to work with the full desktop or laptop version of Climate Consultant, select the appropriate installation version below:

Download Climate Consultant 5.4 [For Windows] (33 MB) (B4, October 7, 2012)

Download Climate Consultant 5.4 [For Mac] (13 MB) (B4, October 7, 2102) Requires Mac OS X 10.6.8 or newer.

Climate Consultant 5.4 is the full release with the most up-to-date graphics for newer operating systems. If you have problems displaying the 3D Charts screens you should download and install Climate Consultant 5.3 instead.

Download Climate Consultant 5.3 [For Windows] (29 MB) (B5, October 7, 2012)

Figure 22: Energy Design Tools web site excerpt (continued)

CLIMATE CONSULTANT Lite (CCLite)

CCLite is a web version of Climate Consultant offering most of the functionality available in the full download version of Climate Consultant although it will only access EPW data for the 16 California Climate zones. It also does not allow project data to be saved for future retrieval or the display of the 3D plots.

GO TO CCLite Page.

PSYCHROMETRIC CHART TUTORIAL

The Psychrometric Chart Tutorial is a dynamic graphic and audio presentation that shows the relationship between air temperature and humidity, and how this influences human thermal comfort. It is written in Flash and you can download a copy below. PsyChartTutorial [Released September 15, 2008] (After downloading the PsyChart.zip file, open the file and then open the PsyChart.html file.)

Download the Flash Player at www.adobe.com/products/flashplayer/

CLIMATE DATA

Climate Data for HEED and Climate Consultant is available for over one thousand locations around the world on the EnergyPlus web site. (See READ-EPW (Automatic) or READ-EPW (Manually) for details.)

4.2 Technology Transfer: HEED-Climate Consultant Workshops

Nine Technology Transfer workshops were presented throughout California. The people who attended were homeowners, contractors, architects, builders, governmental people, and students. These workshops were typically four hours in length in a hands-on format. Most participants brought their own laptop computers and both pieces of software were loaded in. Typically a PowerPoint presentation introduced the latest versions of HEED and Climate Consultant. These workshops were conducted by Dr. Pablo LaRoche who has been involved in presenting many prior workshops, and who uses these tools in his classes at Cal Poly Pomona. In many workshops Carlos Gomez, the Project Systems Programmer also attended for roving user support. This is to Certify that the following workshops have been presented:

4.2.1 Year 1:

Scheduled, organized, and presented three HEED-Climate Consultant Technology Transfer Workshops

Workshop 1 presented at SCG Energy Resources Center, Downey, November 9, 2010

Workshop 2 presented at PGE Pacific Energy Center, San Francisco, October 29, 2010

Workshop 3 presented at Center For Sustainable Energy, San Diego, July 7, 2010

4.2.2 Year 2:

Scheduled, organized, and presented three HEED-Climate Consultant Technology Transfer Workshops

Workshop 4 presented at Center for Sustainable Energy, San Diego, March 2011

Workshop 5 presented at SCG Energy Resources Center, Downey, April 6, 2011

Workshop 6 presented at PGE Pacific Energy Center, San Francisco, May 27, 2011

4.2.3 Year 3:

Scheduled, organized, and presented three HEED-Climate Consultant Technology Transfer Workshops

Workshop 7 presented at PGE Pacific Energy Center, San Francisco, May 19, 2012

Workshop 8 presented at TTG AIA, Pasadena, July 11, 2012

Workshop 9 presented at SCG Energy Resource Center, July 17, 2011 Downey, CA

In addition, a Workshop on Climate Consultant alone was given at PGE Pacific Energy Center, San Francisco, on November 10, 2011

4.3 User Hot Line: Comments on HEED and Climate Consultant

The team maintained a user hot line that answered all user questions within 48 hours. A few of these users have turned up bugs or typographic errors that the team was able to correct in subsequent releases of HEED and Climate Consultant, while others needed clarification on how to use these tools, but most frequent were hardware, graphic drivers, or operating system issues.

The team received on average one query per week which is minimal considering over 120,000 users. Many of these queries began with a compliment from the users on how appreciative they were for such helpful design tools.

The following are some of the comments received from users:

4.3.1 HEED User Comments

Received on the HEED User Hot Line (Names and affiliations have been redacted but are available on request)

Been using HEED a lot on house projects – great tool!

…thank you and UCLA for developing and making the energy programs and information available.

Very cool software and well done! Thanks for your hard work - god knows the construction industry needs this!

Heed Software is a real Wow!! Thank you…. It is indeed superb.

Imagine the ease with which architects and contractors can share information with their clients when everyone in the group is able to use the same software, without worrying about the prohibitive cost or licensing of expensive, specialty programs. What's more, because the program is relatively easy to use, it also means that clients working with professionals can explore different energy-saving options on their own. That can only enhance the communication process…. Excerpt from a Review

Many thanks for elaboration of very visual and user-friendly HEED programme. HEED programme is constructed in a very tempting way,

Hello HEED experts,… I heart HEED!!!

… running HEED … I do appreciate this free utility & thank for your time in developing this.

I have used HEED for several residential projects….. Thanks so much for this great tool

I found it an extremely useful tool and I believe it has a great potential for improving design and learning to generate better options.

… looking at your energy design site. I thought I would let you know how much I appreciate and admire the work you have done. It is a model in so many ways. The fact that it is free and freely distributed is deeply and fundamentally good and right.

I think the program Heed is a very interesting tool for computations.

Thank you for the opportunity to benefit from this program.

First, thank you. I've been using your program for a few weeks now and absolutely love it. It is now a major tool in my design work.

I would just like to thank you for maintaining the resource at energy-design-tools.aud.ucla.edu/ it's essential that information regarding environmental issues are easily and broadly accessible.

Thanks for making your software available. It was very useful, in particular, because it suggested that we should enlarge our south-facing window area, and we are glad we followed that guidance.

thank you for creating such an amazing software like HEED it's really easy to understand...

Thank you very much. You are doing a wonderful thing. This is the missing link you are exposing. Never will we get true green buildings without recognition of what you are doing.

Thanks, Murray. I keep getting wowed by this program as I proceed.

… it is a truly wonderful project you have been handling for many years. Thank you

Thank you so much. I know this program of yours will help me immensely.

Once again, thank you.

I have been enjoying using HEED to model my home.

I was surprised at how well the estimates from HEED match my calculations of yearly BTU usage based on fuel consumption last year.

Thanks again for a great program!

Dear HEED Team: first of all, thank you for a great tool. I am in the process of designing a net zero energy home and have a couple of questions about HEED modeling:

HEED has performed remarkably well for the thermal comfort modeling I'm doing

I want to appreciate the work of you and all those that have contributed to this terrific program.

4.3.2 Climate Consultant User Comments

Received on the Climate Consultant User Hot Line (Names and affiliations have been redacted but are available on request)

I have used Climate Consultant in the past and believe it is a great resource.

The software now makes it possible to integrate your solutions with worldwide climate data—the HEED-developed Climate Consultant 5 performs the graphic analysis. Originally a tool that represented climate data to be easily understood by the building industry, the software now can show the impact of shading provided by distant structures as well as nearby ones, all incorporated into your calculations. It can also help you record and evaluate the impact of temperature and humidity measurements during a single day. These free tools are making designing and redesigning energy efficiency into buildings much easier than ever before—a fitting way to environmentally conscious homeowners to ring in 2012…. Excerpt from a published review…

Thank you for all of these very useful climate analysis tools!

Thank you for this. I just went through the amazing Climate Consultant software and it will indeed help all those dedicated to the feasibility of using maximum passive measures for designing a green building. Some dynamic tools inbuilt into the Software are really outstanding and well appreciated.

About 20 minutes using Climate Consultant (thank you Murray; thank you) gave a pretty clear picture of the potential for cross ventilation.

CC4 turns out to be a useful communications tool when discussing building envelopes and green strategies with Architects and HVAC Engineers.

I downloaded the latest Climate Consultant and the enhancements look great.

I hope this feedback is helpful. Your program certainly has been.

I have started using this software and found it extremely useful in developing early design guideline for building construction.

4.3.3 Multiplier Effect: User Hot Line Comments from Teachers

Comments on the User Hot Line showed that both HEED and Climate Consultant are being used by professional educators and college teachers, which greatly increases the dissemination of these tools by multiplying the number of users who benefit directly from this project:

Thanks so much for your continuing efforts to improve these tools! We have 85 architects taking the Workshops (broken into two sections) for these 4 hour sessions, one a month for 10 months. Getting great feedback.

It is fun to teach students the principles of passive solar heating and cooling and that net zero is an attainable goal :) As I said before, I enjoy using HEED as students can quickly figure things out and do their own explorations. I look forward to the next release!

I commend you and your teams, it is exactly what the building community needs now. I am preparing a lecture … to the design and building community. I wish to feature what I have learned using Heed and to promote the use.

Starting my students on HEED tomorrow. Been playing with it for a few days - great program. Perfect for getting them started on modeling.

I want to say how impressed I am with the tools that you have developed and specifically Climate Consultant, which is such an important and powerful tool. I have used the tool to run exercises in the climate session of the AIA+2030 Professional Education Series

Just a note to let you know that my architecture students are starting to use Climate Consultant 4. The new version is simply splendid. Along with the Psychrometric Tutorial and the Chapter you and Baruch Givoni authored a few years back, my students are sure to improve their comprehension and integration of this material… I will also introduce the students to HEED later in the semester. This is just my long way of saying thank you (and your students) for all of your contributions.

It was a real pleasure to attend your class and to meet you and the rest of the panel. As mentioned, I have known about Climate Consultant for many years and I can't tell you how helpful I think it is to our industry in helping Architects (both those aspiring students and active professionals) to visualize and implement climate-based design tools. I am sure you know how far-reaching and effective the tool is, but it is something that I can definitely attest to.

I, along with my students, find Climate Consultant to be a great tool. Thank you for your consideration, and thanks for generating such a great open access tool.

I have been making great use of your Climate Consultant (v5.1) in my teaching of environmental controls courses… Great interface, very useful to the students as a tool in the early design process. Thanks for all your great work!

I am an architect intern working for the U.S. Army Corps of Engineers. I used the program Climate Consultant 5 as a student in college, and recently made the case to my supervisors that this program would be useful in our office.

In case you've noticed, I'm now using your tools in one of my assignments for 50+ students each fall. Works great, and they REALLY appreciate it after they have had to get the bin data from the LCDC sheets at the library and plot by hand on the psychrometric chart manually.

I want to tell you directly how much my students appreciate the Climate Consultant graphs.

That's a great tool and one that will really help me explain design strategies to students.

CHAPTER 5:
Conclusions and Recommendations

5.1 Project Outcomes: Benefits to California

The goal of this project was to give all Californians a pair of software design tools that will help them create Zero Net Energy and Zero Net Carbon Homes by the year 2020. If the use of HEED, for example, saves an average of just 25 percent of home energy consumption with only a modest 1 percent penetration of the new home market, then it will save Californian ratepayers over 35 times the cost of this project by the year 2020.

5.2 Recommendations for Future Work

By the year 2030 Californians will be expected to make all new commercial buildings Zero Net Energy. More new tools are needed to help Californians improve the efficiency of their commercial buildings as well as homes. New software tools must be launched with only the minimal information that is available at the very beginning of a project, on day one, and will let users easily try out all sorts of alternatives and see graphically how close they are getting to Zero Net Energy.

There are hundreds of thousands of small low-rise non-residential buildings in California that are built or remodeled every year (stores, small offices, schools, studios, warehouses, etc.). Most of existing small low-rise nonresidential buildings will require a deep retrofit well before 2030. The owners of these buildings need a day-one design tool they can use by themselves to test which retrofit alternatives make the best economic sense. The needs of these small building owners are completely different from the huge high-rise building design projects that already have their own complex simulation programs and highly specialized (and highly paid) professionals to fine-tune performance. Californians need a new nonresidential tool SBEED (Small Building Energy Efficiency Design Tool) based on the already successful HEED program. This new design tool should also be designed to support the CEC's Comprehensive Energy Efficiency Program for Existing Buildings to meet the needs of AB758.

The current versions of HEED and Climate Consultant will also need to be upgraded to meet new energy compliance regulations. HEED was created to meet the 2008 Title 24, but soon the 2013 Residential Energy Code takes effect, so now HEED needs to be updated to address these new, more stringent requirements. HEED should also be upgraded to the new 2013 gas and electric utility rates and rate structures and be expanded to support the CEC's Comprehensive Energy Efficiency Program for Existing Homes. Climate Consultant needs to be upgraded for the new comfort criteria in both the new Residential and Nonresidential Codes and a new set of design guidelines needs to be developed for nonresidential building types. Users are also asking for new types of graphic data representation and sun shading calculations.

It is important to develop a tablet versions of the HEED software to allow in-field data input and onsite energy efficiency evaluations. This new technology option will greatly expand the

user base in California for building energy efficiency. The objective is to bring the CEC's offerings into the era of mobile hand-held computing devices and to make energy efficient design accessible and attractive to the new younger generation of Californians.

A final recommendation is to increase technology transfer to all Californians by producing on-line You-Tube type tutorials to show both novice and advanced users how to take full advantage of these new tools. The objective would be to show how these Energy Design Tools are fun and easy for everyone to use, yet run powerful and sophisticated simulations that are trusted and relied upon by beginning users and energy professionals alike. As part of this current PIER project a series of workshops were offered around the state which were very well received but reached only a limited number of people, mostly energy professionals. This internet based approach to technology transfer will create a much stronger market connection to reach and train an essentially limitless audience.

REFERENCES

ANSI/ASHRAE 2007.Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, GA.

Beckman, W.A. and J.A. Duffie.*Solar Energy Thermal Processes*.Solar Energy Laboratory, University of Wisconson-Madison.John Wiley and Sons, New York, NY. 1974.

CECPV Calculator State of California, California Energy Commission & California Public Utilities Commission.Sacramento, CA. 2013.http://www.gosolarcalifornia.org/tools/nshpcalculator/download_calculator.php

California Energy Commission, 2008 Building Energy Efficiency Standards for Residential and NonResidential Buildings, 2008, CEC-400-2008-001-CMF

California Energy Commission, Residential Alternative Calculation Method (ACM) Approval Method, 2008, CEC-400-2008-002

CClite, Energy Design Tools Group, UCLA Department of Architecture and Urban Design. 2013. <http://www.energy-design-tools.aud.ucla.edu>

Climate Consultant. Energy Design Tools Group, UCLA Department of Architecture and Urban Design. 2013. <http://www.energy-design-tools.aud.ucla.edu>

Climate Registry, Greenhouse Gas Production by Electric Utilities in North America**,** Climate Registry Information System (CRIS), http://www.theclimateregistry.org/

EnergyPlus2010. *EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007*.U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.

EnergyPlus Weather. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.

EnergyPro V5, EnergySoft Inc, ***www.energysoft.com***/

HEED (Home Energy Efficient Design). Energy Design Tools Group, UCLA Department of Architecture and Urban Design. 2013. <http:/ / www.energy-design-tools.aud.ucla.edu/ heed/ >

HEED Validation Against the ASHRAE/BESTEST Standard (ASHRAE Standard 140), Grace Tsai and Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2003

HEED Validated Using HERS Bestest Tier 1 and 2: 2008, Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2007

HERS BESTEST 1995. *Home Energy Rating System Building Energy Simulation Test*., R Judkoff and J Neymark, National Renewable Laboratory, 1617 Cole Blvd, Golden Colorado, 80401

Marion, B., M. Anderberg, R. George, P. Gray-Hann, and D. Heimiller.*PVWATTS Version 2 – Enhanced Spatial Resolution for Calculating Grid-Connected PV Performance*. National Renewable Energy Laboratory.Golden, CO. 2001.

Menicucci, D. and J. Fernandez.*User's Manual for PVFORM: A Photovoltaic System Simulation Program for Stand-Alone and Grid-Interactive Application*.SAND85-0376.Sandia National Laboratories. Albuquerque, NM. 1988.

PVWatts™ Grid Data Calculator (Version 2).National Renewable Energy Laboratory. Golden, CO. 6 June 2011. http://www.nrel.gov/rredc/pvwatts/grid.html

Psychrometric Chart Tutorial. Energy Design Tools Group, UCLA Department of Architecture and Urban Design. 2013. <http://www.energy-design-tools.aud.ucla.edu>

Tariff Book, Electric and Gas Rates specific to each Utility, see:

http://www.pge.com/tariffs/

https://www.sce.com/SC3/residential/

http://regarchive.sdge.com/regulatory/currentEffectiveTariffs.shtml

www.socalgas.com/regulatory/tariffs/tariff-Book.shtml

GLOSSARY

AB32 Assembly Bill 32, which calls for substantial Greenhouse Gas (GHG) reductions

AB758 Assembly Bill 758, Comprehensive Energy Efficiency Program for Existing Buildings

ACM Alternative Calculation Manual (CEC Reverence Method containing rules used for modeling residential and non-residential buildings for Performance Compliance

AFUE Annual Fuel Utilization Efficiency, used as a rating for furnace efficiency

AHRI Air Conditioning Heating and Refrigeration Institute, agency that publishes performance data on water heater tanks

ASHRAE American Society of Heating Refrigeration and Air Conditioning Engineers

BTU British Thermal Unit (a measure of heat energy)

CC Climate Consultant, (rarely used acronym) software developed as part of this project

CClite Climate Consultant Lite, an internet based version of Climate Consultant developed as part of this project, so users do not need to download and install the full version

CEC California Energy Commission (aka the Commission or the Energy Commission)

CPUC California Public Utilities Commission (aka the Utility Commission)

CECPV PV Design and Rebate calculation software developed and distributed by the CEC

DOE Department of Energy (US government agency analogous to the CEC)

EER Energy Efficiency Ratio, usually of air conditioners or heat pumps, changes with load

EPW Energy Plus Weather (.epw designates annual 8760 hour files mad available by DOE)

EUI Energy Use Intensity, usually measured or calculated in kBtu/sq.ft.year

GHG Green House Gasses, usually Carbon Dioxide plus others that cause global warming

HEED Home Energy Efficient Design, software program developed as part of this project

HSPF Heating System Performance Factor, a measure of heating efficiency of heat pumps

kBtu One thousand BTUs

kW One thousand Watts

kWh One thousand Watt-hours (a measure of electrical energy)

PV Photovoltaics (process of generating electricity from sunlight, system uses flat panels)

Res Residential, as opposed to Non-Res, Non-Residential

SHW Solar Hot Water (water heated by solar energy, system usually uses flat panels)

SDHW Solar Domestic Hot Water (potable water heated by solar energy, usually uses panels)

SEER Seasonal Energy Efficiency Ratio, usually of air conditioners or heat pumps based on an a kind of annual average instantaneous EER (Energy Efficiency Ratio)

SRCC Solar Ratings Certification Corporations, agency that published performance data for solar water heating panels

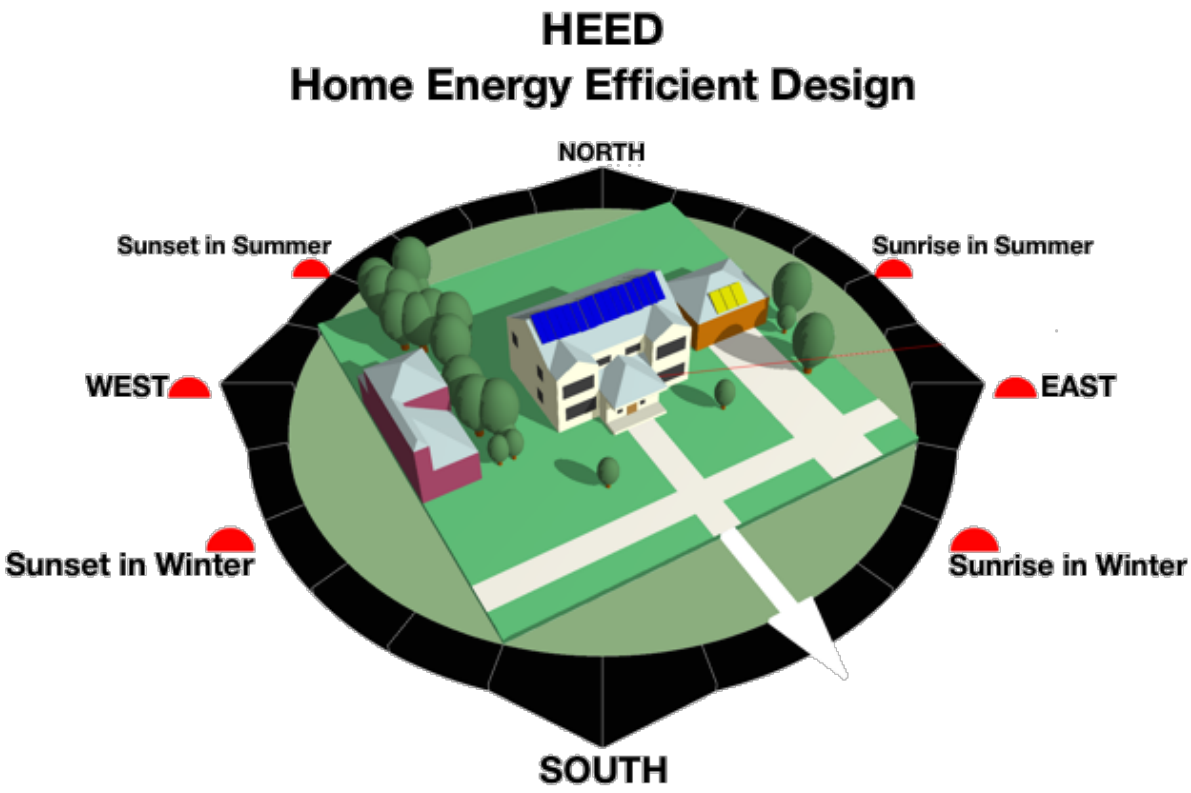
TDV Time Dependent Valuation, revision by the CEC of hourly electricity cost in each climate zone to discourage peak hour consumption

W Watt

Wh Watt-hour (=3.412 Btu)

ZNE Zero Net Energy, describing a building that uses no imported (site) energy

APPENDIX A:
HEED Validation Tests



HEED Validation Reports

HEED 4.0, Build 27 and Build 29
October 2012

Prepared for:

UCLA Department of Architecture and Urban Design
Professor Murray Milne

Prepared by:

Alicyn Henkhaus, EIT

Appendix Table of Contents

EXECUTIVE SUMMARY 33

HEED VALIDATED AGAINST THE ASHRAE/BESTEST STANDARD 140 555

HEED VALIDATED AGAINST THE HERS BESTEST STANDARD 144

COMPARISON OF HEED AND ENERGYPLUS VALIDATION RESULTS 233

VALIDATION OF PV POWER GENERATION SIMULATION IN HEED 299

Please note that table and figure numbers may vary from the individually published reports; they have been re-numbered to ensure that each is uniquely identified.

Executive Summary

HEED: Home Energy Efficient Design

HEED (Home Energy Efficient Design) is an easy-to-use tool that helps homeowners, builders, and architects design more energy efficient homes. HEED uses a program originally called Solar-5, developed at UCLA, for its thermal analysis computation kernel. It uses an hourly heat balance similar to the method used in EnergyPlus. It calculates an hourly heat balance for each of the 8760 hours in a year using standard ASHRAE algorithms, the Mackey and Wright time lag and decrement factor method of accounting for heat flow through opaque walls, the Admittance Factor Method to account for internal thermal mass, and the California Energy Commission's ACM method to calculate the performance of basements. To find the hourly heat balance it uses a successive approximation method to calculate the indoor air temperatures. Thus it can integrate loads and energy calculations at each hourly time step, which means that the HVAC system only adds heating or cooling energy if the indoor air temperature has floated beyond the upper or lower comfort limits.

ANSI/ ASHRAE Standard 140

The American National Standards Institute (ANSI) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) together developed Standard 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. This standard is updated periodically, and versions from 2001 and 2007 have been used to validate different versions of HEED. Standard 140-2007 includes reference results from eight simulation programs: ESP, BLAST, DOE2, SSRE/ SUN, SERIRES, S3PAS, TRANSYS, and TASE. No formal criteria are set by ASHRAE Standard 140-2007 to determine a range of acceptable results (ANSI/ ASHRAE 2007, Section 4.4.1). The acceptance criteria defined for HERS BESTEST were used to calculate whether the HEED results fell within an acceptable range (HERS BESTEST 1995, Appendix H).

HERS BESTEST Standard

The Home Energy Rating System Building Energy Simulation Test (HERS BESTEST) was developed at the National Renewable Energy Laboratory and published in November 1995. The standard includes a methodology for validation and for developing pass/ fail criteria. The pass/ fail criteria for each case are based on reference results from three simulation programs: BLAST 3.0, DOE2.1E, and SERIRES/ SUNCODE 5.7 (HERS BESTEST 1995, Appendix H). Climate data for Colorado Springs, Colorado, were used for the heating tests, and climate data for Las Vegas, Nevada, were used for the cooling tests.

Validation Reports

The validation reports included in this document tested HEED 4.0 (Build 27, Jul 31, 2012). In some cases, tests that did not pass in the initial validation were retested in the latest version of the software (HEED 4.0, Build 29, Sep 26, 2012). Changes made between Build 27 and Build 29 were designed to allow more accurate user input, not change the calculation process. Results

are reported as the annual heating and cooling loads required for each test case in the standards. Each standard also specifies a number of delta tests, which isolate the effects of the changes made between cases.

HEED Validated Against the ASHRAE/ BESTEST Standard 140

Standard 140-2007 includes cases for low-mass and high-mass buildings, and the cases range from extremely abstract to quite realistic. HEED could not run seven of the more abstract cases, because the program does not allow modification of interior infrared emittance, interior shortwave absorption, or exterior combined radiative and convective surface coefficients. HEED passed 100 percent of the cases that it was able to run, for both heating and cooling. HEED also passed 97 percent of the heating and cooling delta tests, failing two. The two failed tests compared annual cooling loads; one tested the effect of night ventilation and the other tested the effect of different thermostat setbacks.

HEED Validated Against the HERS BESTEST Standard

HERS BESTEST includes both active and passive test cases. HEED passed 100 percent of the Annual Heating and Cooling Tests, for 28 active and seven passive cases. HEED also passed 92 percent of the delta tests, failing two. The two failed tests compared annual heating loads as floor insulation varied, one for slab on grade floor construction and the other for finished basements. The insulations levels defined by the basement test cases could not be replicated in HEED.

Comparison of HEED and EnergyPlus Validation Results

EnergyPlus is another whole building energy simulation tool, developed by the U.S. Department of Energy. Unlike HEED, EnergyPlus is a stand-alone calculation engine that is used by many third-party tools with their own graphical user interfaces (DesignBuilder and AECOsim Energy Simulator are two examples). HEED's validation results for ASHRAE Standard 140-2007 were compared with the published results from validation of EnergyPlus Version 6.0.0.023 under the same standard. Only results from the basic low mass (600 series) and high mass (900 series) cases were published. Both HEED and EnergyPlus passed 100 percent of these cases.

Validation of PV Power Generation Simulation in HEED

This document details the validation of photovoltaic (PV) power generation in HEED, which is not covered by either the ASHRAE or HERS standards. HEED's calculations of PV system performance were compared to results from the CECPV calculator; both use the five-parameter model and F-Chart algorithm developed by Bill Beckman. Commercially-available solar kits were used to define the test systems. The annual energy generation reported by HEED was on average 7 percent higher than the results reported by CECPV.

HEED Validated Against the ASHRAE/ BESTEST Standard 140

Alicyn Henkhaus, EIT

August 18, 2012 (Updated October 2, 2012)

Background:

The current release of HEED 4.0 (Build 27, Jul 31, 2012) was validated using ASHRAE Standard 140, 2007. The standard consists of 34 different building design cases that were originally run using seven different building energy performance programs including DOE-2 and ESP. These same cases were also run using EnergyPlus, and the results were published separately.

No formal criteria are set by ASHRAE Standard 140-2007 to determine a range of acceptable results (ANSI/ ASHRAE 2007, Section 4.4.1). The acceptance criteria defined for HERS BESTEST, another standard, were used to calculate whether the HEED results fell within an acceptable range (HERS BESTEST 1995, Appendix H). The aggregated calculations for the seven programs included with ASHRAE 140-2007 were used as reference results. The maximum of the acceptable range is the greater of:

the maximum reference result + 4 MBtu, and

the upper 90 percent confidence interval based on the sample of reference results.

The minimum of the acceptable range is the lesser of:

the minimum reference result - 4 MBtu, and

the lower 90 percent confidence interval based on the sample of reference results.

This methodology was used to establish acceptance ranges for the annual heating, cooling, and delta validations.

Current Test Results:

Six of the cases could not be run using HEED (195, 200, 210, 280, 440, and 810) because HEED does not allow modification of the interior infrared emittance or interior shortwave absorption. Another case (215) could not be run because HEED does not allow modification of the exterior combined radiative and convective surface coefficients for the special case of opaque windows. All (100 percent) of the cases that HEED ran fell within the acceptance range for both heating and cooling. All results are included in Table 5, and displayed in Figure 5 and Figure 6.

Delta tests, which isolate the effects of the changes made between cases, can also be used to evaluate whether annual heating and cooling results are acceptable. Of the heating and cooling delta cases that HEED ran, 95 percent fell within the acceptance range. All results are included in Table 3, and displayed in Figure 3 and Figure 4.

Updated Test Results:

The delta cases that did not pass in the initial validation were retested in the latest version of the software (HEED 4.0, Build 29, Sep 26, 2012). Changes made between Build 27 and Build 29 were designed to allow more accurate user input, not change the calculation process. Of the three failed delta tests, one now passes. All cases used in the delta tests still pass individually. The failed delta tests both compared annual cooling loads. One tested the effect of night ventilation; the other tested the effect of different thermostat setbacks. Overall, HEED passed 97 percent of the heating and cooling delta tests.

The results of the retested cases are included in Table 8.

References:

ANSI/ ASHRAE 2007. Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, GA.

EnergyPlus2010. *EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007*. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.

HEED Validation Against the ASHRAE/ BESTEST Standard (ASHRAE Standard 140), Grace Tsai and Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2003

HEED Validated Using HERS BESTEST Tier 1 and 2: 2008, Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2007

HERS BESTEST 1995. *Home Energy Rating System Building Energy Simulation Test*., R Judkoff and J Neymark, National Renewable Laboratory, 1617 Cole Blvd, Golden Colorado, 80401

HEED is available at no cost from http://www.energy-design-tools.aud.ucla.edu/heed

Figure 1.

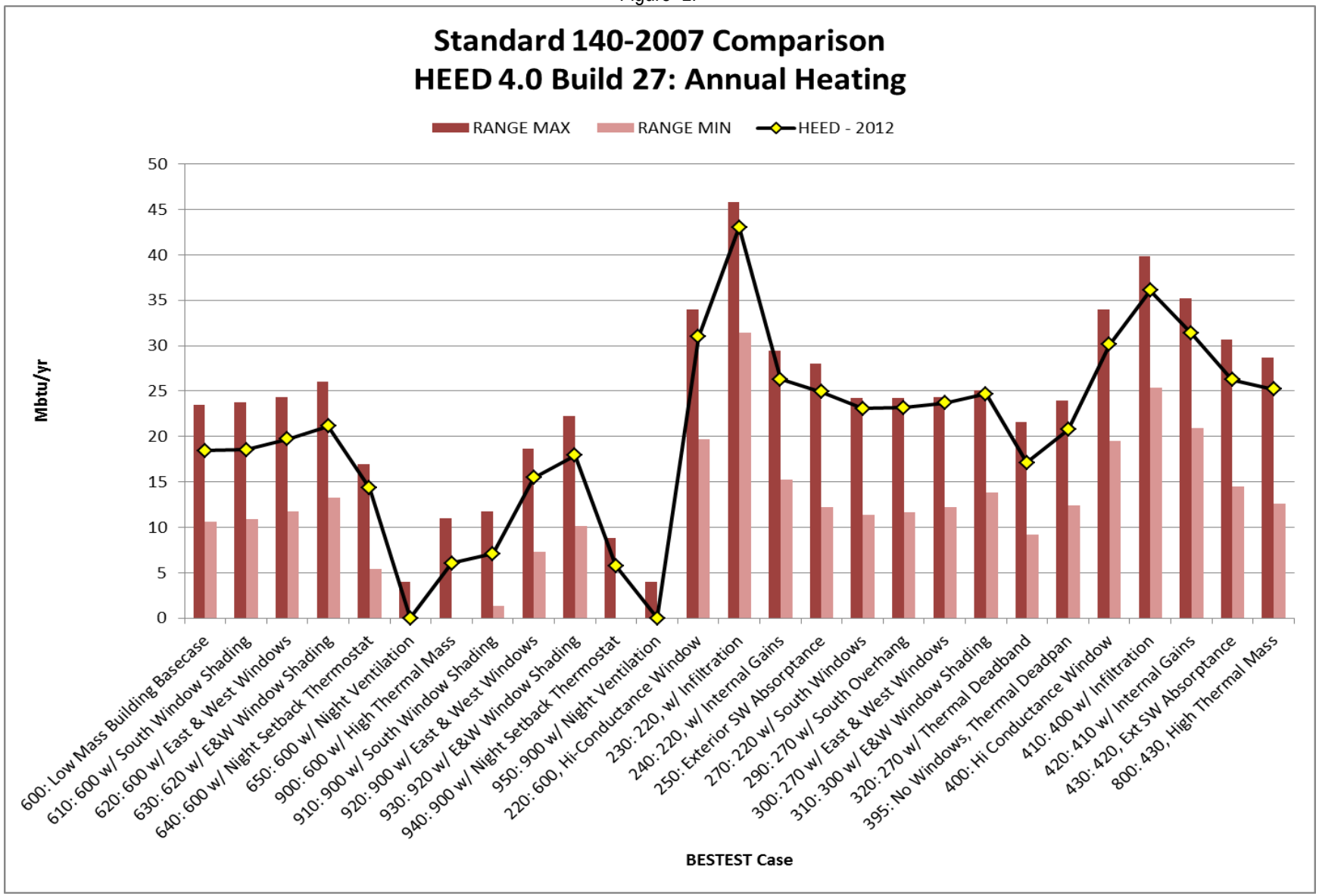

Standard 140-2007 Comparison
HEED 4.0 Build 27: Annual Heating
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
50
45
40
35
30
25
20
15
10
5
0
600: Low Mass Building Basecase
610: 600 w/ South Window Shading
620: 600 w/ East & West Windows
630: 620 w/ E&W Window Shading
640: 600 w/ Night Setback Thermostat
650: 600 w/ Night Ventilation
900: 600 w/ High Thermal Mass
910: 900 w/ South Window Shading
920: 900 w/ East & West Windows
930: 920 w/ E&W Window Shading
940: 900 w/ Night Setback Thermostat
950: 900 w/ Night Ventilation
220: 600, Hi-Conductance Window
230: 220, w/ Infiltration
240: 220, w/ Internal Gains
250: Exterior SW Absorptance
270: 220 w/ South Windows
290: 270 w/ South Overhang
300: 270 w/ East & West Windows
310: 300 w/ E&W Window Shading
320: 270 w/ Thermal Deadband
395: No Windows, Thermal Deadpan
400: Hi Conductance Window
410: 400 w/ Infiltration
420: 410 w/ Internal Gains
430: 420, Ext SW Absorptance
800: 430, High Thermal Mass
BESTEST Case

Figure 2.

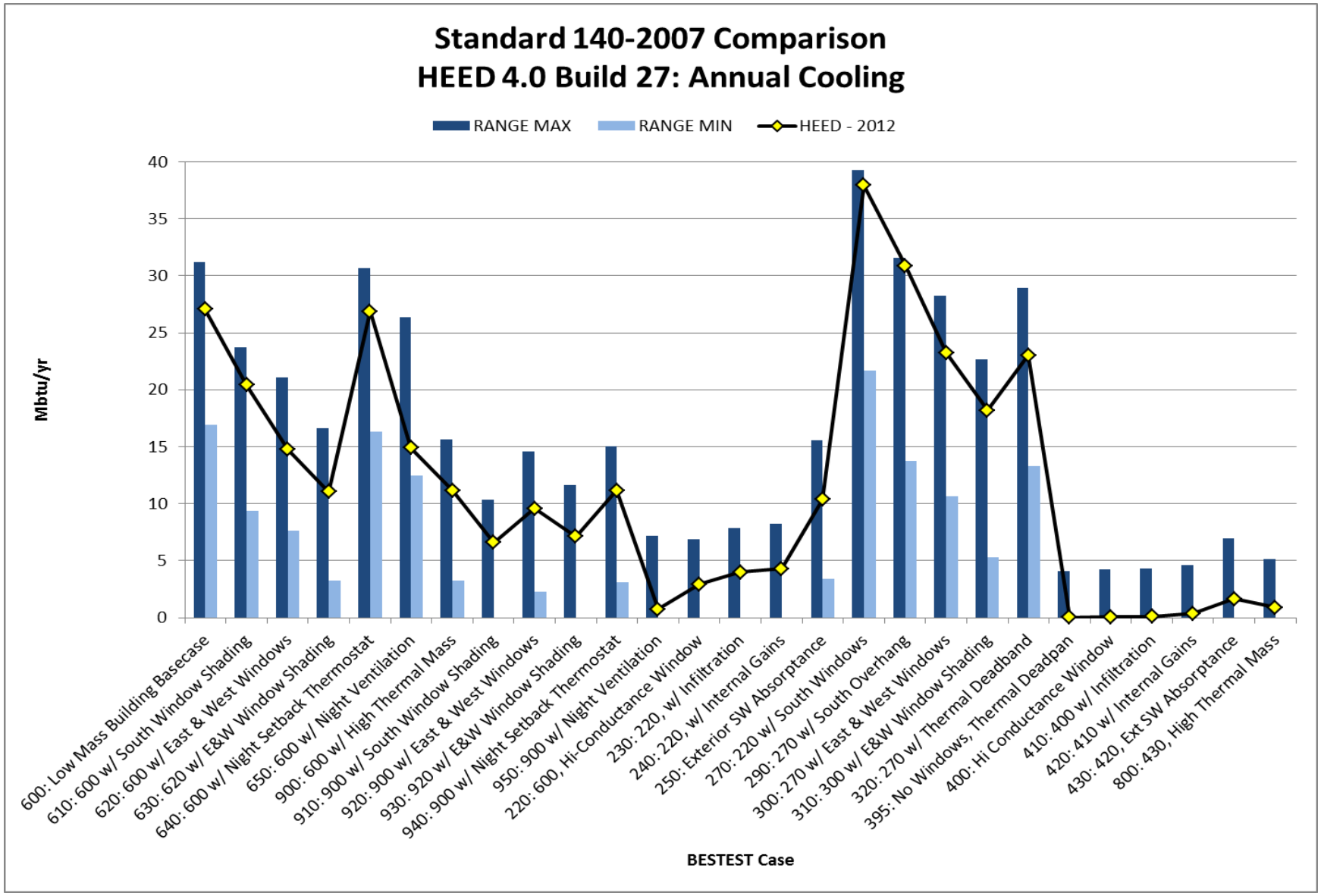

Standard 140-2007 Comparison
HEED 4.0 Build 27: Annual Cooling
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
0
5
10
15
20
25
30
35
40
600: Low Mass Building Basecase
610: 600 w/ South Window Shading
620: 600 w/ East & West Windows
630: 620 w/ E&W Window Shading
640: 600 w/ Night Setback Thermostat
650: 600 w/ Night Ventilation
900: 600 w/ High Thermal Mass
910: 900 w/ South Window Shading
920: 900 w/ East & West Windows
930: 920 w/ E&W Window Shading
940: 900 w/ Night Setback Thermostat
950: 900 w/ Night Ventilation
220: 600, Hi-Conductance Window
230: 220, w/ Infiltration
240: 220, w/ Internal Gains
250: Exterior SW Absorptance
270: 220 w/ South Windows
290: 270 w/ South Overhang
300: 270 w/ East & West Windows
310: 300 w/ E&W Window Shading
320: 270 w/ Thermal Deadband
395: No Windows, Thermal Deadpan
400: Hi Conductance Window
410: 400 w/ Infiltration
420: 410 w/ Internal Gains
430: 420, Ext SW Absorptance
800: 430, High Thermal Mass
BESTEST Case

Figure 3.

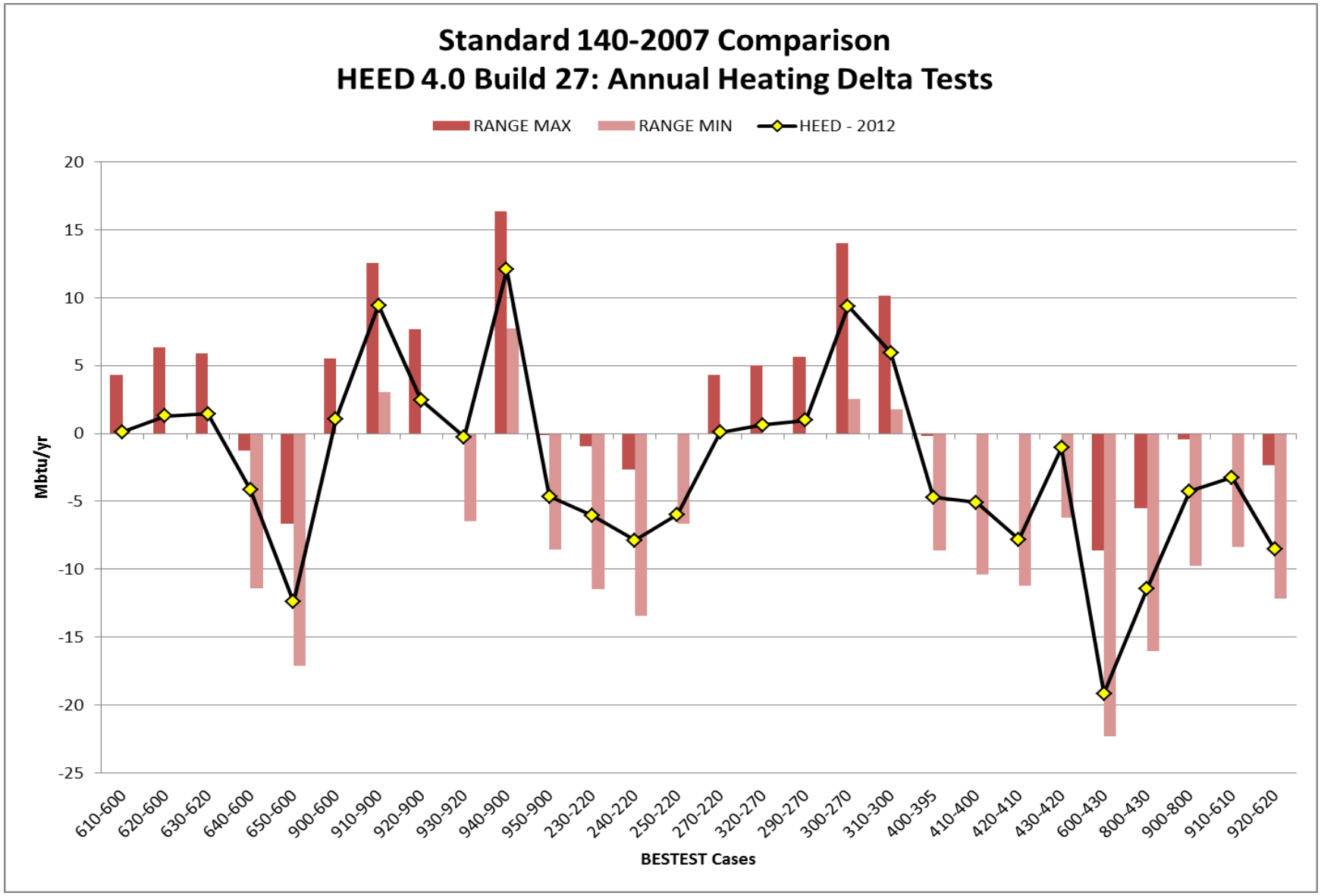

Standard 140-2007 Comparison
HEED 4.0 Build 27: Annual Heating Delta Tests
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
20
15
10
5
0
-5
-10
-15
-20
-25
610-600
620-600
630-620
640-600
650-600
900-600
910-900
920-900
930-920
940-900
950-900
230-220
240-220
250-220
270-220
320-270
290-270
300-270
310-300
400-395
410-400
420-410
430-420
600-430
800-430
900-800
910-610
920-620
BESTEST Cases

Figure 4.

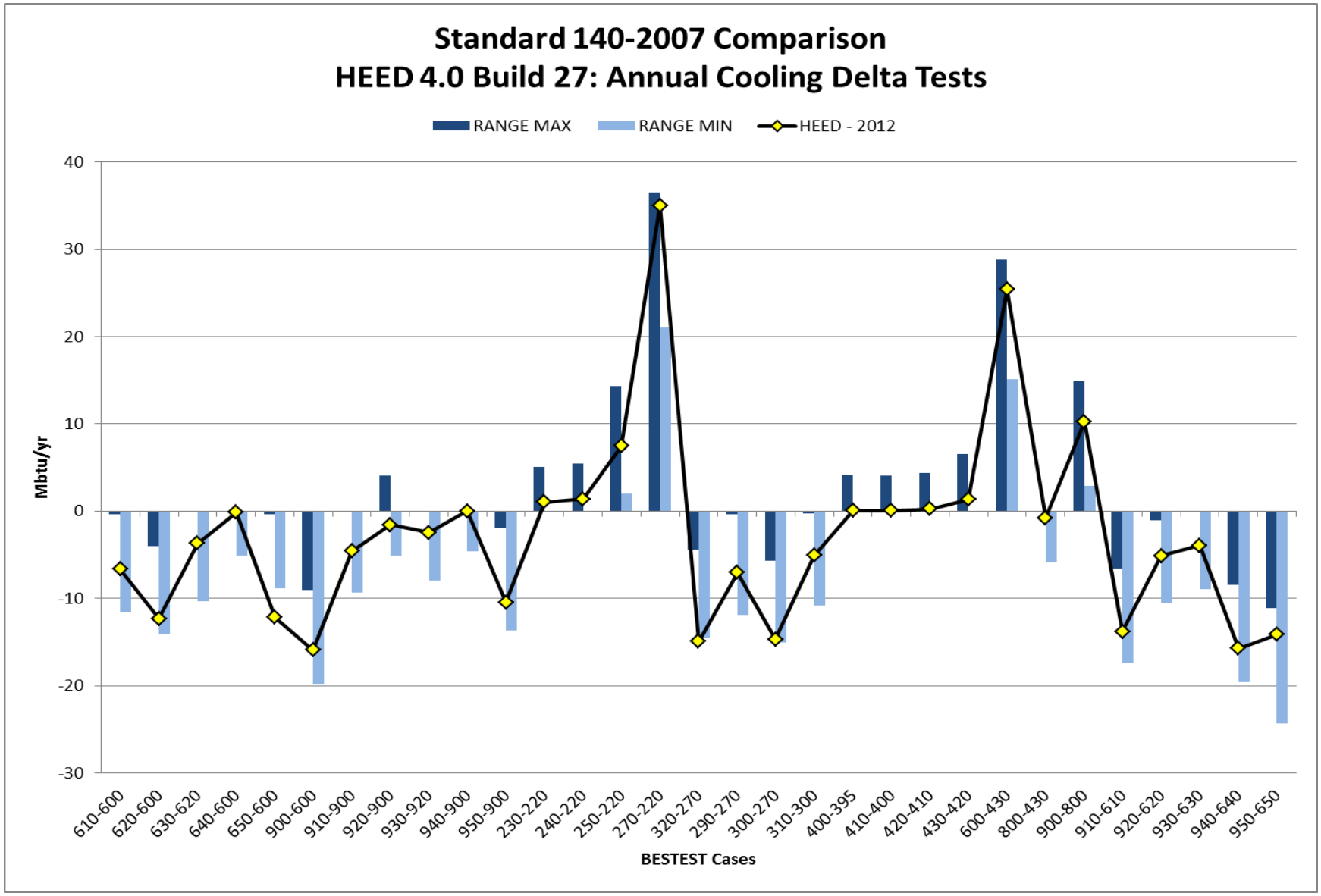

Standard 140-2007 Comparison
HEED 4.0 Build 27: Annual Cooling Delta Tests
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
40
30
20
10
0
-10
-20
-30
610-600
620-600
630-620
640-600
650-600
900-600
910-900
920-900
930-920
940-900
950-900
230-220
240-220
250-220
270-220
320-270
290-270
300-270
310-300
400-395
410-400
420-410
430-420
600-430
800-430
900-800
910-610
920-620
930-630
940-640
950-650
BESTEST Cases

Table 1. Annual Heating and Cooling Validation Results

Case Number	Annual Heating, Bestest Range		HEED HVAC Total Heating Loads Output			Annual Cooling, Bestest Range		HEED HVAC Total Cooling Loads Output		
	Max	Min				Max	Min			
	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS
600: Low Mass Building Basecase	23.4848	10.6622	35.74	18.4418	YES	31.1811	16.9456	52.46	27.0694	YES
610: 600 w/ South Window Shading	23.7476	10.8636	35.94	18.5450	YES	23.7203	9.3619	39.55	20.4078	YES
620: 600 w/ East & West Windows	24.2869	11.7442	38.21	19.7164	YES	21.0787	7.6622	28.58	14.7473	YES
630: 620 w/ E&W Window Shading	26.0787	13.2357	41.01	21.1612	YES	16.6315	3.2663	21.42	11.0527	YES
640: 600 w/ Night Setback Thermostat	16.9796	5.3892	27.74	14.3138	YES	30.6589	16.3142	52.12	26.8939	YES
650: 600 w/ Night Ventilation	4.0000	0.0000	0.00	0.0000	YES	26.3381	12.4370	28.87	14.8969	YES
900: 600 w/ High Thermal Mass	10.9659	0.0000	11.69	6.0320	YES	15.6554	3.2765	21.63	11.1611	YES
910: 900 w/ South Window Shading	11.7885	1.3755	13.78	7.1105	YES	10.3891	0.0000	12.76	6.5842	YES
920: 900 w/ East & West Windows	18.6759	7.3073	29.95	15.4542	YES	14.5530	2.2799	18.59	9.5924	YES
930: 920 w/ E&W Window Shading	22.2084	10.1401	34.70	17.9052	YES	11.6383	0.0000	13.77	7.1053	YES
940: 900 w/ Night Setback Thermostat	8.8157	0.0000	11.19	5.7740	YES	15.0615	3.0956	21.64	11.1662	YES
950: 900 w/ Night Ventilation	4.0000	0.0000	0.00	0.0000	YES	7.1434	0.0000	1.41	0.7276	YES
220: 600, Hi-Conductance Window	33.9900	19.6999	60.01	30.9652	YES	6.8499	0.0000	5.70	2.9412	YES
230: 220, w/ Infiltration	45.7854	31.4133	83.41	43.0396	YES	7.8874	0.0000	7.73	3.9887	YES
240: 220, w/ Internal Gains	29.4200	15.2800	50.99	26.3108	YES	8.2526	0.0000	8.34	4.3034	YES
250: Exterior SW Absorptance	27.9729	12.2152	48.29	24.9176	YES	15.5359	3.4301	20.10	10.3716	YES
270: 220 w/ South Windows	24.2050	11.3926	44.76	23.0962	YES	39.3246	21.6931	73.55	37.9518	YES
290: 270 w/ South Overhang	24.2800	11.6213	44.92	23.1787	YES	31.6078	13.7613	59.86	30.8878	YES
300: 270 w/ East & West Windows	24.3551	12.2493	45.96	23.7154	YES	28.2323	10.6827	45.05	23.2458	YES
310: 300 w/ E&W Window Shading	25.0411	13.8193	47.86	24.6958	YES	22.6725	5.3243	35.23	18.1787	YES
320: 270 w/ Thermal Deadband	21.5462	9.1708	33.21	17.1364	YES	28.9286	13.2732	44.62	23.0239	YES
395: No Windows, Thermal Deadpan	23.9149	12.3790	40.19	20.7380	YES	4.0546	0.0000	0.02	0.0103	YES
400: Hi Conductance Window	33.9320	19.5497	58.35	30.1086	YES	4.2082	0.0000	0.11	0.0568	YES
410: 400 w/ Infiltration	39.8570	25.3381	69.90	36.0684	YES	4.2867	0.0000	0.18	0.0929	YES
420: 410 w/ Internal Gains	35.2324	20.9081	60.78	31.3625	YES	4.6451	0.0000	0.67	0.3457	YES
430: 420, Ext SW Absorptance	30.7136	14.5292	50.90	26.2644	YES	6.9864	0.0000	3.21	1.6564	YES
800: 430, High Thermal Mass	28.6692	12.6145	48.83	25.1963	YES	5.1092	0.0000	1.72	0.8875	YES

Table 2.Cases that Could Not Be Run with HEED

195: 200, Solid Building	Could not define interior infrared emittance (in base case 200)
200: 210, IR	Could not define interior infrared emittance (in base case 210) → identical to case 215
210: 220, Interior IR	Could not define interior infrared emittance → identical to base case 220
215: 220, Exterior IR	Could not define exterior combined surface coefficient for high conductance wall that replaced windows.
280: 270, Int SW Absorptance	Could not define interior shortwave absorptance → identical to case 270
440: 430, Int SW Absorptance	Could not define interior shortwave absorptance → identical to case 430
810: 900, Int SW Absorptance	Could not define interior shortwave absorptance → identical to case 900

Table 3. Delta Heating and Cooling Validation Results

Delta Cases	Annual Heating, Delta Bestest Range		HEED HVAC Total Heating Loads Output			Annual Cooling, Delta Bestest Range		HEED HVAC Total Cooling Loads Output			
	Max	Min				Max	Min				
	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	
610-600	4.3345	0.0000	0.20	0.1032	YES	-0.3413	-11.6008	-12.91	-6.6616	YES	
620-600	6.3277	0.0000	2.47	1.2745	YES	-3.9898	-14.1025	-23.88	-12.3221	YES	
630-620	5.8806	0.0000	2.80	1.4448	YES	0.0000	-10.2970	-7.16	-3.6946	YES	
640-600	-1.2731	-11.3926	-8.00	-4.1280	YES	0.0000	-5.0922	-0.34	-0.1754	YES	
650-600					--	-0.3823	-8.8430	-23.59	-12.1724	NO	Night ventilation
900-600	-6.6690	-17.0957	-24.05	-12.4098	YES	-9.0820	-19.7817	-30.83	-15.9083	YES	
910-900	5.5085	0.0000	2.09	1.0784	YES	0.0000	-9.3277	-8.87	-4.5769	YES	
920-900	12.5496	3.0649	18.26	9.4222	YES	4.0546	-5.1024	-3.04	-1.5686	YES	
930-920	7.6860	0.0000	4.75	2.4510	YES	0.0000	-8.0069	-4.82	-2.4871	YES	
940-900	0.0000	-6.4505	-0.50	-0.2580	YES	0.0000	-4.5939	0.01	0.0052	NO	Thermostat setback
950-900					--	-1.9557	-13.6451	-20.22	-10.4335	YES	
230-220	16.3380	7.7134	23.40	12.0744	YES	5.0376	0.0000	2.03	1.0475	YES	
240-220	-0.1058	-8.5768	-9.02	-4.6543	YES	5.4062	0.0000	2.64	1.3622	YES	
250-220	-0.9420	-11.4847	-11.72	-6.0475	YES	14.3312	1.9796	14.40	7.4304	YES	
270-220	-2.6485	-13.4233	-15.25	-7.8690	YES	36.4747	21.0582	67.85	35.0106	YES	
320-270	0.0000	-6.6587	-11.55	-5.9598	YES	-4.4199	-14.5905	-28.93	-14.9279	NO	Thermostat setback
290-270	4.2901	0.0000	0.16	0.0826	YES	-0.3789	-11.9318	-13.69	-7.0640	YES	
300-270	5.0137	0.0000	1.20	0.6192	YES	-5.6724	-15.0923	-28.50	-14.7060	YES	
310-300	5.6587	0.0000	1.90	0.9804	YES	-0.3209	-10.8055	-9.82	-5.0671	YES	
400-395	14.0172	2.5393	18.16	9.3706	YES	4.1536	0.0000	0.09	0.0464	YES	
410-400	10.1366	1.7884	11.55	5.9598	YES	4.0887	0.0000	0.07	0.0361	YES	
420-410	-0.1707	-8.6451	-9.12	-4.7059	YES	4.3584	0.0000	0.49	0.2528	YES	
430-420	0.0000	-10.3789	-9.88	-5.0981	YES	6.4983	0.0000	2.54	1.3106	YES	
600-430	0.0000	-11.2287	-15.16	-7.8226	YES	28.8466	15.0957	49.25	25.4130	YES	
800-430	0.0000	-6.2150	-2.07	-1.0681	YES	0.0000	-5.8772	-1.49	-0.7688	YES	
900-800	-8.6213	-22.2800	-37.14	-19.1642	YES	14.8977	2.8908	19.91	10.2736	YES	
910-610	-5.4881	-16.0547	-22.16	-11.4346	YES	-6.5598	-17.3926	-26.79	-13.8236	YES	
920-620	-0.4267	-9.7646	-8.26	-4.2622	YES	-1.0376	-10.5257	-9.99	-5.1548	YES	
930-630	0.0000	-8.3447	-6.31	-3.2560	YES	0.0000	-8.9932	-7.65	-3.9474	YES	
940-640	-2.3721	-12.1639	-16.55	-8.5398	YES	-8.4472	-19.5974	-30.48	-15.7277	YES	
950-650					--	-11.1162	-24.3278	-27.46	-14.1694	YES	

Table 4. Validation Results for Cases Retested with HEED 4.0 (Build 29, Sep 26, 2012)

Case Number or Delta Test	Annual Heating, Bestest Range		HEED HVAC Total Heating Loads Output				Annual Cooling Bestest Range		HEED HVAC Total Cooling Loads Output			
	Max	Min	Build 27		Build 29		Max	Min	Build 27		Build 29	
	Mbtu/yr	Mbtu/yr	Mbtu/yr	PASS	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	Mbtu/yr	PASS	Mbtu/yr	PASS
600	23.485	10.662	18.442	YES	18.488	YES	31.181	16.946	27.069	YES	27.069	YES
650	4.000	0.000	0.000	YES	0.000	YES	26.338	12.437	14.897	YES	14.897	YES
900	10.966	0.000	6.032	YES	6.058	YES	15.655	3.277	11.161	YES	11.140	YES
940	8.816	0.000	5.774	YES	0.779	YES	15.062	3.096	11.166	YES	10.712	YES
270	24.205	11.393	23.096	YES	23.107	YES	39.325	21.693	37.952	YES	37.952	YES
320	21.546	9.171	17.136	YES	17.142	YES	28.929	13.273	23.024	YES	23.024	YES
650-600				--		--	-0.382	-8.843	-12.172	NO	-12.172	NO
940-900	0.000	-6.451	-0.258	YES	-5.279	YES	0.000	-4.594	0.005	NO	-0.428	YES
320-270	0.000	-6.659	-5.960	YES	-5.965	YES	-4.420	-14.591	-14.928	NO	-14.928	NO

HEED Validated Against the HERS BESTEST Standard

Alicyn Henkhaus, EIT

August 18, 2012 (Updated October 2, 2012)

Background:

HEED (Home Energy Efficient Design) is an easy-to-use tool that helps homeowners, builders, and architects design more energy efficient homes.

HEED uses a program originally called Solar-5, developed at UCLA, for its thermal analysis computation kernel. It uses an hourly heat balance similar to the method used in EnergyPlus. It calculates an hourly heat balance for each of the 8760 hours in a year using standard ASHRAE algorithms, the Mackey and Wright time lag and decrement factor method of accounting for heat flow through opaque walls, the Admittance Factor Method to account for internal thermal mass, and the California Energy Commission's ACM method to calculate the performance of basements. To find the hourly heat balance it uses a successive approximation method to calculate the indoor air temperatures. Thus it can integrate loads and energy calculations at each hourly time step, which means that the HVAC system only adds heating or cooling energy if the indoor air temperature has floated beyond the upper or lower comfort limits.

HEED has been previously validated using the procedure specified in ANSI/ASHRAE Standard 140-2001, Standard Method of Test for the Evaluation of Energy Analysis Computer Programs (Tsai and Milne, 2003). This method was developed by the International Energy Agency Solar Heating and Cooling Program, Task 12, and was adopted by DOE (U.S. Department of Energy) as the accepted basis for verifying the credibility of computer simulation programs. This procedure involves calculating the annual heating and cooling energy for a series of 34 different test case buildings, ranging from extremely abstract to quite realistic. In the ANSI/ASHRAE test protocols eight different simulation programs were run to establish the maximum and minimum values for each test building, including ESP, BLAST, DOE2, SSRE/SUN, SERIRES,S3PAS,TRANSYS, and TASE. Not all programs were able to run all tests. In the HERS BESTEST protocol, three different simulation programs were run to establish the range of reference results for each test, including BLAST 3.0, DOE2.1E, and SERIRES/SUNCODE 5.7. The acceptance criteria defined for HERS BESTEST, were used to calculate whether the HEED results fell within an acceptable range (HERS BESTEST 1995, Appendix H). The HERS acceptance range is defined by calculating the 90 percent confidence interval, or by adding 4 Mbtu to the maximum value and subtracting up to 4 Mbtu from the minimum value, then using the absolute value that is larger.

Current Test Results:

The current release of HEED 4.0 (Build 27, Jul 31, 2012) was validated using the HERS BESTEST Standard, 1995. The standard consists of 21 different building design cases that were originally run using three different building energy simulation programs. The HERS BESTEST acceptance criteria were used to calculate whether the HEED results fell within an acceptable range. The results tables included with the standard were used to establish acceptable validation ranges for the annual heating and cooling data as well as the delta tests. Climate data for Colorado Springs, Colorado, were used for the heating tests, and climate data for Las Vegas, Nevada, were used for the cooling tests

HEED passed all 28 (100 percent) of the Annual Heating and Cooling Tests. HEED also passed six of the seven Passive Heating and Cooling cases (86 percent). The only case that did not pass was a passive heating building with no glass (P140). Overall, 97 percent of the annual heating and cooling cases that HEED ran fell within the acceptance range. All results are included in Table 5, and displayed in Figure 5 and Figure 6.

Delta tests, which isolate the effects of the changes made between cases, can also be used to evaluate annual heating and cooling results. These tests show that 83 percent of the heating and cooling delta cases fell within the acceptance range. The four cases that failed to pass the delta tests were heated building that had well-insulated walls and roof, no internal loads, slab on grade or insulated slab, and uninsulated basement or insulated basement. Delta test failures were all for comparisons of annual heating loads. All results are included in Table 3, and displayed in Figure 3 and Figure 4.

Updated Test Results:

Cases that did not pass in the initial validation were retested in the latest version of the software (HEED 4.0, Build 29, Sep 26, 2012). Changes made between Build 27 and Build 29 were designed to allow more accurate user input, not change the calculation process. Of the five failed tests (one individual test and four delta tests) three now pass. All cases used in the delta tests still pass individually. HEED has now passed 100 percent of the Annual Heating and Cooling Tests, for 28 active and 7 passive cases.

The failed delta tests both compared annual heating loads. One tested the effect of insulation on slab on grade floor constructions; the other tested the effect of insulation on finished basements. Overall, HEED passed 92 percent of the heating and cooling delta tests.

The results of the retested cases are included in Table 8.

References:

ANSI/ASHRAE 2007. Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, GA.

EnergyPlus2010. *EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007*. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.

HEED Validation Against the ASHRAE/BESTEST Standard (ASHRAE Standard 140), Grace Tsai and Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2003

HEED Validated Using HERS Bestest Tier 1 and 2: 2008, Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2007

HERS BESTEST 1995. *Home Energy Rating System Building Energy Simulation Test*., R Judkoff and J Neymark, National Renewable Laboratory, 1617 Cole Blvd, Golden Colorado, 80401

HEED is available at no cost from http://www.energy-design-tools.aud.ucla.edu/heed

Figure 5.

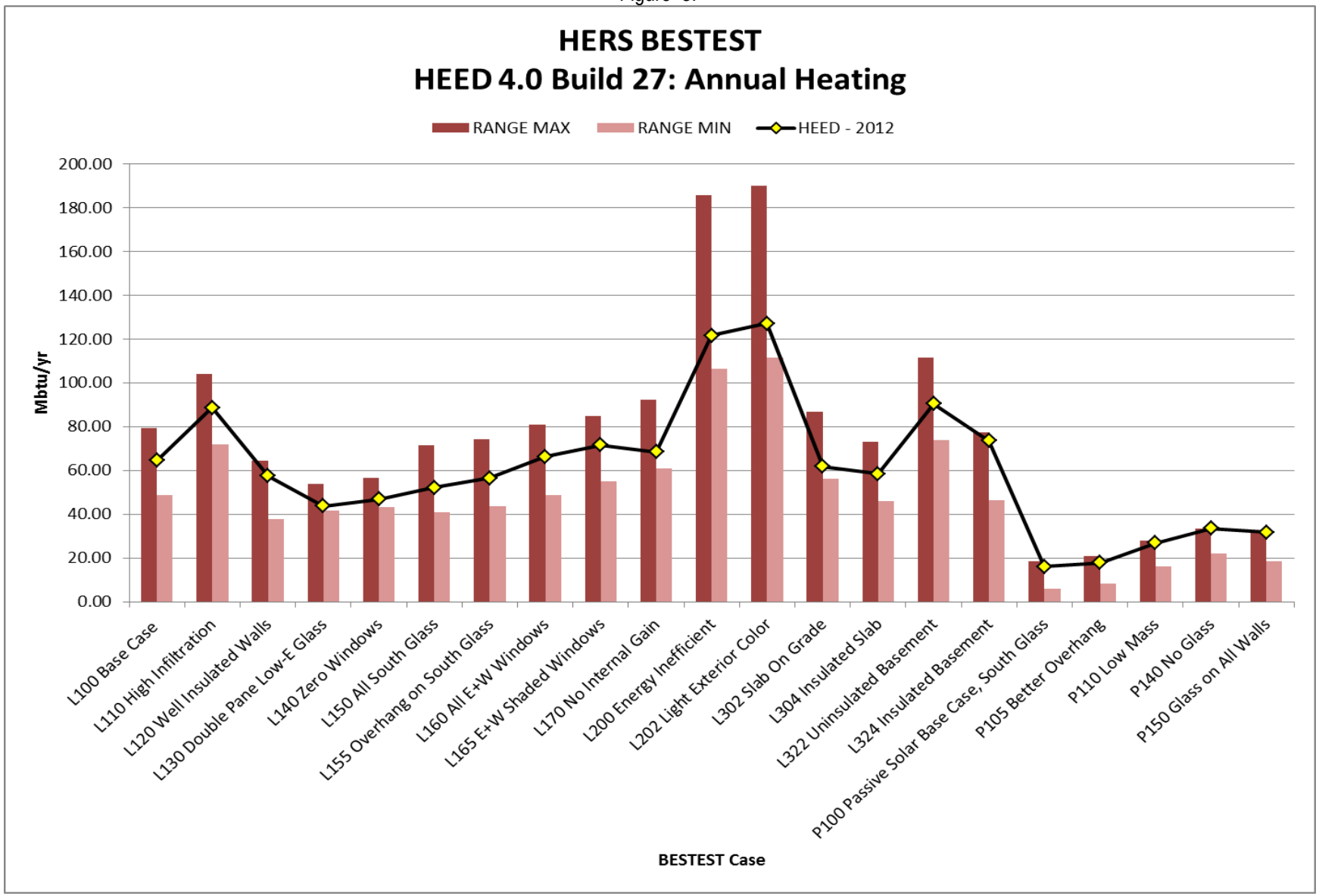

HERS BESTEST
HEED 4.0 Build 27: Annual Heating
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
L100 Base Case
L110 High Infiltration
L120 Well Insulated Walls
L130 Double Pane Low-E Glass
L140 Zero Windows
L150 All South Glass
L155 Overhang on South Glass
L160 All E+W Windows
L165 E+W Shaded Windows
L170 No Internal Gain
L200 Energy Inefficient
L202 Light Exterior Color
L302 Slab On Grade
L304 Insulated Slab
L322 Uninsulated Basement
L324 Insulated Basement
P100 Passive Solar Base Case, South Glass
P105 Better Overhang
P110 Low Mass
P140 No Glass
P150 Glass on All Walls
BESTEST Case

Figure 6.

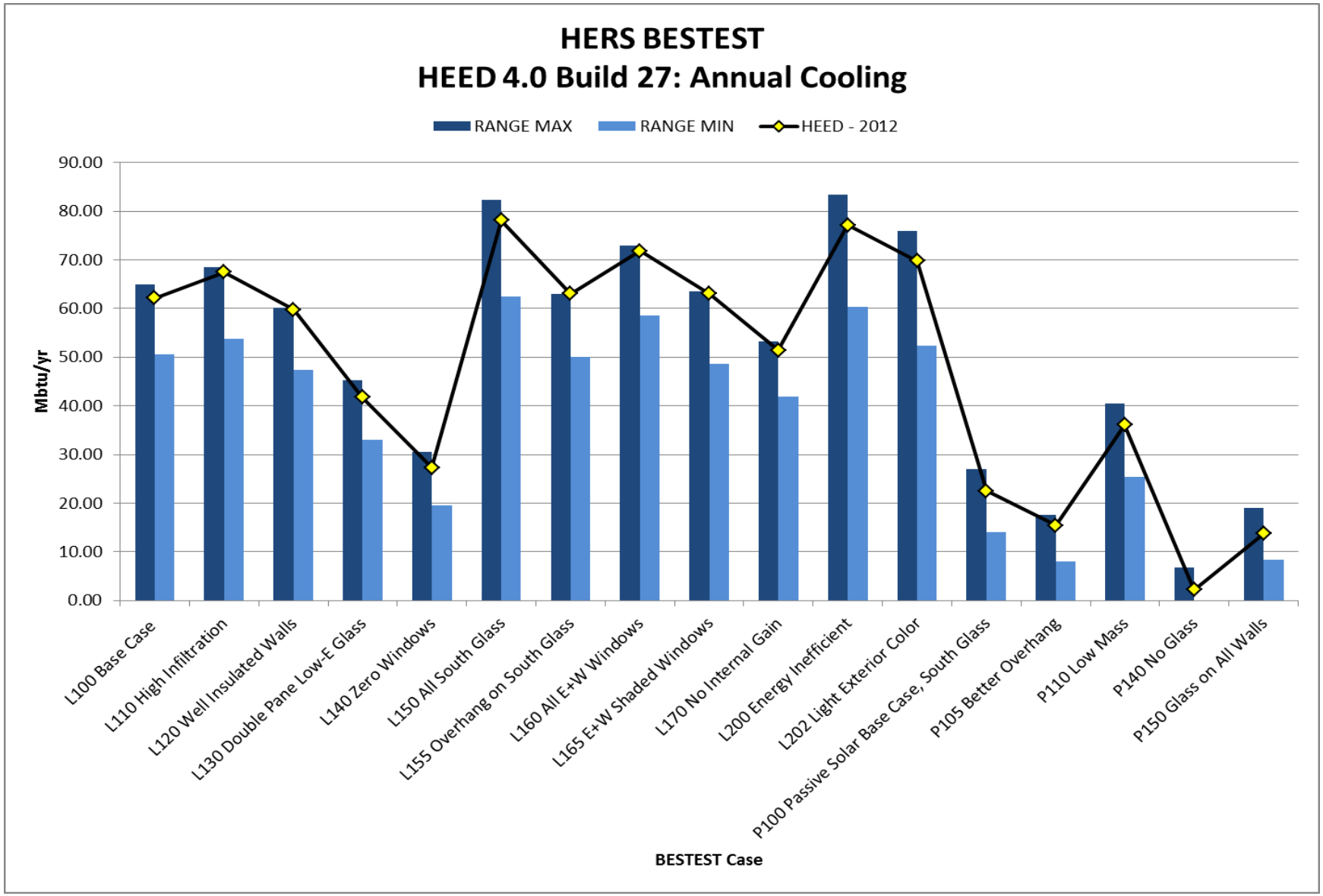

HERS BESTEST
HEED 4.0 Build 27: Annual Cooling
RANGE MAX
RANGE MIN
HEED - 2012
Mbtu/yr
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
L100 Base Case
L110 High Infiltration
L120 Well Insulated Walls
L130 Double Pane Low-E Glass
L140 Zero Windows
L150 All South Glass
L155 Overhang on South Glass
L160 All E+W Windows
L165 E+W Shaded Windows
L170 No Internal Gain
L200 Energy Inefficient
L202 Light Exterior Color
P100 Passive Solar Base Case, South Glass
P105 Better Overhang
P110 Low Mass
P140 No Glass
P150 Glass on All Walls
BESTEST Case

Table 5. Annual Heating and Cooling Validation Results

Case Number	Annual Heating, Bestest Range		Annual Heating Loads, Colorado Springs			Annual Cooling Bestest Range		Annual Sensible Cooling Loads, Las Vegas		
	Max	Min				Max	Min			
	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS
L100 Base Case	79.48	48.75	41.92	64.5149	YES	64.88	50.66	40.40	62.1756	YES
L110 High Infiltration	103.99	71.88	57.54	88.5541	YES	68.50	53.70	43.83	67.4544	YES
L120 Well Insulated Walls	64.30	37.82	37.28	57.3739	YES	60.14	47.34	38.80	59.7132	YES
L130 Double Pane Low-E Glass	53.98	41.82	28.37	43.6614	YES	45.26	32.95	27.14	41.7685	YES
L140 Zero Windows	56.48	43.24	30.42	46.8164	YES	30.54	19.52	17.77	27.3480	YES
L150 All South Glass	71.33	40.95	33.89	52.1567	YES	82.33	62.41	50.73	78.0735	YES
L155 Overhang on South Glass	74.18	43.53	36.64	56.3890	YES	63.06	50.08	40.94	63.0067	YES
L160 All E+W Windows	81.00	48.78	43.09	66.3155	YES	72.99	58.61	46.65	71.7944	YES
L165 E+W Shaded Windows	84.65	55.08	46.50	71.5635	YES	63.59	48.60	40.96	63.0374	YES
L170 No Internal Gain	92.40	61.03	44.45	68.4086	YES	53.31	41.83	33.44	51.4642	YES
L200 Energy Inefficient	185.87	106.41	79.05	121.6580	YES	83.43	60.25	50.12	77.1347	YES
L202 Light Exterior Color	190.05	111.32	82.58	127.0906	YES	75.96	52.32	45.36	69.8090	YES
L302 Slab On Grade	86.90	56.12	40.07	61.6677	YES					
L304 Insulated Slab	73.15	46.11	37.93	58.3743	YES					
L322 Uninsulated Basement	111.69	73.71	29.40	90.4932	YES					
L324 Insulated Basement	77.47	46.38	23.87	73.4719	YES					

Table 6. Annual Heating and Cooling Validation Results, Passive Cases

Case Number	Annual Heating, Bestest Range		Annual Heating Loads, Colorado Springs			Annual Cooling Bestest Range		Annual Sensible Cooling Loads, Colorado Springs		
	Max	Min				Max	Min			
	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS
P100 Passive Solar Base Case, South Glass	18.40	6.02	10.37	15.9594	YES	27.03	14.11	14.62	22.5002	YES
P105 Better Overhang	20.97	8.10	11.56	17.7908	YES	17.63	7.95	10.04	15.4516	YES
P110 Low Mass	27.79	16.19	17.41	26.7940	YES	40.49	25.36	23.42	36.0434	YES
P140 No Glass	33.42	21.82	21.74	33.4579	NO	6.84	0.00	1.44	2.2162	YES
P150 Glass on All Walls	31.99	18.58	20.62	31.7342	YES	19.03	8.42	8.95	13.7741	YES

Figure 7.

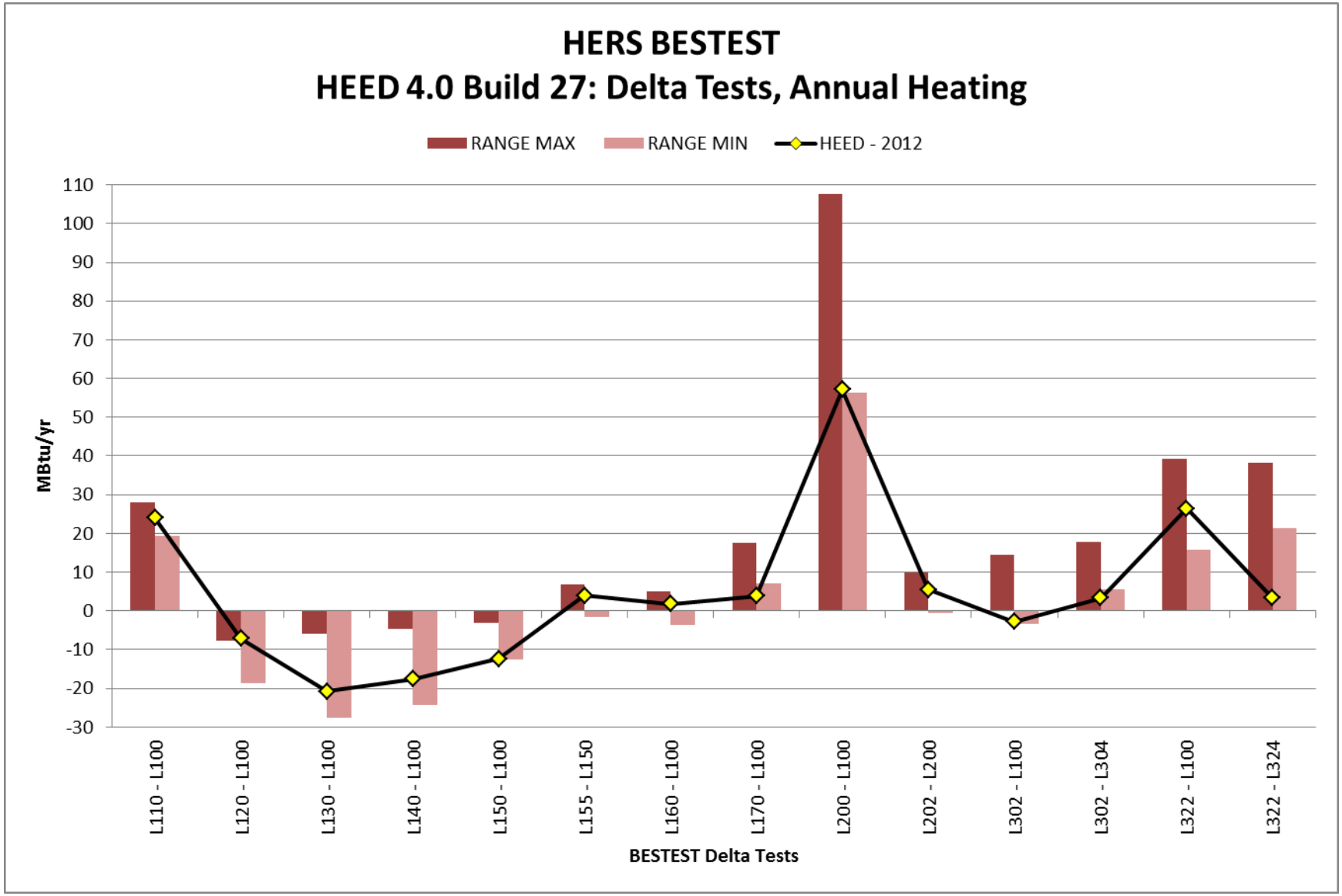

HERS BESTEST
HEED 4.0 Build 27: Delta Tests, Annual Heating
RANGE MAX
RANGE MIN
HEED - 2012
MBtu/yr
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
L110 - L100
L120 - L100
L130 - L100
L140 - L100
L150 - L100
L155 - L150
L160 - L100
L170 - L100
L200 - L100
L202 - L200
L302 - L100
L302 - L304
L322 - L100
L322 - L324
BESTEST Delta Tests

Figure 8.

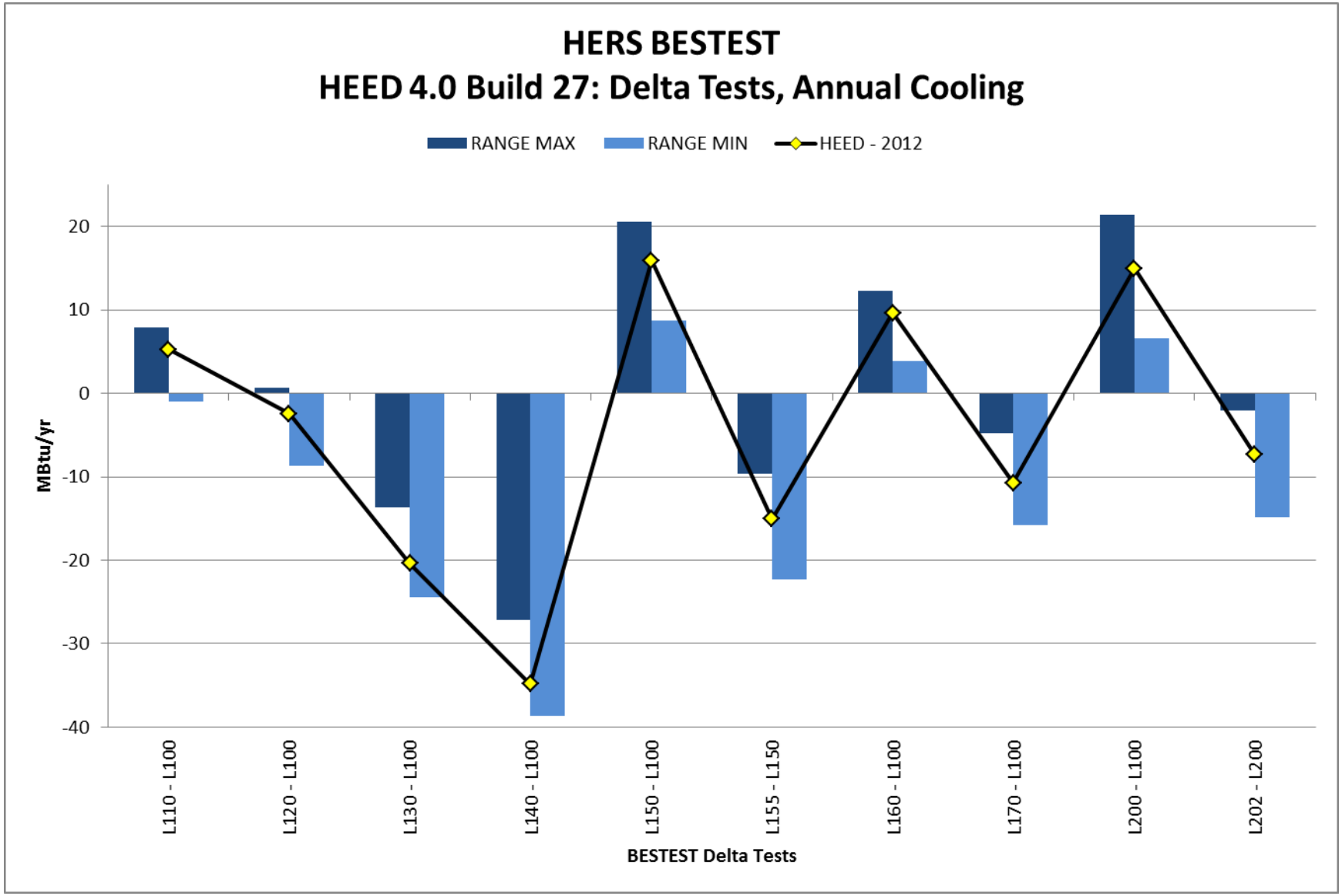

HERS BESTEST
HEED 4.0 Build 27: Delta Tests, Annual Cooling
RANGE MAX
RANGE MIN
HEED - 2012
MBtu/yr
20
10
0
-10
-20
-30
-40
L110 - L100
L120 - L100
L130 - L100
L140 - L100
L150 - L100
L155 - L150
L160 - L100
L170 - L100
L200 - L100
L202 - L200
BESTEST Delta Tests

Table 7. Delta Heating and Cooling Validation Results

Delta Test	Delta Annual Heating, Bestest Range		Delta Annual Heating Loads, Colorado Springs			Delta Annual Cooling Bestest Range		Delta Annual Sensible Cooling Loads, Las Vegas		
	Max	Min				Max	Min			
	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	kBtu/sf/yr	Mbtu/yr	PASS
L110 - L100	28.12	19.36	15.62	24.04	YES	7.84	-0.98	3.43	5.28	YES
L120 - L100	-7.67	-18.57	-4.64	-7.14	NO	0.68	-8.67	-1.60	-2.46	YES
L130 - L100	-5.97	-27.5	-13.55	-20.85	YES	-13.71	-24.4	-13.26	-20.41	YES
L140 - L100	-4.56	-24.42	-11.50	-17.70	YES	-27.14	-38.68	-22.63	-34.83	YES
L150 - L100	-3.02	-12.53	-8.03	-12.36	YES	20.55	8.72	10.33	15.90	YES
L155 - L150	6.88	-1.54	2.75	4.23	YES	-9.64	-22.29	-9.79	-15.07	YES
L160 - L100	5.1	-3.72	1.17	1.80	YES	12.28	3.88	6.25	9.62	YES
L170 - L100	17.64	7.12	2.53	3.89	NO	-4.83	-15.74	-6.96	-10.71	YES
L200 - L100	107.66	56.39	37.13	57.14	YES	21.39	6.63	9.72	14.96	YES
L202 - L200	9.94	-0.51	3.53	5.43	YES	-2.03	-14.86	-4.76	-7.33	YES
L302 - L100	14.5	-3.29	-1.85	-2.85	YES					
L302 - L304	17.75	5.66	2.14	3.29	NO					
L322 - L100	39.29	15.71	-12.52	25.98	YES					
L322 - L324	38.22	21.25	5.53	17.02	NO					

Table 8. Validation Results for Cases Retested with HEED 4.0 (Build 29, Sep 26, 2012)

Case Number or Delta Test	Annual Heating, Bestest Range		Annual Heating Loads, Colorado Springs				Annual Cooling Bestest Range		Annual Sensible Cooling Loads, Las Vegas			
	Max	Min	Build 27		Build 29		Max	Min	Build 27		Build 29	
	Mbtu/yr	Mbtu/yr	Mbtu/yr	PASS	Mbtu/yr	PASS	Mbtu/yr	Mbtu/yr	Mbtu/yr	PASS	Mbtu/yr	PASS
P140	33.42	21.82	33.4579	NO	27.794	YES	6.84	0.00	2.2162	YES	2.201	YES
L100	79.48	48.75	64.5149	YES	64.684	YES	64.88	50.66	62.1756	YES	62.099	YES
L120	64.30	37.82	57.3739	YES	51.049	YES	60.14	47.34	59.7132	YES	59.636	YES
L170	92.40	61.03	68.4086	YES	77.165	YES	53.31	41.83	51.4642	YES	51.387	YES
L302	86.90	56.12	61.6677	YES	61.822	YES						
L304	73.15	46.11	58.3743	YES	58.513	YES						
L322	111.69	73.71	90.4932	YES	76.858	YES						
L324	77.47	46.38	73.4719	YES	67.224	YES						
L120 - L100	-7.67	-18.57	-7.14	NO	-13.635	YES	0.68	-8.67	-2.46	YES	-2.463	YES
L170 - L100	17.64	7.12	3.89	NO	12.481	YES	-4.83	-15.74	-10.71	YES	-10.712	YES
L302 - L304	17.75	5.66	3.29	NO	3.309	NO						
L322 - L324	38.22	21.25	17.02	NO	9.634	NO						

Comparison of HEED and EnergyPlus Validation Results

Alicyn Henkhaus, EIT

October 2, 2012

Background:

The current release of HEED 4.0 (Build 27, Jul 31, 2012) was validated using ASHRAE Standard 140, 2007. The standard consists of 34 different building design cases that were originally run using seven different building energy performance programs including DOE-2 and ESP. These same cases were also run using EnergyPlus, and the results were published separately. See the original validation report ("HEED Validated Against the ASHRAE/BESTEST Standard 140") for complete results.

Comparing HEED and EnergyPlus:

This document compares results from HEED 4.0 (Build 27, Jul 31, 2012) with results from EnergyPlus 2010 for the validation cases in ASHRAE Standard 140-2007. Both programs produce acceptable results for all (100 percent) of the basic low mass (600 series) and high mass (900 series) cases. Annual heating and cooling results for the low mass cases are shown in Table 9; the results for the high mass cases are shown in Table 10. More information on determining the limits of acceptable annual heating and cooling ranges for each case can be found in the original validation report.

The annual heating results for both low and high mass cases are aggregated in Figure 9. HEED consistently produced greater results than EnergyPlus (from 2-6 MBtu/yr) except in the cases where annual heating was 0 MBtu/yr (650 and 950, cases testing night ventilation and defined as having no heater).

Figure 10 combines the annual cooling results from both the low and high mass cases. Neither HEED nor EnergyPlus produced consistently greater results. The difference between results from the two programs varied from 0-4 MBtu/yr. With the exception of cases 620 and 920, the program that produced the greater result for the low mass case also produced the greater result for the corresponding high mass case. (For example, EnergyPlus reported greater annual cooling results for the low mass, night ventilation case 650 as well as for the high mass, night ventilation case 950.) The differences between HEED and EnergyPlus results for cases 620 and 920 were both less than 0.5 MBtu/yr.

References:

ANSI/ASHRAE 2007. Standard 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Atlanta, GA.

EnergyPlus2010. *EnergyPlus Testing with Building Thermal Envelope and Fabric Load Tests from ANSI/ASHRAE Standard 140-2007*. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies.

HEED Validation Against the ASHRAE/BESTEST Standard (ASHRAE Standard 140), Grace Tsai and Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2003

HEED Validated Using HERS Bestest Tier 1 and 2: 2008, Murray Milne, UCLA Department of Architecture and Urban Design, http://www.energy-design-tools.aud.ucla.edu/heed, 2007

HERS BESTEST 1995. *Home Energy Rating System Building Energy Simulation Test*., R Judkoff and J Neymark, National Renewable Laboratory, 1617 Cole Blvd, Golden Colorado, 80401

HEED is available at no cost from http://www.energy-design-tools.aud.ucla.edu/heed

Table 9.

Comparison of HEED and EnergyPlus Validation Results using Standard 140-2007
Using HEED 4.0 (Build 27, July 31, 2012) with Denver-Stapleton, CO, USA (TMY--23062).EPW weather file

Low Mass Building

Case	600 5.2.1 Base Case	610 5.2.2.1.1 South Shading	620 5.2.2.1.2 East/West Window Orientation	630 5.2.2.1.3 East/West Shading	640 5.2.2.1.4 Thermostat Setback	650 5.2.2.1.5 Night Ventilation
Annual Heating (MBtu/yr)						
Maximum	23.485	23.748	24.287	26.079	16.980	4.000
Minimum	10.662	10.864	11.744	13.236	5.389	0.000
EnergyPlus	14.894	15.010	15.399	16.427	9.102	0.000
Pass	YES	YES	YES	YES	YES	YES
HEED	18.442	18.545	19.716	21.161	14.314	0.000
Pass	YES	YES	YES	YES	YES	YES
Annual Cooling (MBtu/yr)						
Maximum	31.181	23.720	21.079	16.632	30.659	26.338
Minimum	16.946	9.362	7.662	3.266	16.314	12.437
EnergyPlus	23.911	16.983	14.963	10.075	22.901	18.901
Pass	YES	YES	YES	YES	YES	YES
HEED	27.069	20.408	14.747	11.053	26.894	14.897
Pass	YES	YES	YES	YES	YES	YES

Table 10.

Comparison of HEED and EnergyPlus Validation Results using Standard 140-2007
Using HEED 4.0 (Build 27, July 31, 2012) with Denver-Stapleton, CO, USA (TMY--23062).EPW weather file

High Mass Building

Case	900 5.2.2.2.1 High Mass Base Building	910 5.2.2.2.2 High Mass South Shading	920 5.2.2.2.3 High Mass East/West Window Orientation	930 5.2.2.2.4 High Mass East/West Shading	940 5.2.2.2.5 High Mass Thermostat Setback	950 5.2.2.2.6 High Mass Night Ventilation
Annual Heating (MBtu/yr)						
Maximum	10.964	11.786	18.672	25.516	8.814	4.000
Minimum	0.000	1.374	7.304	10.136	0.000	0.000
EnergyPlus	3.973	4.870	10.536	12.918	2.481	0.000
Pass	YES	YES	YES	YES	YES	YES
HEED	6.032	7.110	15.454	17.905	5.774	0.000
Pass	YES	YES	YES	YES	YES	YES
Annual Cooling (MBtu/yr)						
Maximum	15.652	10.387	14.550	11.636	15.058	7.142
Minimum	3.274	0.000	2.278	0.000	3.094	0.000
EnergyPlus	9.157	4.608	9.157	5.956	8.894	1.949
Pass	YES	YES	YES	YES	YES	YES
HEED	11.161	6.584	9.592	7.105	11.166	0.728
Pass	YES	YES	YES	YES	YES	YES

Figure 9.

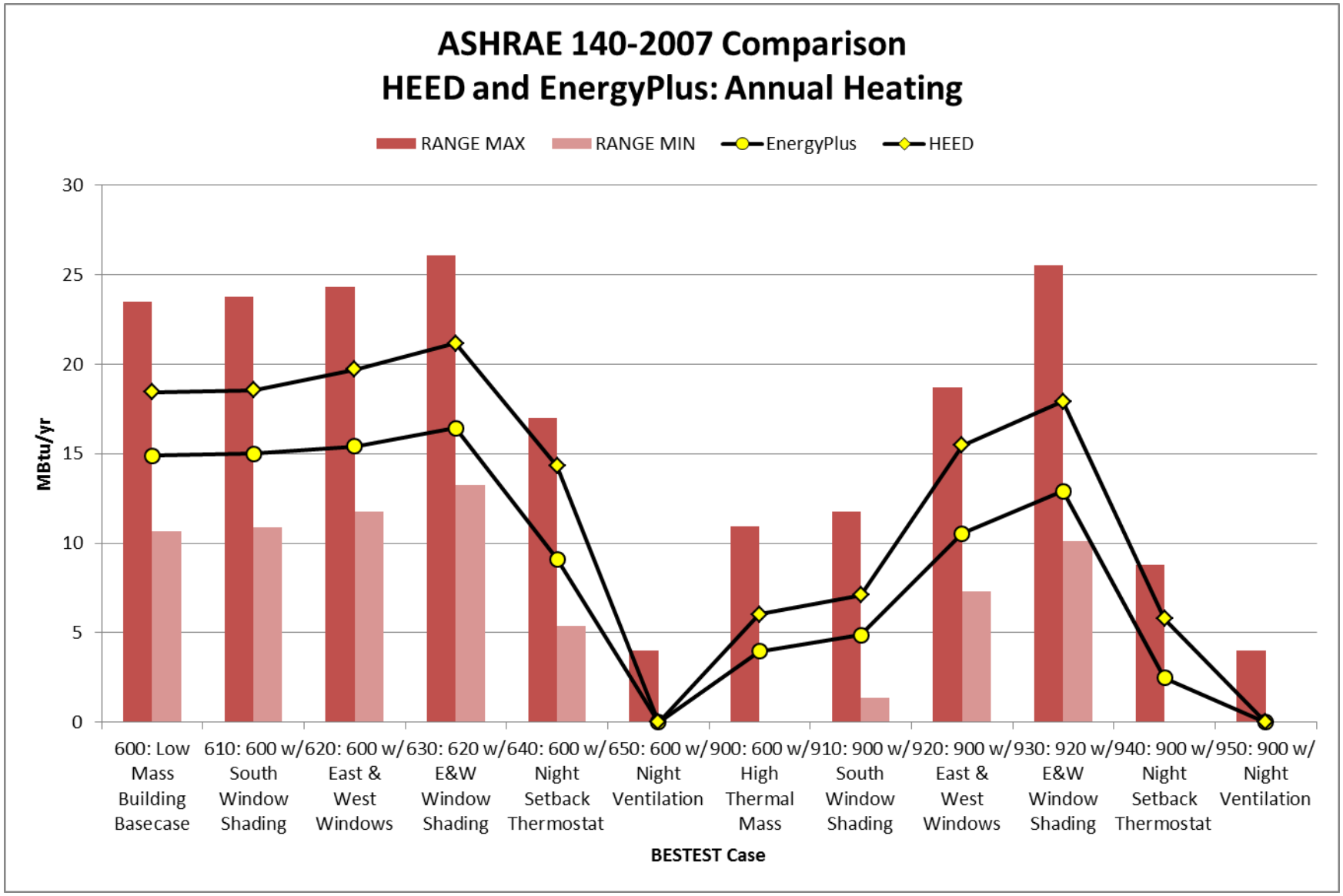
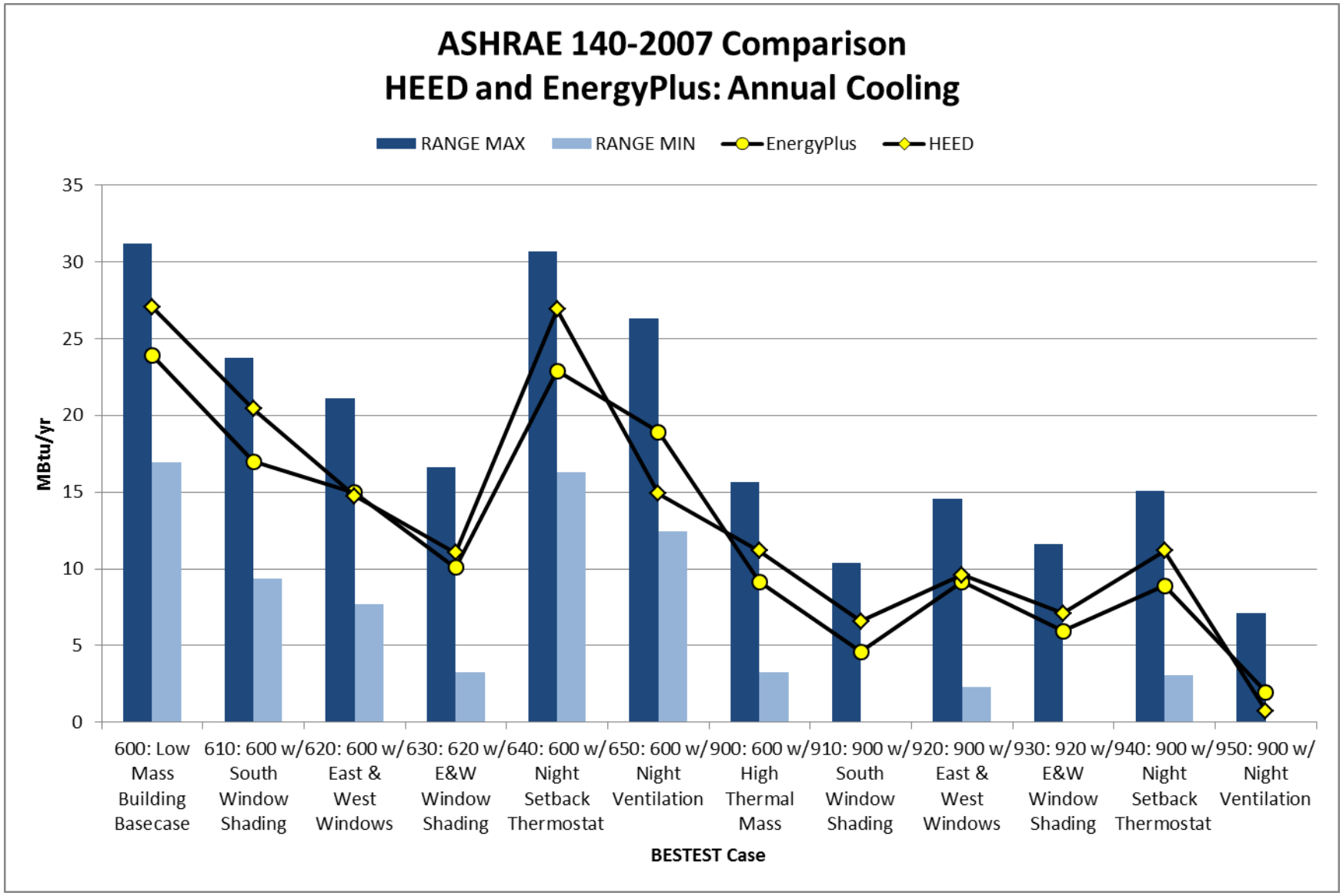

ASHRAE 140-2007 Comparison
HEED and EnergyPlus: Annual Heating
RANGE MAX
RANGE MIN
EnergyPlus
HEED
MBtu/yr
30
25
20
15
10
5
0
600: Low Mass Building Basecase
610: 600 w/ South Window Shading
620: 600 w/ East & West Windows
630: 620 w/ E&W Window Shading
640: 600 w/ Night Setback Thermostat
650: 600 w/ Night Ventilation
900: 600 w/ High Thermal Mass
910: 900 w/ South Window Shading
920: 900 w/ East & West Windows
930: 920 w/ E&W Window Shading
940: 900 w/ Night Setback Thermostat
950: 900 w/ Night Ventilation
BESTEST Case

Figure 10.


ASHRAE 140-2007 Comparison
HEED and EnergyPlus: Annual Cooling
RANGE MAX
RANGE MIN
EnergyPlus
HEED
MBtu/yr
35
30
25
20
15
10
5
0
600: Low Mass Building Basecase
610: 600 w/ South Window Shading
620: 600 w/ East & West Windows
630: 620 w/ E&W Window Shading
640: 600 w/ Night Setback Thermostat
650: 600 w/ Night Ventilation
900: 600 w/ High Thermal Mass
910: 900 w/ South Window Shading
920: 900 w/ East & West Windows
930: 920 w/ E&W Window Shading
940: 900 w/ Night Setback Thermostat
950: 900 w/ Night Ventilation
BESTEST Case

Validation of PV Power Generation Simulation in HEED

Alicyn Henkhaus, EIT

August 20, 2012

Background:

The current release of HEED 4.0 (Build 27, Jul 31, 2012) was validated using ASHRAE Standard 140, 2007 and HERS BESTEST. This document details the validation of photovoltaic (PV) power generation in HEED, which is not covered by either of the previous validation standards. HEED's calculations of PV system performance were compared to results from the CECPV calculator; both use the five-parameter model and F-Chart algorithm developed by Bill Beckman.

Validation Methodology:

HEED, developed at the UCLA Department of Architecture and Urban Design, uses a five-parameter model to calculate photovoltaic (PV) system performance. The PV algorithms in HEED were developed by Bill Beckman at the Solar Energy Laboratory of the University of Wisconsin and David Bradley at TESS, Inc. To validate the PV systems simulated by HEED, results were compared to output from the CECPV Calculator, published by the California Energy Commission (CEC). This calculator uses the same five-parameter model to simulate PV performance, which is then used to calculate and qualify for incentives through the New Solar Homes Partnership in California. The user interfaces and specific list of inputs to each program are slightly different. Table 14 (page 84) is included as reference to compare inputs to the CECPV calculator and the location of the corresponding input in HEED.

Commercially-available solar kits were used to define the test systems for validation.[1] This helped ensure that the inverter in each system was properly matched to the size of the PV array. In this test only system size, panel models, and inverter models were varied. Other specifications of the system and the site remained constant. The PV array was defined as fixed (no tracking), roof mounted (greater than 3.5" from roof), and facing true south with a tilt angle of 34° (equivalent to a roof pitch of 8:12). The site was defined as a one-story, single-family residence in Los Angeles, CA, falling within CA Climate Zone 9 at latitude 34° N. All obstructions were assumed to meet the minimal shading criteria, which state that the closest an obstruction can be to the array is a distance equal to twice its height. The following tables (Table 11 and

Table 12) will show the inputs specific to each calculator, indicating fixed and variable inputs.

[1] Wholesale Solar, http://www.wholesalesolar.com/complete-systems.html.

Table 11. Relevant inputs to HEED.

HEED Screen	Field	Input
Initial Design	What is your Zip code or location?	90024, Los Angeles (Westwood)
Advanced Climate, Site, and Start Date	Latitude	34°
	CA Climate Zone	9 [cannot be edited on this screen, is determined by HEED based on Initial Design input]
Advanced PV Power Design	PV Panel	*Varied*
	Inverter	*Varied*
	Number of Panels in Total Array	*Varied*
	Number of Parallel Strings in this set of Panels	*Varied [generally 1]*
	Panel Tilt	34°
	Array Orientation degrees from South	0° [true south]

Table 12. Inputs to CECPV Calculator.

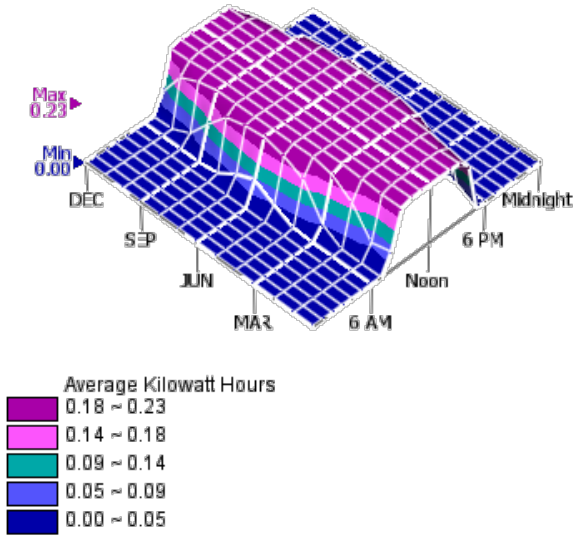
Field	Input
Number of Sites with Solar	1
Number of Inverters per Site with Identical Details	*Varied [generally 1]*
California Flexible Installation	No
PV Module	*Varied*
Standoff Height	Roof Mounted (greater than 3.5 inches from roof)
Mounting Height	One-Story
Number of Series Modules in each String	*Varied*
Number of Parallel Strings per Inverter	*Varied*
Tracking	Fixed
Roof Pitch	34° [equivalent to 8:12]
Azimuth	180° [true south]
Inverter	*Varied*
City Used in Calculator Run	Los Angeles – Climate Zone 9
Project Description	Single Family, Marked Rate, Tier I EE, Dwelling Unit
Minimal Shading	Yes

Fifteen different systems were selected from the list of commercially-available solar kits at WholesaleSolar.com. Each solar kit consists of specific panel and inverter models in specific quantities, from various manufacturers. These were used to define the specifications of the test systems in order to ensure that the panels and inverters were well-matched, under the assumption that manufacturers would not be marketing under-performing systems. However, according to the HEED and CECPV outputs, not all systems were well-matched. If the monthly or daily maximum performance of a system is flat for a number of hours (rather than peaking at a higher value) then it is likely that the inverter is undersized (Figure 11). In the worst case, a system with poorly matched panels and inverter would actually draw power from the grid. Both HEED and CECPV results indicated, by flat daily performance or negative annual output, that components in some of the smaller commercially-packaged systems were not well-matched. Different inverters were selected for these systems and results from HEED and CECPV showed that the new system components were well matched.

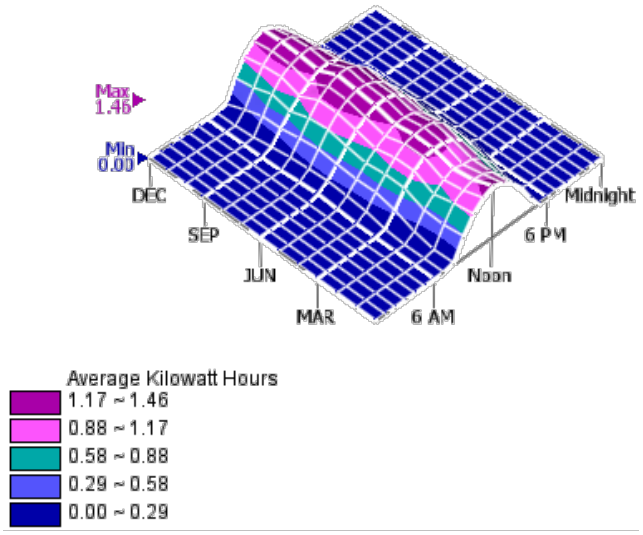
Figure 11. HEED output showing examples of a poorly matched system (a, left) and a well-matched system (b, right). The only change between the two systems is the inverter. Note that the heights and colors of each plot are normalized, i.e., the same color corresponds to a different

range of values on each plot. Examining their respective legends shows that the entire system on the left would be contained in the lowest (blue/ black) range of the system on the right.

a. Schott Solar, 240 W DC panels x8, SE 3300 (240 V)
Poorly matched panels and inverter.



b. Schott Solar, 240 W DC panels x8, TSET TS-S2000 (240 V)
Adequately matched panels and inverter.



Validation Results:

The specific test systems for all cases and their results are shown in Table 13 and Figure 12.

Figure 13 shows a comparison of the monthly output results for one system. The HEED results were between 5 percent and 9 percent higher than the CECPV results for all systems tested.

Some PV systems are large enough to require multiple inverters. This is rarely the case for residential installations, and HEED assumes a single-inverter system. However, an approximation of a multi-inverter system output can be achieved by modeling the portion of the PV modules that are served by one inverter and then scaling the reported output by the number of inverters. For example, a system that equally distributes 40 panels across two inverters can be modeled in HEED as a 20 panel system with one inverter. The annual output reported by HEED would then need to be multiplied by 2 in order to get an approximation for the multi-inverter system. This was done for the largest system modeled. The results for annual energy production were then doubled before comparing with the output from CECPV, which more precisely modeled the system. In this case the approximate results from HEED were 6 percent greater than the CECPV results, which is comparable to the difference in other cases.

Table 13. Results from HEED and CECPV. Systems are ordered by AC system size. *HEED does not explicitly model systems with multiple inverters. This system was modeled as a 20-panel string on 1 inverter, and the output obtained for this system (8098 kWh) was doubled.

Panel Specifications				Inverter Specifications		System Size		Annual kWh per Site		percent Difference
Model	Size (W DC)	Qty.	Total Area (sf)	Model	Qty.	DC (kW)	AC (kW)	HEED	CECPV	$\frac{HEED - CECPV}{CECPV}$
Sharp ND-235QCJ	235	8	140.3	Renergy RS-2000 (240V)	1	1.88	1.61	3150	2966	6%
Schott Solar Perform Poly 240	240	8	144.1	Topper Sun Energy Technology TS-S2000 (240V)	1	1.92	1.65	3262	3002	9%
Schott Solar Perform Poly 245	245	8	144.1	SunPower SPR-2800x (240V)	1	1.96	1.66	3313	3049	9%
Sharp ND-235QCJ	235	10	175.4	Fronius USA IG Plus 3.0-1 UNI (240V)	1	2.35	2.02	3944	3743	5%
Schott Solar Perform Poly 240	240	10	180.1	Xantrex Technology GT2.8-NA-240/208 (240V)	1	2.40	2.04	4056	3731	9%
Sharp ND-235QCJ	235	12	210.5	Fronius USA IG Plus 3.0-1 UNI (240V)	1	2.82	2.43	4710	4503	5%
Sharp ND-235QCJ	235	15	263.1	SolarEdge Technologies SE4000 (240V)	1	3.53	3.10	6087	5704	7%
Schott Solar Perform Poly 240	240	15	270.1	SolarEdge Technologies SE4000 (240V)	1	3.60	3.17	6284	5770	9%
Sharp ND-235QCJ	235	20	350.8	SolarEdge Technologies SE5000 (240V)	1	4.70	4.13	8098	7610	6%
Schott Solar Perform Poly 240	240	20	360.2	Fronius USA IG Plus V 5.0 (240V)	1	4.80	4.14	8269	7588	9%
Schott Solar Perform Poly 245	245	20	360.2	Fronius USA IG Plus V 5.0 (240V)	1	4.90	4.23	8445	7743	9%
Sanyo Electric HIP-200BA20	200	24	299.3	SMA America SB4000US (240V)	1	4.80	4.28	8221	7694	7%
Schott Solar Perform Poly 245	245	20	360.2	SolarEdge Technologies SE5000 (240V)	1	4.90	4.32	8524	7858	8%
Sharp ND-235QCJ	235	30	526.2	Fronius USA IG Plus 7.5-1 UNI (240V)	1	7.05	6.07	12054	11263	7%
Sharp ND-235QCJ	235	40	701.6	SolarEdge Technologies SE5000 (240V)	2*	9.40	8.26	16196	15220	6%

Comparison to PVWatts:

In addition to the results from HEED and CECPV, Figure 12 and Figure 13 include reference results from PVWatts™, a calculator from the National Renewable Energy Laboratory. PVWatts generates annual energy output based on the system size (in kW AC) of an array, not a specific combination of panels and inverter. It uses an algorithm based on PVFORM, which was developed by David Menicucci at Sandia National Laboratories. The DC system size and a DC to AC derate factor (the AC system size divided by the DC system size) were used as inputs to PVWatts. The site location is zip code 90024, which selects Cell ID 0174360, 34.1° N 118.6° W in PVWatts v.2. The array was input as a fixed tilt at 34° facing due south. Figure 12 shows that the annual output from PVWatts generally falls between the outputs reported by HEED and CECPV. The monthly data in Figure 13 shows that HEED and CECPV follow similar monthly trends while PVWatts differs. This may be due to the different algorithms used as well as a different application of site climate data. PVWatts begins hourly performance simulation with the TMY2 station that is climatically similar and nearest to the grid containing the user-defined site location. The performance is then translated back to the original grid using a process that is designed to account for the differences in monthly solar radiation and maximum daily temperature between the TMY2 station and the original grid.

Figure 12. Annual kWh produced by each system. System description (horizontal axis) includes panel model, inverter model, and AC system size.

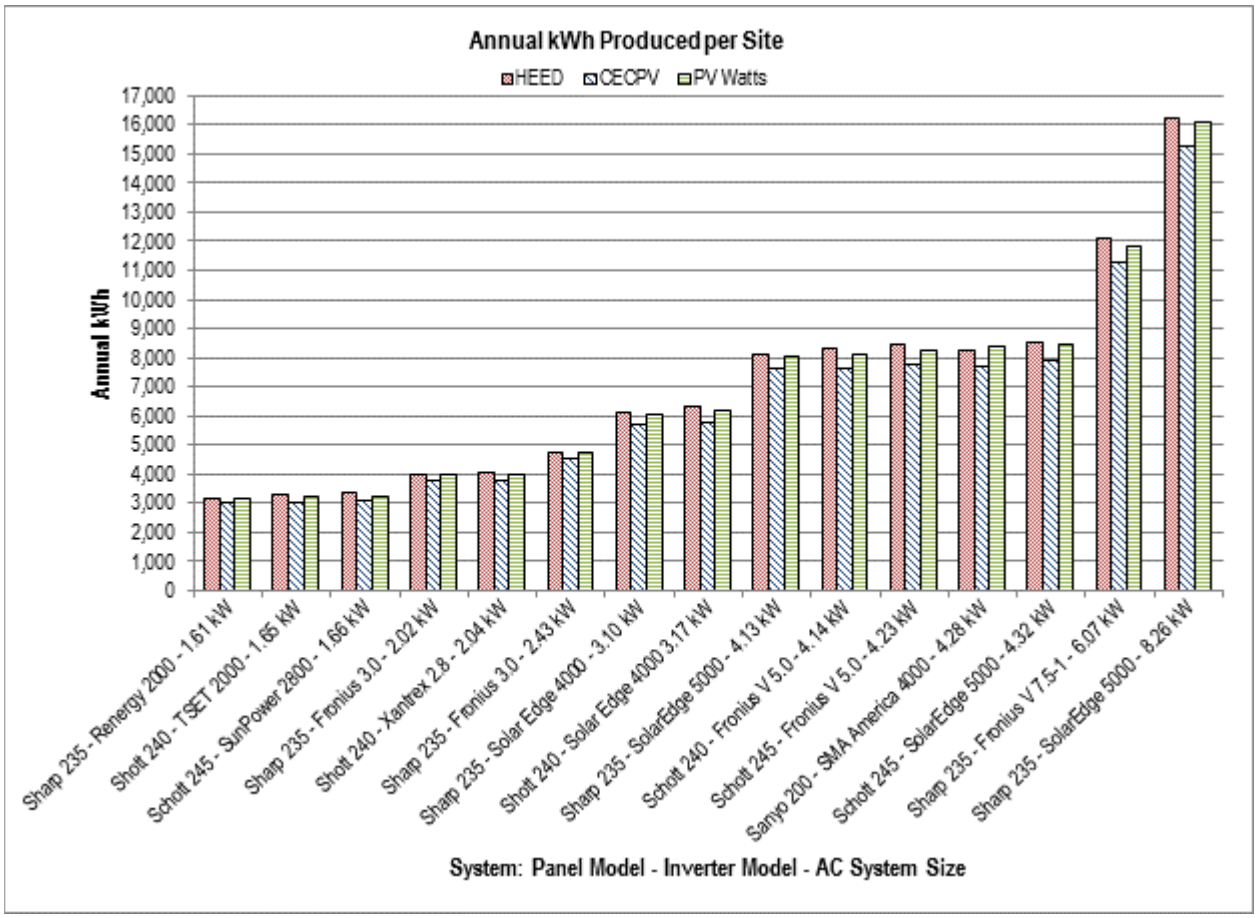


Figure 13. Comparison of monthly output results from HEED, CECPV, and PVWatts.

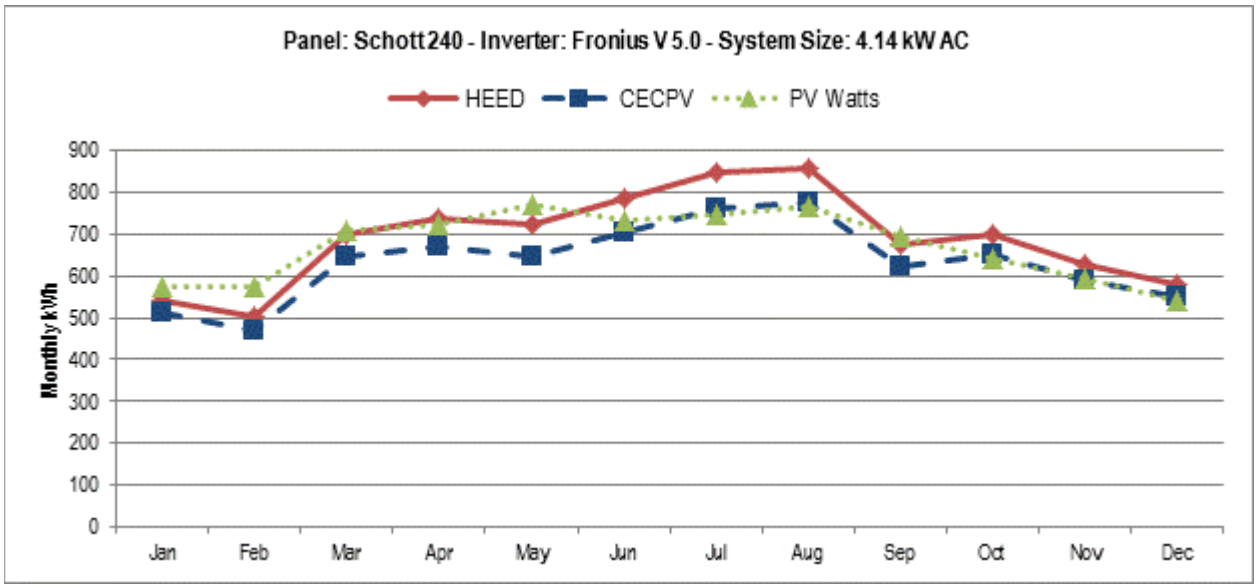


Table 14. Comparison of inputs to CECPV and HEED.

Input	CECPV	HEED
Number of Sites with Solar	1	HEED assumes a single site.
Number of Inverters per Site with Identical Details	1	HEED assumes a single inverter.
PV Module	Selected from a drop-down menu.	Advanced PV Power Design screen: 'PV Panel' drop-down menus for manufacturer and model.
Mounting Configuration	Standoff Height : 'Roof Mounted (greater than 3.5 inches from roof)' Mounting Height : 'One-story'	HEED assumes fixed with a standoff height of at least 3.5".
Total Number of Panels	Number of Series Modules in each String: this value equals the total number of panels divided by the number of parallel strings (next input). Example: if there are 20 total panels and two parallel strings on the inverter, enter '10' here.	Advanced PV Power Design screen: 'Number of Panels in Total Array.' HEED inputs the total number of panels instead of panels/string so these inputs will differ if 'Number of Parallel Strings' is anything other than 1. Example: if there are 20 total panels and two parallel strings on the inverter, enter '20' here.
Number of Parallel Strings per Inverter	Enter value, generally '1'.	Advanced PV Power Design screen: 'Number of Parallel Strings in this set of Panels.'
Tracking or Fixed	'Fixed'	HEED assumes fixed.
Roof Pitch	'Enter Tilt' allows exact input in degrees, pre-defined pitches (e.g., '4:12') are also included.	Advanced PV Power Design screen: 'Panel Tilt' is input in degrees.
Azimuth	Input exact degrees. Due south is 180°, due east is 90°, and due west is 270°.	Advanced PV Power Design screen: 'Array Orientation degrees from South (clockwise positive).' Due south is 0°.
Inverter	Selected from a drop-down menu.	Advanced PV Power Design screen: 'Inverter' drop-down menus for manufacturer and model.
Site Location	City Used in Calculator Run: select closest city from pre-defined list in drop-down menu. The corresponding climate zone will be displayed.	Initial Design screen: 'What is your Zip code or location?' Can input any CA Climate Zone or any EPW file. Select CA zip codes can also be input. The Advanced Climate, Site, and Start Date screen will show which CA Climate Zone corresponds to the selected location.
Panel Shading	'Minimal Shading' can be checked if all obstructions meet the minimal shading criteria (an obstruction is no closer to the panels than twice its height). 'Add Shading Detail' allows the user to input obstructions at specific locations around the panels.	HEED calculates the actual shading from trees, neighbors, etc. as input on the Basic Floor Planner screen.

References:

Beckman, W.A. and J.A. Duffie. *Solar Energy Thermal Processes*. Solar Energy Laboratory, University of Wisconsin-Madison. John Wiley and Sons, New York, NY. 1974.

CECPV Calculator Version 3.0. State of California, California Energy Commission & California Public Utilities Commission. Sacramento, CA. 23 May 2012. <http://www.gosolarcalifornia.org/tools/nshpcalculator/download_calculator.php>

HEED (Home Energy Efficient Design). Energy Design Tools Group, UCLA Department of Architecture and Urban Design. 2012. <http://www.energy-design-tools.aud.ucla.edu/heed/>

Marion, B., M. Anderberg, R. George, P. Gray-Hann, and D. Heimiller. *PVWATTS Version 2 – Enhanced Spatial Resolution for Calculating Grid-Connected PV Performance*. National Renewable Energy Laboratory. Golden, CO. 2001.

Menicucci, D. and J. Fernandez. *User's Manual for PVFORM: A Photovoltaic System Simulation Program for Stand-Alone and Grid-Interactive Application.* SAND85-0376. Sandia National Laboratories. Albuquerque, NM. 1988.

PVWatts™ Grid Data Calculator (Version 2). National Renewable Energy Laboratory. Golden, CO. 6 June 2011. <http://www.nrel.gov/rredc/pvwatts/grid.html>

HEED is available at no cost from http://www.energy-design-tools.aud.ucla.edu/heed