California Energy Commission

STAFF REPORT

# 2016

# RESIDENTIAL ALTERNATIVE CALCULATION METHOD REFERENCE MANUAL

For the *2016 Building Energy Efficiency Standards*

CALIFORNIA
ENERGY COMMISSION

Edmund G. Brown Jr., Governor

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# Summary of Changes

# 2016 Residential Alternative Calculation Method (ACM) Reference Manual (September 2016)

| **Page** | **Description of Change** |
|---|---|
| p. 6 | Update PV Credit Calculation Factors, Table 1. |
| p. 19 | Revise Table 7 to include newly added heating systems. |
| p. 26 | Revise Table 8 to include newly added cooling systems. |
| pp. 36-37 | Modify Section 2.4.6.2 to correct the description for duct location modeling and reporting in a multi-family building. |
| p. 72-73 | Water heating distribution systems in Section 2.9 were updated for consistency between the 2013 and 2016 compliance programs. |
| p. 73-74 | Modify the standard design description for the recirculation system in buildings with central water heating. |
| p. 85 | Update the Table of EDR Adjustments by End Use for Gas Fuel Type |
| APPENDIX A | Revises to remove a multi-family distribution system type that no longer exists. |
| APPENDIX B | |
| pp. B-3 – 4 | Revised language supporting the ability to model multiple water heating systems. |
| p. B-7 | Revised the names of distribution systems to match the program. |
| pp. B-19 -20 | Update load dependent energy factor (LDEF) calculations. |
| p. B-21 | Correct the reference to the Appliance Efficiency Regulations. |

OTHER APPENDICES UNCHANGED

## ACKNOWLEDGMENTS

The *Building Energy Efficiency Standards* were adopted and put into effect in 1978 and have been updated periodically in the intervening years. The Standards are a unique California asset and have benefitted from the conscientious involvement and enduring commitment to the public good of many persons and organizations along the way. The *2016 Standards* development and adoption process continued that long-standing practice of maintaining the Standards with technical rigor, challenging but achievable design and construction practices, public engagement and full consideration of the views of stakeholders.

The revisions in the *2016 Standards* were conceptualized, evaluated and justified through the excellent work of Energy Commission staff and consultants. This document was created with the assistance of Energy Commission staff including Todd Ferris, Larry Froess, P.E., Jeff Miller, P.E., Dee Anne Ross, Peter Strait, and Danny Tam.

Other key technical staff contributors included Mark Alatorre, Payam Bozorgchami, P.E., Bill Pennington, Maziar Shirakh, P.E., and the Energy Commission's Web Team. Deputy Director Dave Ashuckian, PE of the Efficiency Division, and Office Manager Christopher Meyer provided policy guidance to the Staff. Galen Lemei provided legal counsel to the staff.

Special thanks to the key consultants, including Scott Criswell, Bruce Wilcox, Ken Nittler, Robert Scott, and Jennifer Roberts.

## ABSTRACT

The *2016 Building Energy Efficiency Standards for Low-Rise Residential Buildings* allow compliance by either a prescriptive or performance method. Performance compliance uses computer modeling software to trade off efficiency measures. For example, to allow more windows, the designer will specify more efficient windows, or to allow more west-facing windows, they will install a more efficient cooling system. Computer performance compliance is typically the most popular compliance method because of the flexibility it provides in the building design.

Energy compliance software must be certified by the California Energy Commission, following rules established for the modeling software. This document establishes the rules for creating a building model, describing how the proposed design (energy use) is defined, how the standard design (energy budget) is established, and ending with what is reported on the Certificate of Compliance (CF1R). This document **does not** specify the minimum capabilities of vendor-supplied software. The Energy Commission reserves the right to approve vendor software for limited implementations of what is documented in this manual.

This *Residential Alternative Calculation Method (ACM) Reference Manual* explains how the proposed and standard designs are determined.

The 2016 Compliance Manager is the simulation and compliance rule implementation software specified by the Energy Commission. The Compliance Manager, called California Building Energy Code Compliance (CBECC), models all features that affect the energy performance of the building. This document establishes the process of creating a building model. Each section describes how a given component, such as a wall, is modeled for the proposed design, standard design, and ends with what is reported on the Certificate of Compliance (CF1R) for verification by the building enforcement agency.

**Keywords:** ACM, Alternative Calculation Method, *Building Energy Efficiency Standards*, California Energy Commission, California Building Energy Code Compliance, CBECC, Certificate of Compliance, CF1R, compliance manager, compliance software, computer compliance, energy budget, energy standards, energy use, performance compliance, design, proposed design, standard design

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# 1 Introduction

## 1.1 Purpose

This manual documents the rules used for modeling residential buildings for performance compliance under California's *2016 Building Energy Efficiency Standards for Low-Rise Residential Buildings*, similar to the Alternative Calculation Methods (ACM) used in the past to document software rules. This document explains how the proposed design (energy use) and standard design (energy budget) are established for a given building.

The 2016 Compliance Manager is the simulation and compliance rule implementation software specified by the California Energy Commission. For example, attics, crawl spaces, basements, and attached unconditioned spaces (garages and storage) are defined in the building modeling software.

Documentation of detailed calculation algorithms is contained in the companion volume:

> *Appendix E, 2016 Residential Alternative Calculation Method Algorithms*

This document is designed to establish the process of creating a building model. Each section describes how the proposed design (energy use) is defined, how the standard design (energy budget) is established, and what is reported on the Certificate of Compliance (CF1R).

This *Reference Manual* documents the compliance analysis modeling rules for all aspects of the Energy Commission's ACM Reference Method. This document **does not** specify the minimum capabilities of vendor-supplied software. The Energy Commission reserves the right to approve vendor software for limited implementations of what is documented in this manual.

## 1.2 Other Documents

The basis of this document is the *2016 Building Energy Efficiency Standards*. Documents also relied upon include the *Reference Appendices for the 2016 Building Energy Efficiency Standards* and the *2016 Residential Compliance Manual (CEC-400-2015-032)*.

Detailed modeling information for the software user can be found in the *California Building Energy Code Compliance (CBECC) User Manual*.

# 2 The Proposed Design and Standard Design

## 2.1 Overview

This chapter describes how the proposed design is modeled and how the standard design is established.

### 2.1.1 Proposed Design

The building configuration is defined by the user through entries for floor areas, wall areas, roof and ceiling areas, fenestration (which includes skylight) and door areas. Each is entered along with performance characteristics such as U-factors, SHGC, thermal mass, and so forth. Information about the orientation and tilt is required for walls, fenestration, and other elements. The user entries for all these building elements are consistent with the actual building design and configuration. If the compliance software models the specific geometry of the building by using a coordinate system or graphic entry technique, the data generated are consistent with the actual building design and configuration.

### 2.1.2 Standard Design

For low-rise residential buildings, the standard design building, from which the energy budget is established, is in the same location and has the same floor area, volume, and configuration as the proposed design, except that wall and window areas are distributed equally among the four main compass points, north, east, south and west. For additions and alterations, the standard design shall have the same wall and fenestration areas and orientations as the proposed building. The details are described below.

The *energy budget* for the residential standard design is the energy that would be used by a building similar to the proposed design if the proposed building met the requirements of the prescriptive standards. The compliance software generates the standard design automatically, based on fixed and restricted inputs and assumptions. Custom budget generation shall not be accessible to program users for modification when the program is used for compliance or when compliance forms are generated by the program.

The basis of the standard design is prescriptive Package A (from Section 150.1(c) of the standards, Table 150.1-A). Package A requirements vary by climate zone. Reference Joint Appendix JA2, Table 2-1, contains the 16 California climate zones and representative cities. The climate zone can be found by city, county and zip code in JA2.1.1.

The following sections present the details on how the proposed design and standard design are determined. For many modeling assumptions, the standard design is the same as the proposed design. When a building has special features, for which the Commission has established alternate modeling assumptions, the standard design features will differ from the proposed design so the building receives appropriate credit for its efficiency. Typically, these measures require verification. Alternate features, such as zonal control, are documented as *special features* on the Certificate of Compliance. Verified features are also documented on the CF1R.

## 2.2 The Building

***PROPOSED DESIGN***

The building is defined through entries for zones, surfaces, and equipment. Zone types include attic, conditioned space, crawl space, basements, and garages. The roof (such as asphalt shingles or tile) is defined as either part of the attic or as part of a cathedral ceiling (also called a *rafter roof*). Surfaces separating conditioned space from exterior or unconditioned spaces (such as garage or storage) are modeled as interior surfaces adjacent to the unconditioned zone. Exterior surfaces of an attached garage or storage space are modeled as part of the unconditioned zone.

The input file will include entries for floor areas, wall, door, roof and ceiling areas, and fenestration and skylight areas, as well as the water heating, space conditioning, ventilation, and distribution systems.

Each surface area is entered along with performance characteristics, including building materials, U-factor and SHGC. The orientation and tilt (see Figure 1) is required for envelope elements.

Building elements are to be consistent with the actual building design and configuration.

***STANDARD DESIGN***

To determine the standard design for low-rise buildings, a building with the same general characteristics (number of stories, attached garage, climate zone) and with wall and window areas distributed equally among the four main compass points is created by the software. Energy features are set to be equal to Section 150.1(c) and Table 150.1-A. For additions and alterations, the standard design for existing features in the existing building shall have the same wall and fenestration areas and orientations as the proposed building. The details are described below.

***VERIFICATION AND REPORTING***

All inputs that are used to establish compliance requirements are reported on the CF1R for verification.

### *2.2.1 Climate and Weather*

***PROPOSED DESIGN***

The user specifies the climate zone based on the zip code of the proposed building. Compliance requirements, weather, design temperatures, and Time Dependent Valuation (TDV) of energy factors are a function of the climate zone. Compliance software assumes that the ground surrounding residential buildings has a reflectivity of 20 percent in both summer and winter.

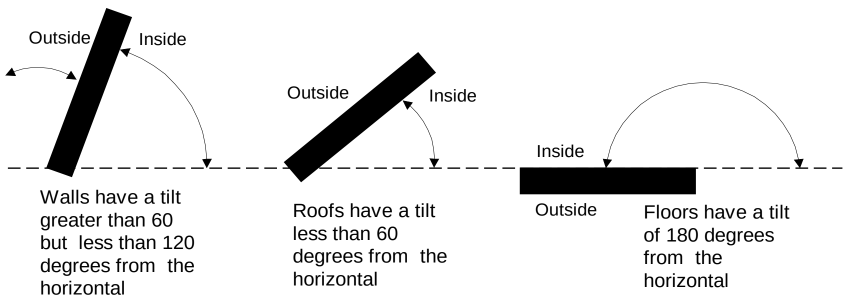
***Standard Design***

The standard design climate zone is the same as the proposed design.

***Verification and Reporting***

The zip code and climate zone of the proposed design is reported on the CF1R for verification.

Figure 1: Surface Definitions




## *2.2.2 Standards Version*

This input determines the appropriate federal appliance efficiency requirement for the standard design to compare with the proposed design.

***Proposed Design***

The user inputs Compliance2017.

***Standard Design***

The standard design cooling equipment efficiency is based on the federal requirements. A minimum SEER and EER (if applicable) that meet the current standard for the type of equipment is modeled.

***Verification and Reporting***

Compliance version is reported on the CF1R.

## *2.2.3 PV System Credit*

The compliance credit available for photovoltaic (PV) systems is available for new construction only and is dependent on the climate zone and dwelling unit size. The credit may be used to tradeoff any efficiency measure, with limits as described below. The PV system must meet the eligibility and verification requirements of Residential Appendix RA4.6.1 and must meet the minimum system size described below.

The PV compliance credit for both single- and multi-family buildings is calculated by the compliance software and is equal to:

Equation 1: $PV_{credit} = TDV_{std} * PV_{maxpct} / 100.0$

Where:

$PV_{credit}$ = PV compliance credit (kTDV/ft$^2$)
$TDV_{std}$ = Standard Design Compliance Total (kTDV/ft$^2$)
$PV_{maxpct}$ = Maximum PV Credit Percentage from Table 1

The minimum PV system size for compliance credit is calculated by the compliance software and is equal to:

Equation 2: $PV_{minsize} = ROUND((PV_{threshold} + PV_{addedsize}) * N_{dwellingunits}, 1)$

For average dwelling units less than or equal to $CFA_{threshold}$:

Equation 3: $PV_{addedsize} = 0$

For average dwelling units larger than $CFA_{threshold}$:

Equation 4: $PV_{addedsize} = PV_{credit} * (CFA_{dwellingunit} – CFA_{threshold}) / PV_{genrate}$

Where:

$PV_{minsize}$ = Minimum PV System Size (kWdc) for compliance credit
$PV_{threshold}$ = Threshold PV System Size per dwelling unit (kWdc) from Table 2
$N_{dwellingunits}$ = Number of dwelling units
$PV_{addedsize}$ = Added PV System Size (kWdc) required
$CFA_{dwellingunit}$ = Average Conditioned floor area per dwelling unit (ft$^2$)
$CFA_{threshold}$ = Average Threshold Conditioned floor per dwelling unit (ft$^2$) from Table 2
$PV_{generate}$ = PV Generation Rate (kTDV/kWdc) from Table 1

If the PV size entered by the user is less than PV minimum size then there is no compliance credit.

Equation 5: $PV_{credit} = 0$ when $PV_{usersize} < PV_{minsize}$

Where:

$PV_{minsize}$ = Minimum PV System Size (kWdc) for compliance credit
$PV_{usersize}$ = PV size entered by user (kWdc)

**Table 1: PV Credit Calculation Factors**

| Climate Zone | PV Generation Rate (kTDV/kWdc) | Maximum PV Credit for Single Family | Maximum PV Credit for Multi Family |
|---|---|---|---|
| 01 | 26762 | ~~8.6~~8.4% | ~~4.5~~4.7% |
| 02 | 30021 | ~~9.1~~11.4% | ~~5.1~~5.3% |
| 03 | 31137 | ~~7.4~~7.9% | ~~3.3~~3.4% |
| 04 | 30935 | ~~20.3~~23.2% | ~~11.1~~9.9% |
| 05 | 33490 | ~~8.1~~8.6% | ~~2.7~~2.7% |
| 06 | 30081 | 0.0% | 0.0% |
| 07 | 30701 | 0.0% | 0.0% |
| 08 | 29254 | ~~27.5~~31.2% | ~~9.2~~9.0% |
| 09 | 29889 | ~~26.1~~25.2% | ~~11.1~~9.8% |
| 10 | 30200 | ~~23.5~~22.4% | ~~10.1~~9.1% |
| 11 | 29693 | ~~18.4~~17.8% | ~~8.8~~8.1% |
| 12 | 29328 | ~~22.6~~20.7% | ~~9.4~~9.0% |
| 13 | 29553 | ~~20.4~~19.5% | ~~9.2~~8.6% |
| 14 | 31651 | ~~16.7~~16.1% | ~~8.2~~7.7% |
| 15 | 29177 | ~~17.0~~16.2% | ~~7.7~~7.1% |
| 16 | 30930 | ~~15.7~~14.6% | ~~8.4~~7.4% |

**Table 2: PV Threshold Factors**

| Dwelling Type | PV threshold (kWdc) | CFA threshold ($ft^2$) |
|---|---|---|
| Single Family | 2.0 | 2000 |
| Multi Family | 1.0 | 1000 |

The maximum PV credits in Table 1 are calculated by using a prototype analysis with the proposed features set equal to the 2016 prescriptive requirements except replacing the 2016 high performance attics (HPA) and high performance walls (HPW) with the 2013 prescriptive requirements. The percentages are calculated by dividing the compliance margin (kTDV/$ft^2$) by the standard design compliance energy use (kTDV/$ft^2$) and multiplying by -100. Climate zones 6 and 7 have no 2016 requirement for either HPA or HPW, so there is no PV credit in those climate zones.

#### *Proposed Design*

The software allows the user to input the rated power output of the solar system in kilowatts direct current (DC). If the rated system is greater than or equal to the minimum PV system size, the software calculates the solar credit and subtracts it from the proposed design. If the rated system is less than the minimum PV system size, the software sets the solar credit to zero and displays a message to the user that the minimum PV system size criteria was not met.

##### STANDARD DESIGN

The standard design has no PV system.

##### VERIFICATION AND REPORTING

A solar credit is reported as a special feature on the CF1R.

### 2.2.4 Existing Condition Verified

These inputs are used for additions and alterations. The standard design assumption for existing conditions vary based on whether the existing conditions are verified by a home energy rating system (HERS) rater prior to construction. See Section 2.10.3 for more information.

##### PROPOSED DESIGN

The user inputs either yes or no. "Yes" indicates that the existing building conditions verified by a HERS rater. Default assumption is "no."

##### STANDARD DESIGN

The standard design assumption is based on Section 150.2(b), Table 150.2-C. If the user input is "no," the standard design for the existing component is based on the value in the second column. If the proposed design response is "yes," the standard design value for the existing components is the value in the third column.

##### VERIFICATION AND REPORTING

Verification of existing conditions is a special feature and is reported in the HERS required verification listings on the CF1R.

### 2.2.5 Air Leakage and Infiltration

Air leakage is a building level characteristic. The compliance software distributes the leakage over the envelope surfaces in accordance with the building configuration and constructs a pressure flow network to simulate the air flows between the conditioned zones, unconditioned zones and outside.

#### 2.2.5.1 *Building Air Leakage and Infiltration (ACH50)*

The air flow through a blower door at 50 Pascal (Pa) of pressure measured in cubic feet per minute is called cfm50. Cfm50 x 60 minutes divided by the volume of conditioned space is the air changes per hour at 50 Pa, called ACH50.

Specific data on ACH50 may be entered if the single-family building or townhouse will have verified building air leakage testing. In multi-family buildings, due to the lack of an applicable measurement standard, ACH50 is fixed at the above defaults.

##### PROPOSED DESIGN

ACH50 defaults to 5 for new construction in single-family buildings and townhomes and 7 for all other buildings that have heating and/or cooling system ducts outside of conditioned space and for buildings with no cooling system. In single-family buildings and townhomes with no heating and/or cooling system ducts in unconditioned space the default ACH50 is 4.4 and 6.2 for all others.

Specific data on ACH50 may be entered if the single-family building or townhouse will have verified building air leakage testing. User input of an ACH50 that is less than the default value becomes a special feature that requires HERS verification.

Due to the lack of an applicable measurement standard, ACH50 is fixed at the above defaults and is not a compliance variable in multi-family buildings.

***STANDARD DESIGN***

The standard design shall have 5 ACH50 for single family buildings and 7 for other buildings (ducted space conditioning).

***VERIFICATION AND REPORTING***

When the user chooses verified building air leakage testing (any value less than the standard design), diagnostic testing for reduced infiltration, with the details and target values modeled in the proposed design, is reported in the HERS required verification listing on the CF1R.

### 2.2.5.2 *Defining Air Net Leakage*

The compliance software creates an air leakage network for the proposed and standard design using the building description. Air leakage is distributed across the envelope surfaces according to the factors in Table 3. The air network is insensitive to wind direction. For buildings modeled with multiple conditioned zones, either a 20 square foot open door or 30 square foot open stairwell (in a multi-story building) is assumed between any two conditioned zones.

The only difference between the air network for the proposed and standard designs is the ACH50 if the user specifies a value lower than the default.

Multi-family buildings that have floors between dwelling units must define each floor as a separate zone or each dwelling unit as a separate zone.

**Table 3: Air Leakage Distribution**

| | % of Total Leakage by Surface | | | |
|---|---|---|---|---|
| **Configuration** | **Ceilings** | **Floors** | **Exterior Walls** | **House to Garage Surfaces** |
| Slab on Grade | 50 | 0 | | |
| Raised Floor | 40 | 10 | | |
| No Garage | | | 50 | 0 |
| Attached Garage | | | 40 | 10 |

## 2.2.6 *Insulation Construction Quality*

The compliance software user may specify either standard (unverified) or improved (verified high quality insulation installation, also called *quality insulation installation* or QII)) for the proposed design. Buildings with standard insulation installation are modeled in the program with lower performing cavity insulation in framed walls, ceilings, and floors and with added winter heat flow between the conditioned zone and attic to represent construction cavities open to the attic. (See Table 4.) Standard insulation does not affect the performance of continuous sheathing in any construction.

#### PROPOSED DESIGN

The compliance software user may specify improved quality insulation installation at the building level. The default is unverified/standard insulation installation. See Section 2.3.3 for information on modeling spray foam insulation.

#### STANDARD DESIGN

The standard design is modeled with standard insulation installation quality.

#### VERIFICATION AND REPORTING

The presence of improved/verified high quality insulation installation is reported in the HERS required verification listings on the CF1R. Improved quality insulation installation is certified by the installer and field verified to comply with RA3.5. Credit for verified quality insulation installation is applicable to ceilings/attics, knee walls, exterior walls and exterior floors.

**Table 4: Modeling Rules for Standard Insulation Installation Quality**

| Component | Modification |
|---|---|
| Walls | Multiply the cavity insulation R-value/inch by 0.7 |
| Ceilings/Roofs | Multiply the blown and batt insulation R-value/inch by 0.96-0.00347*R |
| Ceiling below attic | Add a heat flow from the conditioned zone to the attic of 0.015 times the area of the ceiling below attic times (the conditioned zone temperature - attic temperature) whenever the attic is colder than the conditioned space |

For alterations to existing pre-1978 construction, if existing wall construction is assumed to have no insulation, no wall degradation is assumed for the existing wall.

### 2.2.7 Number of Bedrooms

#### PROPOSED DESIGN

The number of bedrooms in a building is used to establish the indoor air quality (IAQ) mechanical ventilation requirements and to determine if a building qualifies as a compact building for purposes of incentive programs.

#### STANDARD DESIGN

The standard design shall have the same number of bedrooms as the proposed design.

**VERIFICATION AND REPORTING**

The number of bedrooms is reported on the CF1R for use in field verification.

### 2.2.8 Dwelling Unit Types

Internal gains and indoor air quality (IAQ) ventilation calculations depend on the conditioned floor area and number of bedrooms. For multi-family buildings with individual IAQ ventilation systems, each combination of bedrooms and conditioned floor area has a different minimum ventilation cfm that must be verified. A *dwelling unit type* is one or more dwelling units in the building, each of which has the same floor area, number of bedrooms, and appliances.

**PROPOSED DESIGN**

For each dwelling unit type the user inputs the following information:

- Unit name
- Quantity of this unit type in building
- Conditioned floor area (CFA) in square feet per dwelling unit
- Number of bedrooms

**STANDARD DESIGN**

The standard design shall have the same number and type of dwelling units as the proposed design.

**VERIFICATION AND REPORTING**

The number of units of each type and minimum IAQ ventilation for each unit is reported on the CF1R for use in field verification.

### 2.2.9 Front Orientation

The input for the building front orientation is the actual azimuth of the front of the building. This will generally be the side of the building where the front door is located. The orientation of the other sides of a building viewed from the outside looking at the front door are called front, left, right, back, or a value relative to the front, and the compliance software calculates the actual azimuth from this input. Multiple orientation compliance can be selected for newly constructed buildings only.

**PROPOSED DESIGN**

The user specifies whether compliance is for multiple orientations or for a site-specific orientation. For site-specific orientation the user inputs the actual azimuth of the front in degrees from true north.

**STANDARD DESIGN**

The compliance software constructs a standard design building that has 25 percent of the proposed model wall and window areas facing each cardinal orientation regardless of the proposed model distribution of wall and window area.

#### VERIFICATION AND REPORTING

A typical reported value would be "290 degrees (west)". This would indicate that the front of the building faces north 70° west in surveyors terms. The closest orientation on 45° compass points should be reported in parenthesis (for example: north, northeast, east, southeast, south, southwest, west, or northwest). When compliance is shown for multiple orientations, "all orientations" or “cardinal” is reported as a special feature on the CF1R and the energy use results are reported for four orientations including north, east, south, and west.

### 2.2.10 Natural Gas Availability

The user specifies whether natural gas is available at the site. This is used to establish the TDV values from Reference Appendices JA3 used by the compliance software in determining standard and proposed design energy use.

#### PROPOSED DESIGN

The user specifies whether natural gas is available at the site. For newly constructed buildings, natural gas is available if a gas service line can be connected to the site without a gas main extension. For additions and alterations, natural gas is available if a gas service line is connected to the existing building.

#### STANDARD DESIGN

The standard design TDV values for space heating are as defined in Section 2.4.1 and for water heating are as defined in Section 2.9.

#### VERIFICATION AND REPORTING

Whether natural gas is or is not available is reported on the CF1R.

### 2.2.11 Attached Garage

The user specifies whether there is an attached garage. The garage zone is modeled as an unconditioned zone (see Section 2.8).

#### PROPOSED DESIGN

The user specifies whether there is an attached unconditioned garage.

#### STANDARD DESIGN

The standard design has the same attached garage assumption as the proposed design.

#### VERIFICATION AND REPORTING

Features of an attached garage are reported on the CF1R.

### 2.2.12 Lighting

Details of the calculation assumptions for lighting loads are included Appendix C and are based on the Codes and States Enhancement Initiative (CASE) report on plug loads and lighting (Rubin 2016, see Appendix D).

#### PROPOSED DESIGN

Fraction of portable lighting, power adjustment multiplier and the exterior lighting power adjustment multiplier (Watts/$ft^2$ – Watts per square foot) are fixed assumptions.

#### STANDARD DESIGN

The standard design lighting is set equal to the proposed design lighting.

#### VERIFICATION AND REPORTING

No lighting information is reported on the CF1R for compliance with Title 24, Part 6.

### 2.2.13 Appliances

Details of the calculation assumptions for appliances and plug loads are contained in Appendix C and based on the Codes and States Enhancement Initiative (CASE) report on plug loads and lighting (Rubin 2016, see Appendix D).

#### PROPOSED DESIGN

All buildings are assumed to have a refrigerator, dishwasher and cooking appliance. Optionally, buildings can have a clothes washer and clothes dryer. The user can select fuel type as gas or electric for the clothes dryer and cooking appliance.

#### STANDARD DESIGN

The standard design appliances are set equal to the proposed appliances.

#### VERIFICATION AND REPORTING

No information for the appliance types listed above is reported on the CF1R for compliance with Title 24, Part 6.

## 2.3 Building Materials and Construction

### 2.3.1 Materials

Only materials approved by the Commission may be used in defining constructions. Additional materials may be added to the Compliance Manager.

Table 5 shows partial list of the materials currently available for construction assemblies.

**Table 5: Materials List**

| Material Name | Thickness (in.) | Conductivity (Btu/h-°F-ft) | Coefficient for Temperature Adjustment of Conductivity (°F(-1)) | Specific Heat (Btu/lb-°F) | Density (lb/ft$^3$) | R-Value per Inch (°F-ft$^2$-h/ Btu-in) |
|---|---|---|---|---|---|---|
| Gypsum Board | 0.5 | 0.09167 | 0.00122 | 0.27 | 40 | 0.9091 |
| Wood layer | Varies | 0.06127 | 0.0012 | 0.45 | 41 | 1.36 |
| R4 Synth Stucco | 1 | 0.02083 | 0.00418 | 0.35 | 1.5 | 4 |
| 3 Coat Stucco | 0.875 | 0.4167 | | 0.2 | 116 | 0.2 |
| Carpet | 0.5 | 0.02 | | 0.34 | 12.3 | 4.1667 |
| Light Roof | 0.2 | 1 | | 0.2 | 120 | 0.0833 |
| 5 PSF Roof | 0.5 | 1 | | 0.2 | 120 | 0.0833 |
| 10 PSF Roof | 1 | 1 | | 0.2 | 120 | 0.0833 |
| 15 PSF Roof | 1.5 | 1 | | 0.2 | 120 | 0.0833 |
| 25 PSF Roof | 2.5 | 1 | | 0.2 | 120 | 0.0833 |
| TileGap | 0.75 | 0.07353 | | 0.24 | 0.075 | 1.1333 |
| SlabOnGrade | 3.5 | 1 | | 0.2 | 144 | 0.0833 |
| Earth | | 1 | | 0.2 | 115 | 0.0833 |
| SoftWood | | 0.08167 | 0.0012 | 0.39 | 35 | 1.0204 |
| Concrete | | 1 | | 0.2 | 144 | 0.0833 |
| Foam Sheathing | varies | varies | 0.00175 | 0.35 | 1.5 | varies |
| Ceiling Insulation | varies | varies | 0.00418 | 0.2 | 1.5 | varies |
| Cavity Insulation | varies | varies | 0.00325 | 0.2 | 1.5 | varies |
| Vertical Wall Cavity | 3.5 | 0.314 | 0.00397 | 0.24 | 0.075 | |
| GHR Tile | 1.21 | 0.026 | 0.00175 | 0.2 | 38 | |
| ENSOPRO | 0.66 | 0.03 | 0.00175 | 0.35 | 2 | |
| ENSOPRO Plus | 1.36 | 0.025 | 0.00175 | 0.35 | 2 | |
| Door | | | | | | |

#### *Material Name*

The material name is used to select the material for a construction.

#### *Thickness*

Some materials, such as three-coat stucco, are defined with a specific thickness (not editable by the compliance user). The thickness of other materials, such as softwood used for framing, is selected by the compliance user based on the construction of the building.

#### *Conductivity*

The conductivity of the material is the steady state heat flow per square foot, per foot of thickness, or per degree Fahrenheit temperature difference. It is used in simulating the heat flow in the construction.

#### COEFFICIENT FOR TEMPERATURE ADJUSTMENT OF CONDUCTIVITY

The conductivity of insulation materials vary with their temperature according to the coefficient listed. Other materials have a coefficient of zero (0) and their conductivity does not vary with temperature.

#### SPECIFIC HEAT

The specific heat is the amount of heat in British thermal units (Btu) it takes to raise the temperature of one pound of the material one degree Fahrenheit.

#### DENSITY

The density of the material is its weight in pounds per cubic foot.

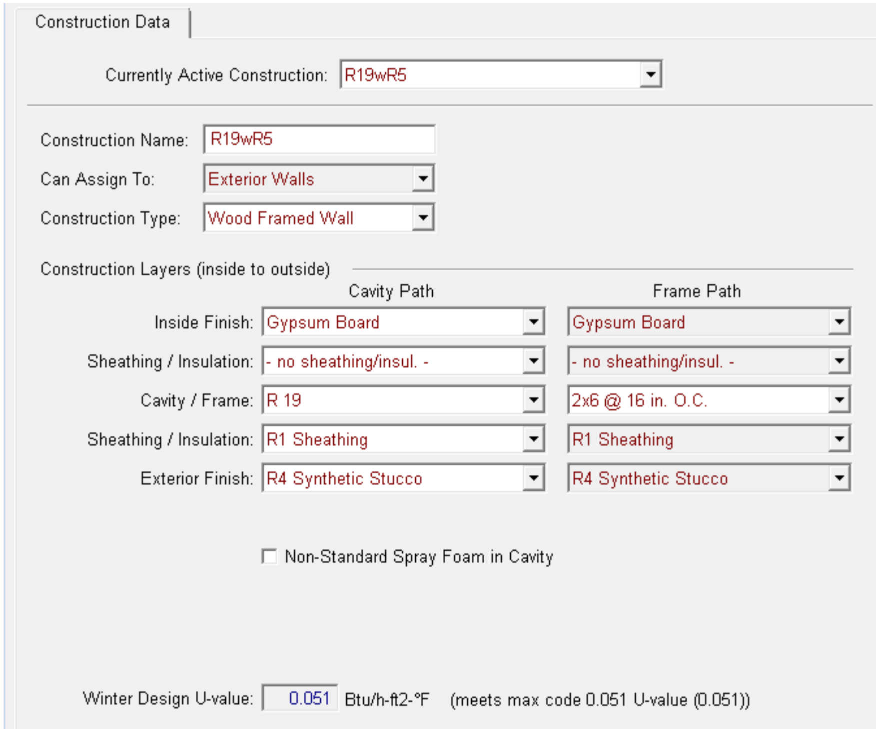
#### R-VALUE PER INCH

The R-value is the resistance to heat flow for a 1-inch thick layer.

### 2.3.2 Construction Assemblies

Constructions are defined by the compliance user for use in defining the building. The user assembles a construction from one or more layers of materials as shown in Figure 2. For framed constructions there is a framing layer that has parallel paths for the framing and the cavity between the framing members. The layers that are allowed depend on the surface type. The compliance manager calculates a winter design U-factor that is compared to a construction that meets the prescriptive standard. The U-factor is displayed as an aid to the user. The calculations used in the energy simulation are based on each individual layer and framing rather than the U-factor.

Figure 2: Example Construction Data Screen




### ASSEMBLY TYPES

The types of assemblies are:

Exterior wall
Interior wall
Underground walls
Attic roof
Cathedral roof
Ceiling below attic
Interior ceiling
Interior floor
Exterior floor (over unconditioned space or exterior)
Floor over crawl space

### CONSTRUCTION TYPE:

1. Ceiling below attic (the roof structure is not defined here, but is part of the attic), wood framed. In a residence with a truss roof, the ceiling is where the insulation is located, while the structure above the ceiling is encompassed by the term attic or roof. The attic or roof consists of (moving from inside to outside) the radiant barrier, below deck insulation, framing, above deck insulation, and the roofing product, such as asphalt or tile roofing. See more in Section 2.4.5.

2. Cathedral ceiling (with the roof defined as part of the assembly), wood framed. Since there is no attic, the roof structure is connected to the insulated assembly at this point.

3. Roof, structurally insulated panels (SIP).

4. Walls (interior, exterior, underground), wood or metal framed, or structurally insulated panel (SIP).

5. Floors (over exterior, over crawl space, or interior).

6. Party surfaces separate conditioned space included in the analysis from conditioned space that may or may not be included in the analysis. Party surfaces for spaces that are modeled include surfaces between multi-family dwelling units. Party surfaces for spaces not included in the analysis include spaces joining an addition alone to the existing dwelling. Interior walls, ceilings or floors can be party surfaces.

***CONSTRUCTION LAYERS:***

All assemblies have a cavity path and a frame path.

Spray foam insulation may use either default values with no special inspection requirements, or higher values when supported by an ESR number (see details Section 2.3.3 and RA3.5) verified by a HERS rater.

As assemblies are completed, the screen displays whether the construction meets the prescriptive requirement for that component.

***PROPOSED DESIGN***

The user defines a construction for each surface type included in the proposed design. Any variation in insulation R-value, framing size or spacing, interior or exterior sheathing or interior or exterior finish requires the user to define a different construction. Insulation R-values are based on manufacturer-rated properties rounded to the nearest whole R-value. Layers such as sheetrock, wood sheathing, stucco and carpet whose properties are not compliance variables are included as generic layers with standard thickness and properties.

Walls separating the house from an attached unconditioned attic or garage are modeled as interior walls with unconditioned space as the adjacent zone, which the compliance manager recognizes as a demising wall. Floors over a garage are modeled as floor over exterior. The exterior walls, floor, ceiling/roof of the garage are modeled as part of the unconditioned garage zone.

***STANDARD DESIGN***

The compliance software assembles a construction that meets the prescriptive standards for each user-defined construction or assembly.

***VERIFICATION AND REPORTING***

All proposed constructions, including insulation, frame type, frame size, and exterior finish or exterior condition are listed on the CF1R. Non-standard framing (e.g., 24" on center wall framing, advanced wall framing) is reported as a special feature.

### 2.3.3 Spray Foam Insulation

The R-values for spray-applied polyurethane foam (SPF) insulation differ depending on whether the product is open cell or closed cell.

**Table 6: Required Thickness Spray Foam Insulation**

| Required R-values for SPF insulation | R-11 | R-13 | R-15 | R-19 | R-21 | R-22 | R-25 | R-30 | R-38 |
|---|---|---|---|---|---|---|---|---|---|
| Required thickness closed cell @ R5.8/inch | 2.00 inches | 2.25 inches | 2.75 inches | 3.50 inches | 3.75 inches | 4.00 inches | 4.50 inches | 5.25 inches | 6.75 inches |
| Required thickness open cell @ R3.6/inch | 3.0 inches | 3.5 inches | 4.2 inches | 5.3 inches | 5.8 inches | 6.1 inches | 6.9 inches | 8.3 inches | 10.6 inches |

Additional documentation and verification requirements for a value other than the default values shown in Table 6 is required (see RA3.5.6).

#### 2.3.3.1 *Medium Density Closed-Cell SPF Insulation*

The default R-value for spray foam insulation with a closed cellular structure is R-5.8 per inch, based on the installed nominal thickness of insulation. Closed cell insulation has an installed nominal density of 1.5 to 2.5 pounds per cubic foot (pcf).

#### 2.3.3.2 *Low Density Open-Cell SPF Insulation*

The default R-value for spray foam insulation with an open cellular structure is calculated as R-3.6 per inch, calculated based on the nominal required thickness of insulation. Open cell insulation has an installed nominal density of 0.4 to 1.5 pounds per cubic foot (pcf).

***PROPOSED DESIGN***

The user will select either typical values for open cell or closed cell spray foam insulation or higher than typical values, and enter the total R-value (rounded to the nearest whole value).

***STANDARD DESIGN***

The compliance software assembles a construction that meets the prescriptive standards for each assembly type (ceiling/roof, wall, and floor).

***VERIFICATION AND REPORTING***

When the user elects to use higher than typical R-values for open cell or closed cell spray foam insulation, a special features note is included on the CF1R requiring documentation requirements specified in RA4.1.7. Additionally, a HERS verification requirement for the installation of spray foam insulation using higher than default values is included on the CF1R.

## 2.4 Building Mechanical Systems

A space-conditioning system (also referred to as HVAC system) is made up of the heating subsystem (also referred to as heating unit or heating equipment or heating system), cooling subsystem (also referred to as cooling unit or cooling equipment or cooling system) (if any), the distribution subsystem details and fan subsystem (if any). Ventilation cooling systems and indoor air quality ventilation systems are defined at the building level for single-family dwellings or as part of the dwelling unit information for multi-family buildings (see also Sections 2.4.9 and 2.4.10).

### *2.4.1 Heating Subsystems*

The heating subsystem describes the equipment that supplies heat to a space conditioning system. Heating subsystems are categorized according to the types shown in Table 7.

**Table 7: HVAC Heating Equipment Types**

| Name | Heating Equipment Description |
|---|---|
| CntrlFurnace | Gas- or oil-fired central furnaces, propane furnaces or heating equipment considered equivalent to a gas-fired central furnace, such as wood stoves that qualify for the wood heat exceptional method. Gas fan-type central furnaces have a minimum AFUE=78%. Distribution can be gravity flow or use any of the ducted systems. (Efficiency metric: AFUE) |
| WallFurnaceGravity | Non-central gas- or oil-fired wall furnace, gravity flow. Equipment has varying efficiency requirements by capacity. Distribution is ductless. (Efficiency metric: AFUE) |
| WallFurnaceFan | Non-central gas- or oil-fired wall furnace, fan-forced. Equipment has varying efficiency requirements by capacity. Distribution is ductless. (Efficiency metric: AFUE) |
| FloorFurnace | Non-central gas- or oil-fired floor furnace. Equipment has varying efficiency requirements by capacity. Distribution is ductless. (Efficiency metric: AFUE) |
| GroundSourceHeatPump | A water-to-air heat pump or water-to-water heat pump using fluid flowing through underground piping as a heat source/heat sink, that provides heating, cooling, or heating and cooling conditioning with forced air or hydronic distribution. May also provide heat for domestic hot water. (Efficiency metric: COP) |
| RoomHeater | Non-central gas- or oil-fired room heaters. Non-central gas- or oil-fired wall furnace, gravity flow. Equipment has varying efficiency requirements by capacity. Distribution is ductless. (Efficiency metric: AFUE) |
| WoodHeat | Wood-fired stove. In areas with no natural gas available, a wood heating system with any back-up heating system, is allowed to be installed if exceptional method criteria described in the Residential Compliance Manual are met. (Efficiency Metric: N/A) |
| Boiler | Gas or oil boilers. Distribution systems can be Radiant, Baseboard or any of the ducted systems. Boiler may be specified for dedicated hydronic systems. Systems in which the boiler provides space heating and fires an indirect gas water heater (IndGas) may be listed as Boiler/CombHydro Boiler and is listed under "Equipment Type" in the HVAC Systems listing. (Efficiency metric: AFUE) |
| SplitHeatPump | Heating side of a split heat pump heating system that has one or more outdoor units supply heat to each habitable space in the dwelling unit. Heat is at least partly distributed using one of the ducted systems. (Efficiency metric: HSPF) |
| SDHVSplitHeatPump | Heating side of a small Duct, High Velocity, Central split system that produces at least 1.2 inches of external static pressure when operated at the certified air volume rate of 220–350 CFM per rated ton of cooling and uses high velocity room outlets generally greater than 1,000 fpm that have less than 6.0 square inches of free area. (Efficiency Metric: HSPF) |
| ~~DuctlessHeatPump~~ | ~~One or more heat pump outdoor units that use refrigerant to transport heat to at least one terminal in each habitable space in the dwelling unit. These include small ductless mini-split and multiple-split heat pumps and packaged terminal (commonly called "through-the-wall") units. Heat is not distributed using ducts either inside or outside of the conditioned space. (Efficiency metric: COP)~~ |
| DuctlessMiniSplitHeatPump: | Heating side of a heat pump system that has single outdoor section and one or more ductless indoor sections. The indoor section(s) cycle on and off in unison in response to a single indoor thermostat. (Efficiency Metric: HSPF) |
| DuctlessMultiSplitHeatPump | Heating side of a heat pump system that has a single outdoor section and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats. (Efficiency Metric: HSPF) |
| DuctlessVRFHeatPump | Heating side of a variable refrigerant flow (VRF) heat pump system that has one or more outdoor sections and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats. (Efficiency Metric: HSPF) |
| RoomHeatPump | Same as DuctlessHeatPump except that heat is not supplied to each habitable space in the dwelling unit. (Efficiency metric: COP) |

| Name | Heating Equipment Description |
|---|---|
| PkgHeatPump | Heating side of central packaged heat pump systems. Central packaged heat pumps are heat pumps in which the blower, coils and compressor are contained in a single package, powered by single phase electric current, air cooled, and rated below 65,000 Btu/h. Distribution system is one of the ducted systems. (Efficiency metric: HSPF) |
| LrgPkgHeatPump | Heating side of large packaged units rated at or above 65,000 Btu/h (heating mode). Distribution system is one of the ducted systems. These include water source and ground source heat pumps. (Efficiency metric: COP) |
| Electric | All electric heating systems other than space conditioning heat pumps. Included are electric resistance heaters, electric boilers and storage water heat pumps (air-water) (StoHP). Distribution system can be Radiant, Baseboard or any of the ducted systems. |
| CombHydro | Water heating system can be storage gas (StoGas, LgStoGas), storage electric (StoElec) or heat pump water heaters (StoHP). Distribution systems can be Radiant, Baseboard, or any of the ducted systems and can be used with any of the terminal units (FanCoil, RadiantFlr, Baseboard, and FanConv). (Efficiency metric: AFUE) |
| AirToWaterHeatPump | An air-source heat pump that uses hydronic distribution to provide heating, cooling, or heating and cooling conditioning. May also provide heat for domestic hot water. (Efficiency metric: COP) |

#### *PROPOSED DESIGN*

The user selects the type and supplies inputs for the heating subsystem in the heating system data screen shown in Figure 3. The user inputs the appropriate rated heating efficiency factor. Except for heat pumps, the rated heating capacity is not used as a compliance variable by the compliance software. For heat pumps the user inputs the rated heating capacity at 47°F and 17°F for the heat pump compressor to be installed and the software sizes the backup electric resistance heat for use in the simulation.

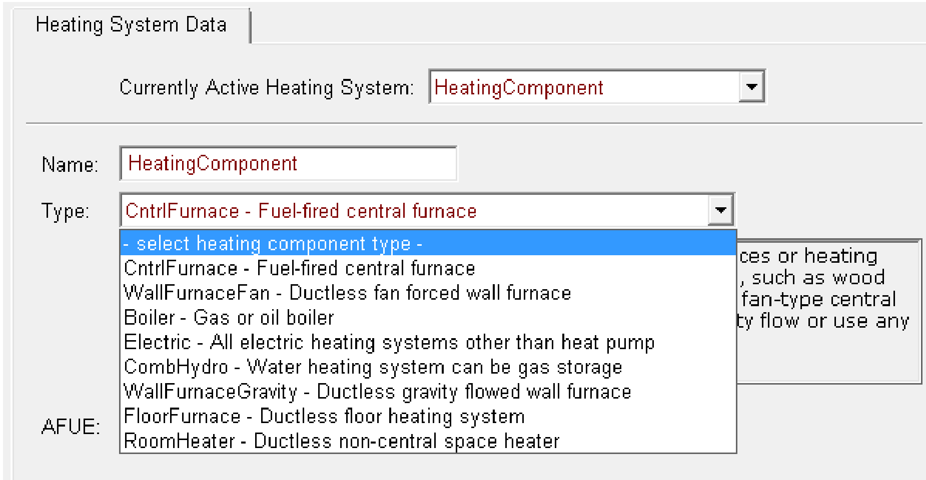
Until there is an approved compliance option for ductless heat pumps (ductless mini-split, multi-split, and VRF systems) these systems are simulated as a minimum efficiency split system equivalent to the standard design and with default duct conditions.

#### *STANDARD DESIGN*

When electricity is used for heating, the heating equipment for the standard design is an electric split system heat pump with default ducts in the attic and a heating seasonal performance factor (HSPF) meeting the *Appliance Efficiency Regulations* (CEC-400-2014-009) requirements for split systems with default ducts in the attic. The standard design heat pump compressor size is determined by the software as the larger of the compressor size calculated for air conditioning load, or the compressor with a 47 degree F rating that is 75 percent of the heating load (at the heating design temperature).

When electricity is not used for heating, the equipment used in the standard design building is a gas furnace (or propane if natural gas is not available) with default ducts in the attic and an annual fuel utilization efficiency (AFUE) meeting the *Appliance Efficiency Regulations* minimum efficiency for central systems. When a proposed design uses both electric and non-electric heat, the standard design is a gas furnace.

Figure 3: Heating System Data Screen




***VERIFICATION AND REPORTING***

The proposed heating system type and rated efficiency are reported in the compliance documentation. For heat pumps, which are supplemented by electric resistance back-up heating, the rated heating capacity of each proposed heat pump is reported on the CF1R to verify that installed capacity is equal or larger than the capacities modeled at 47° and 17°.

## *2.4.2 Combined Hydronic Space/Water Heating*

Combined hydronic space/water heating is a system whereby a water heater is used to provide both space heating and water heating. Dedicated hydronic space-heating systems are also a modeling capability. Space-heating terminals may include fan coils, baseboards, and radiant surfaces (floors, walls or ceilings).

For combined hydronic systems, the water-heating portion is modeled in the normal manner. For space heating, an effective AFUE is calculated for gas water heaters. For electric water heaters, an effective HSPF is calculated. The procedures for calculating the effective AFUE or HSPF are described below.

Combined hydronic space conditioning cannot be combined with zonal control credit.

***PROPOSED DESIGN***

When a fan coil is used to distribute heat, the fan energy and the heat contribution of the fan motor must be considered. The algorithms for fans used in combined hydronic systems are the same as those used for gas furnaces and are described in Chapter 3.

If a large fan coil is used and air-distribution ducts are located in the attic, crawlspace or other unconditioned space, the efficiency of the air-distribution system must be determined using methods consistent with those described in Section 2.4.6. Duct efficiency is accounted for when the distribution type is ducted.

#### 2.4.2.1 *Large or Small Storage Gas Water Heater*

When storage gas water heaters are used in combined hydronic applications, the effective AFUE is given by the following equation:

Equation 6 $$AFUE_{eff} = RE - \left[ \frac{PL}{RI} \right]$$

Where:

$AFUE_{eff}$ = The effective AFUE of the gas water heater in satisfying the space heating load.

RE = The recovery efficiency (or thermal efficiency) of the gas storage water heater. A default value of 0.70 may be assumed if the recovery efficiency is unknown. This value is generally available from the Energy Commission appliance directory.

PL = Pipe losses (kBtu/h). This can be assumed to be zero when less than 10 feet of piping between the water heater storage tank and the fan coil or other heating elements are located in unconditioned space.

RI = The rated input of the gas water heater (kBtu/h) available from the Energy Commission appliance directory.

#### 2.4.2.2 *Instantaneous Gas Water Heater*

When instantaneous gas water heaters are used in combined hydronic applications, the effective AFUE is given by the following equation:

Equation 7 $$AFUE_{eff} = EF$$

Where:

$AFUE_{eff}$ = The effective AFUE of the gas water heater in satisfying the space heating load.

EF = The rated Energy Factor of the instantaneous gas water heater.

#### 2.4.2.3 *Storage Electric Water Heater*

The HSPF of storage water heaters used for space heating in a combined hydronic system is given by the following equations.

Equation 8 $$HSPF_{eff} = 3.413\left[ 1 - \frac{PL}{3.413kWi} \right]$$

Where:

$HSPF_{eff}$ = The effective HSPF of the electric water heater in satisfying the space heating load.

PL = Pipe losses (kBtu/h). This can be assumed to be zero when less than 10 feet of piping between the water heater storage tank and the fan coil or other heating elements are located in unconditioned space.

kWi = The kilowatts of input to the water heater available from the Energy Commission's appliance directory.

**STANDARD DESIGN**

When electricity is used for heating, the heating equipment for the standard design is an electric split system heat pump with an HSPF meeting the *Appliance Efficiency Regulations* requirements for split systems. The standard design heat pump compressor size is determined by the software based on the compressor size calculated for the air conditioning system.

When electricity is not used for heating, the equipment used in the standard design building is a gas furnace (or propane if natural gas is not available) with default ducts in the attic and an AFUE meeting the *Appliance Efficiency Regulations* minimum efficiency for central systems. When a proposed design uses both electric and non-electric heat, the standard design is a gas furnace.

## 2.4.3 Special Systems – Hydronic Distribution Systems and Terminals

[Not yet implemented]

**PROPOSED DESIGN**

This listing is completed for hydronic systems that have more than 10 feet of piping (plan view) located in unconditioned space. As many rows as necessary may be used to describe the piping system.

**STANDARD DESIGN**

The standard design is established for a hydronic system in the same way as for a central system, as described in Section 2.4.1.

**VERIFICATION AND REPORTING**

A hydronic or combined hydronic system is reported on the CF1R.

Other information reported includes:

- *Piping Run Length (ft).* The length (plan view) of distribution pipe located in unconditioned space, in feet, between the primary heating/cooling source and the point of distribution.
- *Nominal Pipe Size (in.).* The nominal (as opposed to true) pipe diameter in inches.
- *Insulation Thickness (in.).* The thickness of the insulation in inches. Enter "none" if the pipe is uninsulated.
- *Insulation R-value (hr-ft$^2$- °F/Btu).* The installed R-value of the pipe insulation. Minimum pipe insulation for hydronic systems is as specified in Section 150.0(j).

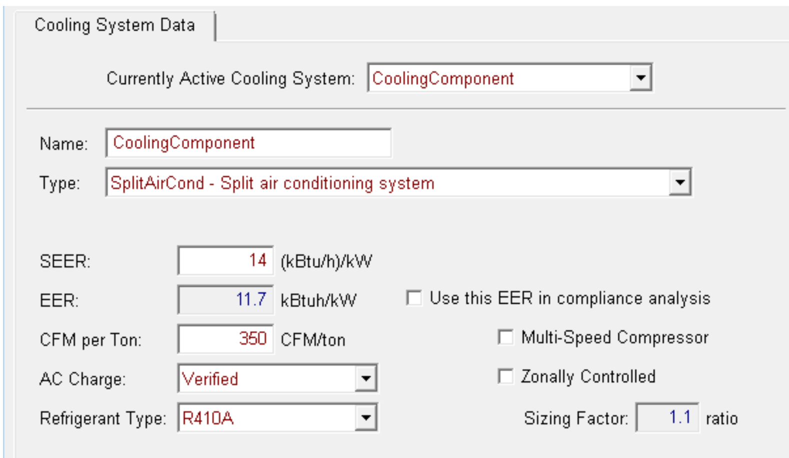
### 2.4.4 Ground-Source Heat Pump

A ground-source heat pump system, which uses the earth as a source of energy for heating and as a heat sink for energy when cooling, is simulated as a minimum efficiency split system equivalent to the standard design with default duct conditions in place of the proposed system. The mandatory efficiencies for ground-source heat pumps are a minimum coefficient of performance (COP) for heating and EER for cooling.

### 2.4.5 Cooling Subsystems

The cooling subsystem describes the equipment that supplies cooling to a space-conditioning system.

Figure 4: Cooling System Data




#### PROPOSED DESIGN

Cooling subsystems are categorized according to the types shown in **Table 8**. The user selects the type of cooling equipment and enters basic information to model the energy use of the equipment. Enter the cooling equipment type and additional information based on the equipment type and zoning, such as the SEER and EER. For some types of equipment, the user may also specify that the equipment has a multi-speed compressor and if the system is zoned or not via checkboxes. For ducted cooling systems the cooling air flow from the conditioned zone through the cooling coil is input as CFM per ton. The rated cooling capacity is not a compliance variable.

Until there is an approved compliance option for ductless heat pumps (ductless mini-split, multi-split, and variable refrigerant flow (VRF) systems) these systems are simulated as a minimum efficiency split system equivalent to the standard design with default duct conditions.

See sections below for the details of specific inputs.

#### STANDARD DESIGN

The cooling system for the standard design building is a non-zonal control split system air conditioner or heat pump meeting the minimum requirements of the *Appliance Efficiency Regulations*.

The standard design system shall assume verified refrigerant charge in climate zones 2 and 8 through 15 for all ducted split systems, ducted package systems, mini-split, multi-split, and VRF systems. Mandatory fan efficacy is assumed in all climate zones.

#### VERIFICATION AND REPORTING

Information shown on the CF1R includes cooling equipment type and cooling efficiency (SEER and/or EER). Measures requiring verification are listed in the HERS verification section of the CF1R.

### 2.4.5.1 *Verified Refrigerant Charge or Fault Indicator Display*

Proper refrigerant charge is necessary for electrically driven compressor air-conditioning systems to operate at full capacity and efficiency. Software calculations set the compressor efficiency multiplier to 0.90 to account for the effect of improper refrigerant charge or 0.96 for proper charge.

#### PROPOSED DESIGN

The software allows the user to indicate if systems will have diagnostically tested refrigerant charge or a field-verified fault indicator display (FID). This applies only to ducted split systems and packaged air conditioners and heat pumps.

#### STANDARD DESIGN

The standard design building is modeled with either diagnostically tested refrigerant charge or a field-verified FID if the building is in climate zone 2 or 8-15, and refrigerant charge verification is required by Section 150.1(c) and Table 150.1-A for the proposed cooling system type.

#### VERIFICATION AND REPORTING

These features require field verification or diagnostic testing and are reported in the HERS required verification listings on the CF1R. Details on refrigerant charge measurement are discussed in *Reference Residential Appendix RA3.2*. Information on the requirements for FIDs is located in *Reference Joint Appendix JA6.1*.

**Table 8: HVAC Cooling Equipment Types**

| Name | Cooling Equipment Description |
|---|---|
| NoCooling | Entered when the proposed building is not cooled or when cooling is optional (to be installed at some future date). Both the standard design equivalent building and the proposed design use the same default system (refer to Section 2.4.8.3). (Efficiency metric: SEER) |
| SplitAirCond | Split air conditioning systems. Distribution system is one of the ducted systems. (Efficiency metric: SEER and EER) |
| PkgAirCond | Central packaged air conditioning systems less than 65,000 Btu/h cooling capacity. Distribution system is one of the ducted systems. (Efficiency metric: SEER and EER) |
| LrgPkgAirCond | Large packaged air conditioning systems rated at or above 65,000 Btu/h cooling capacity. Distribution system is one of the ducted systems. (Efficiency metric: EER) |
| SDHVSplitAirCond | Small duct, high velocity, split A/C system. (Efficiency Metric: SEER) |
| DuctlessSplitAirCond | One or more split air conditioning outdoor units that use refrigerant to transport cooling to at least one terminal in each habitable space in the dwelling unit. These include small ductless mini-split and multiple-split heat air conditioners and packaged terminal (commonly called "through-the-wall") units. Cooling is not distributed using ducts either inside or outside of the conditioned space. (Efficiency metric: EER) |
| RoomAirCond | Same as DuctlessSplitAirCond except that cooling is not supplied to each habitable space in the dwelling unit. (Efficiency metric: EER) |
| SplitHeatPump | Cooling side of split heat pump systems. Distribution system is one of the ducted systems. (Efficiency metric: SEER and EER<65,000 Btu/h EER>65,000 Btu/h) |
| PkgHeatPump | Cooling side of central single-packaged heat pump systems with a cooling capacity less than 65,000 Btu/h. Distribution system is one of the ducted systems. (Efficiency metric: SEER) |
| LrgPkgHeatPump | Cooling side of large packaged heat pump systems rated at or above 65,000 Btu/h cooling capacity. Distribution system is one of the ducted systems. (Efficiency metric: EER) |
| SDHVSplitHeatPump | Cooling side of a small Duct, High Velocity, Central split system that produces at least 1.2 inches of external static pressure when operated at the certified air volume rate of 220–350 CFM per rated ton of cooling and uses high velocity room outlets generally greater than 1,000 fpm that have less than 6.0 square inches of free area. (Efficiency Metric: SEER) |
| ~~DuctlessHeatPump~~ | ~~One or more heat pump outdoor units that use refrigerant to transport cooling to at least one terminal in each habitable space in the dwelling unit. These include small ductless mini-split and multiple-split heat pumps and packaged terminal (commonly called "through-the-wall") units. Cooling is not distributed using ducts either inside or outside of the conditioned space. (Efficiency metric: EER)~~ |
| DuctlessMiniSplitAirCond | Ductless mini-split A/C system. (Efficiency Metric: SEER) |
| DuctlessMultiSplitAirCond | Ductless multi-split A/C system. (Efficiency Metric: SEER) |
| DuctlessVRFAirCond | Ductless variable refrigerant flow (VRF) A/C system. (Efficiency Metric: SEER) |
| DuctlessMiniSplitHeatPump: | Cooling side of a heat pump system that has single outdoor section and one or more ductless indoor sections. The indoor section(s) cycle on and off in unison in response to a single indoor thermostat. (Efficiency Metric: SEER) |
| DuctlessMultiSplitHeatPump | Cooling side of a heat pump system that has a single outdoor section and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats. (Efficiency Metric: SEER) |
| DuctlessVRFHeatPump | Cooling side of a variable refrigerant flow (VRF) heat pump system that has one or more outdoor sections and two or more ductless indoor sections. The indoor sections operate independently and can be used to condition multiple zones in response to multiple indoor thermostats. (Efficiency Metric: SEER) |
| RoomHeatPump | Same as DuctlessHeatPump except that cooling is not supplied to each habitable space in the dwelling unit. (Efficiency metric: EER) |

| Name | Cooling Equipment Description |
|---|---|
| AirToWaterHeatPump | An air-source heat pump that uses hydronic distribution to provide heating, cooling, or heating and cooling conditioning. May also provide heat for domestic hot water. (Efficiency metric: EER) |
| GroundSourceHeatPump | A water-to-air heat pump or water-to-water heat pump using fluid flowing through underground piping as a heat source/heat sink, that provides heating, cooling, or heating and cooling conditioning with forced air or hydronic distribution. May also provide heat for domestic hot water. (Efficiency metric: EER) |
| EvapDirect | Direct evaporative cooling systems. Assume minimal efficiency air conditioner. The default distribution system location is DuctAttic; evaporative cooler duct insulation requirements are the same as those for air conditioner ducts. (Efficiency metric: SEER) |
| EvapIndirDirect | Indirect-direct evaporative cooling systems. Assume energy efficiency ratio of 13 EER. Requires air flow and media saturation effectiveness from the CEC directory. (Efficiency metric: EER) |
| EvapIndirect | Indirect cooling systems. The default distribution system location is DuctAttic; evaporative cooler duct insulation requirements are the same as those for air conditioner ducts. Assume energy efficiency ratio of 13 EER. Requires air flow and media saturation effectiveness from the CEC directory. (Efficiency metric: EER) |
| EvapCondenser | Evaporatively Cooled Condensers. A split mechanical system, with a water-cooled condenser coil. (Efficiency metric: EER) |

**Table 9: Summary of Air Conditioning Measures Requiring Verification**

| Measure | Description | Procedures (Need Update) |
|---|---|---|
| Verified Refrigerant Charge | Air-cooled air conditioners and air-source heat pumps be diagnostically tested to verify that the system has the correct refrigerant charge. The system must also meet the system airflow requirement. | RA3.2, RA1.2 |
| Verified Fault Indicator Display | A Fault Indicator Display can be installed as an alternative to refrigerant charge testing. | RA3.4.2 |
| Verified System Airflow | When compliance requires verified System Airflow greater than or equal to a specified criterion. | RA3.3 |
| Verified Air-handling Unit Fan Efficacy | To verify that Fan Efficacy (Watt/cfm) is less than or equal to a specified criterion. | RA3.3 |
| Verified EER | Credit for increased EER by installation of specific air conditioner or heat pump models. | RA3.4.3, RA3.4.4.1 |
| Verified SEER | Credit for increased SEER. | RA3.4.3, RA3.4.4.1 |
| Evaporatively Cooled Condensers | Must be combined with duct leakage testing, refrigerant charge, and verified EER. | RA3.1, RA3.1.4.3, RA3.2, RA1.2, RA3.4.3, RA3.4.4.1 |

#### 2.4.5.2 *Verified System Airflow*

Adequate airflow from the conditioned space is required to allow ducted air-conditioning systems to operate at their full efficiency and capacity. Efficiency is achieved by the air distribution system design by improving the efficiency of motors or air distribution systems with less resistance to airflow. Software calculations account for the impact of airflow on sensible heat ratio and compressor efficiency.

A value less than 350 cfm/ton (minimum 150 cfm/ton) is a valid input only if zonally controlled equipment is selected and multi-speed compressor is not selected.

The mandatory requirement in Section 150.0(m)13 is for an air-handling unit with a verified airflow rate greater than or equal to 350cfm/ton. Credit for a higher airflow rate requires diagnostic testing using procedures in *Reference Residential Appendix RA3.3*.

For Single Zone Systems:

- Installers may elect to use an alternative to HERS verification of 350 cfm/ton: HERS verification of a return duct design that conforms to the specification given in Table 150.0-B or C.
- The return duct design alternative is not an input to the compliance software but must be documented on the certificate of installation.

- If a value greater than 350 cfm/ton is modeled for compliance credit, the alternative return duct design method using Table 150.0-B or C is not allowed for use in demonstrating compliance.
- Multispeed or variable-speed compressor systems must verify airflow rate (cfm/ton) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For Zonally Controlled Systems:

- The Table 150.0-B or C return duct design alternative is not allowed for zonally controlled systems.
- Multispeed, variable-speed and single-speed compressor systems must all verify airflow rate (cfm/ton) by operating the system at maximum compressor capacity and maximum system fan speed with all zones calling for conditioning.
- Single-speed compressor systems must also verify airflow rate (cfm/ton) in every zonal control mode.

##### PROPOSED DESIGN

The default cooling airflow is 150 cfm/ton for a system with zonally controlled selected and multi-speed compressor not selected (single speed). The default cooling airflow is 350 cfm/ton for all other ducted cooling systems. Users may model a higher-than-default airflow and receive credit in the compliance calculation if greater verified system airflow is diagnostically tested using the procedures of *Reference Residential Appendix RA3.3*.

##### STANDARD DESIGN

The standard design shall assume a system that complies with mandatory (Section 150.0) and prescriptive (Section 150.1) requirements for the applicable climate zone.

##### VERIFICATION AND REPORTING

The airflow rate verification compliance target (cfm or cfm/ton) is reported in the HERS required verification listings of the CF1R. When there is no cooling system it is reported on the CF1R as a special feature.

#### 2.4.5.3 *Verified Air-Handling Unit Fan Efficacy*

The mandatory requirement in Section 150.0(m)13 is for an air-handling unit fan efficacy less than or equal to 0.58 Watts/cfm as verified by a HERS rater. Users may model a lower fan efficacy (W/cfm) and receive credit in the compliance calculation if the proposed fan efficacy value is diagnostically tested using the procedures in *Reference Residential Appendix RA3.3*.

For Single Zone Systems:

- Installers may elect to use an alternative to HERS verification of 0.58 Watts/cfm: HERS verification of a return duct design that conforms to the specification given in Table 150.0-B or C.

- The return duct design alternative is not an input to the compliance software, but must be documented on the Certificate of Installation.
- If a value less than 0.58 Watts/cfm is modeled by the software user for compliance credit, the alternative return duct design method using Table 150.0-B or C is not allowed for use in demonstrating compliance.
- Multispeed or variable-speed compressor systems must verify fan efficacy (Watt/cfm) for system operation at the maximum compressor speed and the maximum air handler fan speed.

For Zonally Controlled Systems:

- The Table 150.0-B or C return duct design alternative is not allowed for zonally controlled systems
- Multispeed, variable-speed and single-speed compressor systems must all verify fan efficacy (Watt/cfm) by operating the system at maximum compressor capacity and maximum system fan speed with all zones calling for conditioning.
- Single speed compressor systems must also verify fan efficacy in every zonal control mode.

#### *PROPOSED DESIGN*

The software shall allow the user to enter the fan efficacy. The default mandatory value is 0.58 W/cfm. Users may, however, specify a lower value and receive credit in the compliance calculation if verified and diagnostically tested using the procedures of *Reference Appendices*, *Residential Appendix RA3.3*.

If no cooling system is installed a default value of 0.58 W/cfm is assumed.

#### *STANDARD DESIGN*

The standard design shall assume a verified fan efficacy complying with the mandatory requirement for less than or equal to 0.58 Watts/cfm.

#### *VERIFICATION AND REPORTING*

For user inputs lower than the default mandatory 0.58 Watts/cfm, fan efficacy is reported in the HERS required verification listings of the CF1R.

For default mandatory 0.58 Watts/cfm, the choice of either fan efficacy or alternative return duct design according to Table 150.0-B or C is reported in the HERS required verification listings of the CF1R.

When there is no cooling system it is reported on the CF1R as a special feature.

### 2.4.5.4 *Verified Energy Efficiency Ratio (EER)*

***Proposed Design***

Software shall allow the user the option to enter an EER rating for central cooling equipment. For equipment that is rated only with an EER (room air conditioners), the user will enter the EER. The *Appliance Efficiency Regulations* require a minimum SEER and EER for central cooling equipment. Only if a value higher than a default minimum EER is used is it reported as a HERS verified measure.

***Standard Design***

The standard design for central air-conditioning equipment is 11.7 EER.

***Verification and Reporting***

EER verification is only required if higher than 11.7 EER is modeled. The EER rating is verified using rating data from AHRI Directory of Certified Product Performance at www.ahridirectory.org or another directory of certified product performance ratings approved by the Energy Commission for determining compliance. Verified EER is reported in the HERS required verification listings on the CF1R.

### 2.4.5.5 *Verified Seasonal Energy Efficiency Ratio (SEER)*

***Proposed Design***

The software allows the user to specify the SEER value.

***Standard Design***

The standard design is based on the default minimum efficiency SEER for the type of cooling equipment modeled in the proposed design, based on the applicable *Appliance Efficiency Regulations*. For central-cooling equipment, the minimum efficiency is 14 SEER and 11.7 EER.

***Verification and Reporting***

If a SEER higher than the default minimum efficiency is modeled in software, the SEER requires field verification. The higher than minimum SEER rating is verified using rating data from AHRI Directory of Certified Product Performance at www.ahridirectory.org or another directory of certified product performance ratings approved by the Commission for determining compliance. Verified SEER is reported in the HERS required verification listings on the CF1R.

### 2.4.5.6 *Verified Evaporatively-Cooled Condensers*

***Proposed Design***

Software shall allow users to specify an evaporatively-cooled condensing unit. The installation must comply with the requirements of RA4.3.2 to ensure the predicted energy savings are achieved. This credit must be combined with verified refrigerant charge testing, EER, and duct leakage testing.

#### STANDARD DESIGN

The standard design is based on a split system air conditioner meeting the requirements of Section 150.1(c) and Table 150.1-A.

#### VERIFICATION AND REPORTING

An evaporatively-cooled condensing unit, verified EER, and duct leakage testing are reported in the HERS required verification listings on the CF1R.

### 2.4.5.7 *Evaporative Cooling*

Evaporative cooling technology is best suited for dry climates where direct and/or indirect cooling of the supply air stream can occur without compromising indoor comfort. Direct evaporative coolers are the most common system type currently available but provide less comfort and deliver more moisture to the indoor space. They are assumed to be equivalent to a minimum split-system air conditioner. The evaporative cooling modeling methodology addresses two performance issues. The first performance issue is the increase in indoor relative humidity levels during periods with extended cooler operation. Since modeling of indoor air moisture levels is beyond the capability of simulation models, a simplified algorithm is used to prohibit evaporative cooler operation during load hours when operation is expected to contribute to uncomfortable indoor conditions. The algorithm disallows cooler operation when outdoor wet bulb temperatures are 70°F, or above. The second performance issue relates to evaporative cooler capacity limitations. Since evaporative coolers are 100 percent outdoor air systems, their capacity is limited by the outdoor wet bulb temperature. Each hour with calculated cooling load, the algorithm will verify that the cooling capacity is greater than the calculated cooling load.

#### PROPOSED DESIGN

Software shall allow users to specify one of three types of evaporative cooling: (1) direct evaporative cooler is the most commonly available system type, (2) indirect, or (3) indirect-direct. Product specifications and other modeling details are found in the Energy Commission appliance directory for evaporative cooling. Direct system types are assigned an efficiency of 14 SEER (or minimum appliance efficiency standard for split system cooling). The default system type is evaporative direct. For indirect or indirect-direct, select the appropriate type, from the Energy Commission appliance directory and input a 13 EER as well as the air flow and media saturation effectiveness or cooling effectiveness from the Energy Commission appliance directory.

#### STANDARD DESIGN

The standard design is based on a split-system air conditioner meeting the requirements of Section 150.1(c) and Table 150.1-A.

#### VERIFICATION AND REPORTING

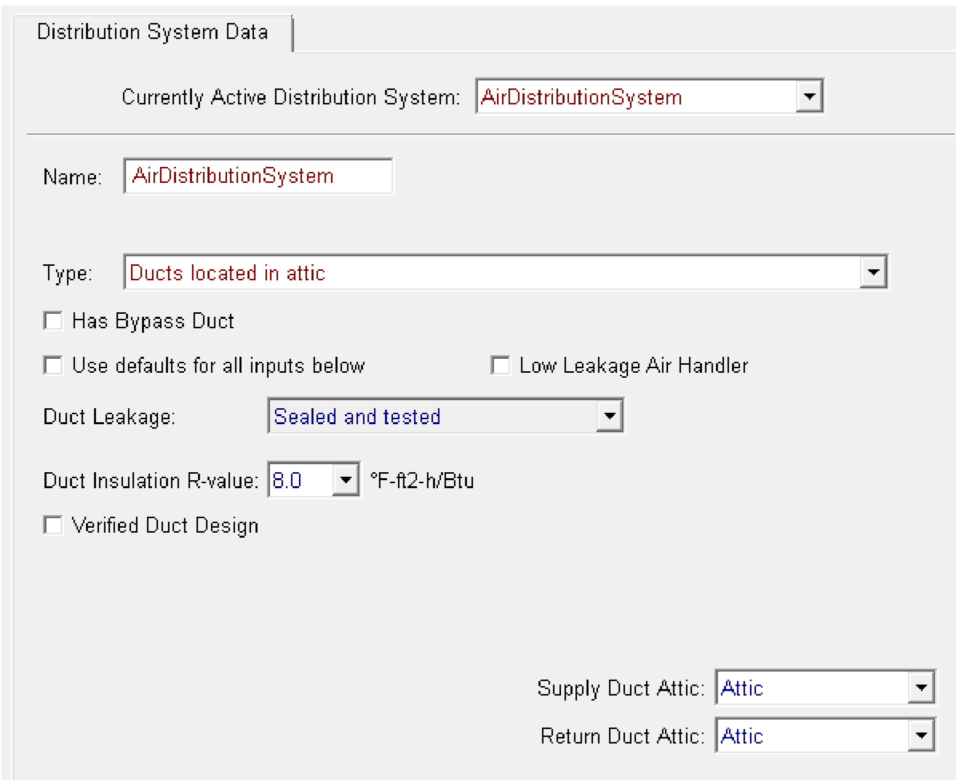
When a direct evaporative cooling system is modeled, the system type and minimum efficiency are shown in the appropriate section of the CF1R. When indirect or indirect-direct evaporative cooling is modeled, the EER verification is shown in the HERS verification section of the CF1R along with the system type, air-flow and system effectiveness.

## 2.4.6 Distribution Subsystems

If multiple HVAC distribution systems serve a building, each system and the conditioned space it serves may be modeled in detail separately or the systems may be aggregated together and modeled as one large system. If the systems are aggregated together they must be the same type and all meet the same minimum specifications.

For the purposes of duct efficiency calculations, the supply duct begins at the exit from the furnace or air handler cabinet.

Figure 5: Distribution System Data




### 2.4.6.1 *Distribution Type*

Fan-powered, ducted distribution systems that can be used with most heating or cooling systems. When ducted systems are used with furnaces, boilers, or combined hydronic/water heating systems the electricity used by the fan is calculated. R-value and duct location are specified when a ducted system is specified.

#### *PROPOSED DESIGN*

The compliance software shall allow the user to select from the basic types of HVAC distribution systems and locations listed in Table 10. For ducted systems, the default location of the HVAC ducts and the air handler are in conditioned space for multi-family buildings and in the attic for all other buildings.

The software will allow users to select default assumptions or specify any of the verified or diagnostically tested HVAC distribution system conditions in the proposed design (see Figure 5 and

Table 11), including duct leakage target, R-value, supply and return duct area, diameter and location.

**Table 10: HVAC Distribution Type and Location Descriptors**

| Name | HVAC Distribution Type and Location Description |
|---|---|
| Ducts located in attic (Ventilated and Unventilated) | Ducts located overhead in the attic space. |
| Ducts located in a crawl space | Ducts located under floor in the crawl space. |
| Ducts located in a garage | Ducts located in an unconditioned garage space. |
| Ducts located within the conditioned space (except < 12 lineal ft) | Ducts located within the conditioned floor space except for less than 12 linear feet of duct, furnace cabinet and plenums - typically an HVAC unit in the garage mounted on return box with all other ducts in conditioned space. |
| Ducts located entirely in conditioned space | HVAC unit or systems with all HVAC ducts (supply and return) located within the conditioned floor space. Location of ducts in conditioned space eliminates conduction losses but does not change losses due to leakage. Leakage from either ducts that are not tested for leakage or from sealed ducts is modeled as leakage to outside the conditioned space. |
| Distribution system without ducts (none) | Air distribution systems without ducts such as ductless split system air conditioners and heat pumps, window air conditioners, through-the-wall heat pumps, wall furnaces, floor furnaces, radiant electric panels, combined hydronic heating equipment, electric baseboards or hydronic baseboard finned-tube natural convection systems, etc. |
| Ducts located in outdoor locations | Ducts located in exposed locations outdoors. |
| Verified low leakage ducts located entirely in conditioned space | Duct systems for which air leakage to outside is equal to or less than 25 cfm when measured in accordance with Reference Residential Appendix RA3.1.4.3.8. |
| Ducts located in multiple places | Ducts with different supply and return duct locations. |

**Table 11: Summary of Verified Air-Distribution Systems**

| Measure | Description | Procedures |
|---|---|---|
| Verified Duct Sealing | Mandatory measures require that space-conditioning ducts be sealed. Field verification and diagnostic testing is required to verify that approved duct system materials are utilized and that duct leakage meets the specified criteria. | RA3.1.4.3 |
| Verified Duct Location, Reduced Surface Area and R-value | Compliance credit can be taken for improved supply duct location, reduced surface area and R-value. Field verification is required to verify that the duct system was installed according to the duct design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.[1] For buried duct measures Verified Insulation Construction Quality (QII) is required as well as duct sealing. | RA3.1.4.1, 3.1.4.1.1 |
| Low Leakage Ducts in Conditioned Space | When the Standards specify use of the procedures in Section RA3.1.4.3.8 to determine if space conditioning system ducts are located entirely in directly conditioned space, the duct system location is verified by diagnostic testing. Compliance credit can be taken for verified duct systems with low air leakage to the outside when measured in accordance with Reference Appendices, Residential Appendix Section RA3.1.4.3.8. Field Verification for ducts in conditioned space is required. Duct sealing is required. | RA3.1.4.3.8 |
| Low Leakage Air-handling Units | Compliance credit can be taken for installation of a factory sealed air-handling unit tested by the manufacturer and certified to the Commission to have met the requirements for a Low Leakage Air-Handling Unit. Field verification of the air handler’s model number is required. Duct sealing is required. | RA3.1.4.3.9 |
| Verified Return Duct Design | Verification to confirm that the return duct design conforms to the criteria given in Table 150.0-B or Table 150.0-C. as an alternative to meeting 0.58 W/cfm fan efficacy of Section 150.0(m)0. | RA3.1.4.4 |
| Verified Bypass Duct Condition | Verification to determine if system is zonally controlled, and confirm that bypass ducts condition modeled matches installation. | RA3.1.4.6 |

1. Compliance credit for increased duct insulation R-value (not buried ducts) may be taken without field verification if the R-value is the same throughout the building, and for supply ducts located in crawl spaces and garages where all supply registers are either in the floor or within 2 feet of the floor. If these conditions are met, HERS rater verification is not required.

#### *STANDARD DESIGN*

The standard heating and cooling system for central systems is modeled with non-designed air distribution ducts located as described in Table 12, with duct leakage as specified in Table 15. The standard design duct insulation is determined by Package A (assuming attic option B) as R-6 in climate zones 3 and 5-7, and R-8 in climate zones 1-2, 4 and 8-16. The standard design building is assumed to have the same number of stories as the proposed design for purposes of determining the duct efficiency.

**Table 12: Summary of Standard Design Duct Location**

| Configuration of the Proposed Design | Standard Design | |
|---|---|---|
| | **Standard Design Duct Location** | **Detailed Specifications** |
| Attic over the dwelling unit | Ducts and air handler located in the attic | Ducts sealed (mandatory requirement)<br>No credit for verified R-value, location or duct design |
| No attic but crawl space or basement | Ducts and air handler located in the crawl space or basement | |
| Multi-family buildings and buildings with no attic, crawl space or basement | Ducts and air handler located indoors | |

*This table is applicable only when the standard design system has air-distribution ducts as determined in Table 10.*

#### *VERIFICATION AND REPORTING*

Distribution type, location, R-value, and whether tested and sealed will be shown on the CF1R. If there are no ducts, this is shown as a special feature on the CF1R. Any duct location other than attic (for example: crawl space) is shown as a special feature on the CF1R. Ducts in crawl space or basement shall include a special feature note if supply registers are located within 2 feet of the floor. Measures that require HERS verification will be shown in the HERS required verification section of the CF1R.

### 2.4.6.2 *Duct Location*

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses.

#### *PROPOSED DESIGN*

If any part of the supply or return duct system is located in an unconditioned attic, that entire duct system is modeled with an attic location. If no part of the supply or return duct system is located in the attic, but the duct system is not entirely in conditioned space, it is modeled in the unconditioned zone, which contains the largest fraction of its surface area. If the supply or return duct system is located entirely in conditioned space ~~or the building type is multifamily~~, the duct system is modeled in conditioned space.

For ducted HVAC systems with some or all ducts in unconditioned space, the user specifies the R-value and surface area of supply and return ducts, and the duct location.

Duct location and areas other than the defaults shown in Table 13 may be used following the verification procedures in *Reference Residential Appendix RA3.1.4.1*.

#### STANDARD DESIGN

The standard design duct location is determined from the building conditions (see Table 12).

#### VERIFICATION AND REPORTING

Duct location is reported on the CF1R. Ducts located entirely in conditioned space ~~in other than multi-family buildings or~~ and verified low leakage ducts entirely in conditioned space are reported in the HERS required verification listing on the CF1R.

Default duct locations are as shown in Table 13. The duct surface area for crawl space and basement applies only to buildings or zones with all ducts installed in the crawl space or basement. If the duct is installed in locations other than crawl space or basement, the default duct location is "Other." For houses with two or more stories, 35 percent of the default duct area may be assumed to be in conditioned space as shown in Table 13.

The surface area of ducts located in conditioned space is ignored in calculating conduction losses.

**Table 13: Location of Default Duct Area**

| Supply Duct Location | Location of Default Duct Surface Area | |
|---|---|---|
| | One story | Two or more story |
| All in crawl space | 100% crawl space | 65% crawl space 35% conditioned space |
| All in basement | 100% basement | 65% basement 35% conditioned space |
| Other | 100% attic | 65% attic 35% conditioned space |

## 2.4.6.3 *Duct Surface Area*

The supply-side and return-side duct surface areas are treated separately in distribution efficiency calculations. The duct surface area is determined using the following methods.

## 2.4.6.4 *Default Return Duct Surface Area*

Default return duct surface area is calculated using:

Equation 9 $$A_{r,out} = K_r \times A_{floor}$$

Where $K_r$ (return duct surface area coefficient) is 0.05 for one-story buildings and 0.1 for two or more stories.

## 2.4.6.5 *Default Supply Duct Surface Area*

#### STANDARD DESIGN

The standard design and default proposed design supply duct surface area is calculated using Equation 10.

Equation 10 $$A_{s,out} = 0.27 \times A_{floor} \times K_S$$

Where $K_s$ (supply duct surface area coefficient) is 1 for one-story buildings and 0.65 for two or more stories.

### 2.4.6.6 *Supply Duct Surface Area for Less Than 12 feet of Duct In Unconditioned Space*

***PROPOSED DESIGN***

For proposed design HVAC systems with air handlers located outside the conditioned space but with less than 12 linear feet of duct located outside the conditioned space including air handler and plenum, the supply duct surface area outside the conditioned space is calculated using Equation 11. The return duct area remains the default for this case.

Equation 11 $$A_{s,out} = 0.027 \times A_{floor}$$

### 2.4.6.7 *Diagnostic Duct Surface Area*

Proposed designs may claim credit for reduced surface area using the procedures in *Reference Residential Appendix RA3.1.4.1*.

The surface area of each duct system segment shall be calculated based on its inside dimensions and length. The total supply surface area in each unconditioned location (attic, attic with radiant barrier, crawl space, basement, other) is the sum of the area of all duct segments in that location. The surface area of ducts completely inside conditioned space need not be input in the compliance software and is not included in the calculation of duct system efficiency. The area of ducts in floor cavities or vertical chases that are surrounded by conditioned space and separated from unconditioned space with draft stops are also not included.

### 2.4.6.8 *Bypass Duct*

Section 150.1(c)13 prohibits use of bypass ducts unless a bypass duct is otherwise specified on the certificate of compliance. A bypass duct may be needed for some single speed outdoor condensing unit systems. The software allows users to specify a bypass duct for the system. Selection of a bypass duct does not trigger changes in the ACM modeling defaults, but verification by a HERS rater is required utilizing the procedure in *Reference Residential Appendix Section RA3.1.4.6*.

Note: specification of a single-speed condensing unit for the system will trigger a default airflow rate value of 150 cfm/ton for the calculations which reduces the compliance margin as compared to systems that model 350 cfm/ton. Users may model airflow rates greater than 150 cfm/ton and receive credit in the calculations as described in Section 2.4.5.2.

***PROPOSED DESIGN***

Software shall allow users to specify whether a bypass duct is or is not used for a zonally controlled forced air system.

***STANDARD DESIGN***

The standard design is based on a split system air conditioner meeting the requirements of Section 150.1(c) and Table 150.1-A. The system is not a zonally controlled system.

***VERIFICATION AND REPORTING***

An HVAC system with zonal control, and whether the system is assumed to have a bypass duct or have no bypass duct, is reported in the HERS required verification listings on the CF1R.

### 2.4.6.9 *Duct System Insulation*

For the purposes of conduction calculations in both the standard and proposed designs, 85 percent of the supply and return duct surface is assumed to be duct material at its specified R-value and 15 percent is assumed to be air handler, plenum, connectors and other components at the mandatory minimum R-value.

The area weighted effective R-value is calculated by the compliance software using Equation 12 and including each segment of the duct system that has a different R-value.

*Equation 12*

$$R_{eff} = \frac{(A_1 + A_2 .... + A_N)}{\left[\frac{A_1}{R_1} + \frac{A_2}{R_2} .... + \frac{A_N}{R_N}\right]}$$

Where:

$R_{eff}$ = Area weighted effective R-value of duct system for use in calculating duct efficiency, (h-ft²-°F/Btu)

$A_N$ = Area of duct segment n, square feet

$R_n$ = R-value of duct segment n including film resistance (duct insulation rated R + 0.7) (h-ft²-°F/Btu)

***PROPOSED DESIGN***

The software user inputs the R-value of the proposed duct insulation and details. The default duct thermal resistance is based on Table 150.1-A, Attic Option B, which is R-6 in climate zones 3 and 5-7, R-8 in zones 1-2, 4, and 8-16.

Duct location and duct R-value are reported on the CF1R. Credit for systems with mixed insulation levels, non-standard supply and return duct surface areas, or ducts buried in the attic require the compliance and diagnostic procedures in *Reference Residential Appendix RA3.1.4.1*.

If a verified duct design is selected, non-standard values for the supply-duct surface area and the return-duct surface area may be input by the user. A verified duct design must be verified by a HERS rater according to the procedures in *Reference Residential Appendix RA3.1.4.1.1*. Supply and return duct R-values, location and areas are reported on the CF1R when non-standard values are specified.

#### *STANDARD DESIGN*

Package A required duct insulation R-values for the attic option B, for applicable climate zone are used in the standard design.

#### *VERIFICATION AND REPORTING*

Duct location, duct R-value, supply, and return duct areas are reported on the CF1R.

### 2.4.6.10 *Buried Attic Ducts*

Ducts partly or completely buried in blown attic insulation in dwelling units meeting the requirements for verified quality insulation installation may take credit for increased effective duct insulation.

The duct design shall identify the segments of the duct that meet the requirements for being buried, and these are separately input into the computer software. Ducts to be buried shall have a minimum of R-6.0 duct insulation prior to being buried. The user shall calculate the correct R-value based on the modeled attic insulation R-value, insulation type, and duct size for ducts installed on the ceiling, and whether the installation meets the requirements for deeply buried ducts for duct segments buried in lowered areas of ceiling.

The portion of duct runs directly on or within 3.5 inches of the ceiling gypsum board and surrounded with blown attic insulation of R-30 or greater may take credit for increased effective duct insulation as shown in Table 14. Credit is allowed for buried ducts on the ceiling only in areas where the ceiling is level and there is at least 6 inches of space between the outer jacket of the installed duct and the roof sheathing above.

Duct segments deeply buried in lowered areas of ceiling and covered by at least 3.5 inches of insulation above the top of the duct insulation jacket may claim effective insulation of R-25 for fiberglass insulation and R-31 for cellulose insulation.

#### *PROPOSED DESIGN*

The software shall allow the user to specify the effective R-value of buried ducts. This feature must be combined with duct sealing and verified quality insulation installation. The default is no buried ducts.

#### *STANDARD DESIGN*

The standard design has no buried ducts

#### *VERIFICATION AND REPORTING*

Buried duct credit is reported in the HERS required verification listing on the CF1R.

**Table 14: Buried Duct Effective R-values**

| | Nominal Round Duct Diameter | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Attic Insulation | 4'' | 5'' | 6'' | 7'' | 8'' | 10'' | 12'' | 14'' | 16'' |
| | Effective Duct Insulation R-value for Blown Fiberglass Insulation | | | | | | | | |
| R-30 | R-13 | R-13 | R-13 | R-9 | R-9 | R-4.2 | R-4.2 | R-4.2 | R-4.2 |
| R-38 | R-25 | R-25 | R-25 | R-13 | R-13 | R-9 | R-9 | R-4.2 | R-4.2 |
| R-40 | R-25 | R-25 | R-25 | R-25 | R-13 | R-13 | R-9 | R-9 | R-4.2 |
| R-43 | R-25 | R-25 | R-25 | R-25 | R-25 | R-13 | R-9 | R-9 | R-4.2 |
| R-49 | R-25 | R-25 | R-25 | R-25 | R-25 | R-25 | R-13 | R-13 | R-9 |
| R-60 | R-25 | R-25 | R-25 | R-25 | R-25 | R-25 | R-25 | R-25 | R-13 |
| | Effective Duct Insulation R-value for Blown Cellulose Insulation | | | | | | | | |
| R-30 | R-9 | R-4.2 | R-4.2 | R-4.2 | R-4.2 | R-4.2 | R-4.2 | R-4.2 | R-4.2 |
| R-38 | R-15 | R-15 | R-9 | R-9 | R-4.2 | R-4.2 | R-4.2 | R-4.2 | R-4.2 |
| R-40 | R-15 | R-15 | R-15 | R-9 | R-9 | R-4.2 | R-4.2 | R-4.2 | R-4.2 |
| R-43 | R-15 | R-15 | R-15 | R-15 | R-9 | R-4.2 | R-4.2 | R-4.2 | R-4.2 |
| R-49 | R-31 | R-31 | R-15 | R-15 | R-15 | R-9 | R-9 | R-4.2 | R-4.2 |
| R-60 | R-31 | R-31 | R-31 | R-31 | R-31 | R-15 | R-15 | R-9 | R-9 |

### 2.4.6.11 *Duct/Air Handler Leakage*

Duct/air handler average leakage factors shown in Table 15 are used in simulating the duct system. The supply duct leakage for each case is the table value times 1.17. The return leakage is the table value times 0.83.

***PROPOSED DESIGN***

For each ducted system the software user specifies one of the duct/air handler leakage cases shown in Table 15.

***STANDARD DESIGN***

For ducted systems the standard design is sealed and tested duct systems in existing dwelling units or new duct systems.

***VERIFICATION AND REPORTING***

Sealed and tested duct systems are listed in the HERS verification section of the CF1R.

### 2.4.6.12 *Low Leakage Air Handlers*

***PROPOSED DESIGN***

Credit can be taken for installation of a factory sealed air-handling unit tested by the manufacturer and certified to the Energy Commission to meet the requirements for a low leakage air-handler. Field verification of the air handler model number is required.

***STANDARD DESIGN***

The standard design has a normal air handler.

***VERIFICATION AND REPORTING***

A low leakage air handler is reported on the compliance report and field verified in accordance with the procedures specified in *Reference Appendices, Residential Appendix RA3.1.4.3.9*.

### 2.4.6.13 *Verified Low-Leakage Ducts in Conditioned Space*

***PROPOSED DESIGN***

For ducted systems the user may specify that all ducts are entirely in conditioned space and the software will model the duct system with no leakage and no conduction losses.

***STANDARD DESIGN***

The standard design has ducts in the default location.

***VERIFICATION AND REPORTING***

Systems that have all ducts entirely in conditioned space are reported on the compliance documents and this is verified by measurements showing duct leakage to outside conditions is equal to or less than 25 cfm when measured in accordance with *Reference Appendices, Residential Appendix RA3*.

**Table 15: Duct/Air Handler Leakage Factors**

| Case | Average of Supply and Return |
|---|---|
| Untested duct systems in homes built prior to June 1, 2001 | 0.86 |
| Untested duct systems in homes built after June 1, 2001 | 0.89 |
| Sealed and tested duct systems in existing dwelling units | 0.915 |
| Sealed and tested new duct systems | 0.965 |
| Verified low leakage ducts in conditioned space | 1.00 |
| Low leakage air handlers in combination with sealed and tested new duct systems | 0.97 or as measured |

## *2.4.7 Space Conditioning Fan Subsystems*

Fan systems move air for air conditioning, heating and ventilation systems. The software allows the user to define fans to be used for space conditioning, indoor air quality and ventilation cooling. Indoor air quality and ventilation cooling are discussed in Sections 2.4.9 and 2.4.10.

***PROPOSED DESIGN***

For the space conditioning fan system, the user selects the type of equipment and enters basic information to model the energy use of the equipment. For ducted central air conditioning and heating systems the fan efficacy default is the mandatory minimum verified efficacy of 0.58 W/cfm (also assumed when there is no cooling system).

##### STANDARD DESIGN

The standard design fan shall meet the minimum Section 150.1(c) and Table 150.1-A requirements.

##### VERIFICATION AND REPORTING

Minimum verified fan efficacy is a mandatory requirement for all ducted cooling systems. Fan efficacy is reported in the HERS required verification listings on the CF1R.

### 2.4.8 Space Conditioning Systems

This section describes the general procedures for heating and cooling systems in low-rise residential buildings. The system includes the cooling system, the heating system, distribution system, and mechanical fans.

If multiple systems serve a building, each system and the conditioned space it serves may be modeled in detail separately or the systems may be aggregated together and modeled as one large system. If the systems are aggregated together they must be the same type and all meet the same minimum specifications.

#### 2.4.8.1 Multiple System Types Within Dwelling

##### PROPOSED DESIGN

For proposed designs using more than one heating system type, equipment type or fuel type, and the types do not serve the same floor area, the user shall zone the building by system type.

##### STANDARD DESIGN

The standard design shall have the same zoning and heating system types as the proposed design.

##### VERIFICATION AND REPORTING

The heating system type of each zone is shown on the CF1R.

#### 2.4.8.2 Multiple Systems Serving Same Area

If a space or a zone is served by more than one heating system, compliance is demonstrated with the most time-dependent valuation (TDV) energy-consuming system serving the space or the zone. For spaces or zones that are served by electric resistance heat in addition to other heating systems, the electric resistance heat is deemed to be the most TDV energy-consuming system unless the supplemental heating meets the Exception to Section 150.1(c)6. See eligibility criteria in *Residential Compliance Manual* Section 4.2.2 for conditions under which the supplemental heat may be ignored.

For floor areas served by more than one cooling system, equipment, or fuel type, the system, equipment, and fuel type that satisfies the cooling load is modeled.

#### 2.4.8.3 *No Cooling*

***PROPOSED DESIGN***

When the proposed design has no cooling system, the proposed design is required to model the standard design cooling system defined in Section 150.1(c) and Table 150.1-A. Since the proposed design system is identical to the standard design system, there is no penalty or credit.

***STANDARD DESIGN***

The standard design system is the specified in Section 150.1(c) and Table 150.1-A for the applicable climate zone.

***VERIFICATION AND REPORTING***

No cooling is reported as a special feature on the CF1R.

#### 2.4.8.4 *Zonally Controlled Forced-Air Cooling Systems*

Zonally controlled central forced-air cooling systems must be able to deliver, in every zonal control mode, an airflow to the dwelling of ≥ 350 CFM per ton of nominal cooling capacity, and operating at an air-handling unit fan efficacy of ≤ 0.58 W/CFM. This is a HERS verified measure, complying with *Residential Appendix RA3.3*.

An exception allows multispeed or variable speed compressor systems, or single speed compressor systems to meet the mandatory airflow (cfm/ton) and fan efficacy (Watt/cfm) requirements by operating the system at maximum compressor capacity and system fan speed with all zones calling for conditioning, rather than in every zonal control mode.

***PROPOSED DESIGN***

The user selects zonally controlled as a cooling system input.

***STANDARD DESIGN***

The standard design building does not have a zonally controlled cooling system.

***VERIFICATION AND REPORTING***

Zonally controlled forced air cooling systems are required to have the system bypass duct status verified by a HERS rater according to the procedures in *Reference Residential Appendix RA3.1.4.6*, and the fan efficacy and airflow rate are required to be verified according to the procedures in *RA3.3*.

### *2.4.9 Indoor Air Quality Ventilation*

The standards require mechanical ventilation that complies with ASHRAE Standard 62.2 to provide acceptable indoor air quality for all newly constructed buildings and additions greater than 1,000 square feet. ASHRAE Standard 62.2 provides several ways to comply with the requirement for mechanical ventilation and these are described in the *Residential Compliance Manual*.

For the purposes of estimating the energy impact of this requirement in compliance software, the minimum ventilation rate is met either by a standalone indoor air quality (IAQ) fan system or a central air handler fan system that can introduce outdoor air. In many cases, this energy is substantially compliance neutral because the standard design is typically set equal to the proposed design.

The simplest IAQ fan system is an exhaust fan/bathroom fan that meets the criteria in ASHRAE Standard 62.2 for air delivery and low noise. More advanced IAQ fan systems that have a supply or both supply and exhaust fans are also possible. To calculate the energy use of standalone IAQ fan systems, the systems are assumed to be on continuously.

To calculate the energy use of central fan integrated ventilation, the systems are assumed to be on for at least 20 minutes each hour as described below. The fan flow rate and fan power ratio may be different than the values used when the system is on to provide for heating or cooling depending on the design or controls on the IAQ ventilation portion of the system.

The minimum ventilation rate for continuous ventilation of each single-family dwelling unit is given in Equation 13.

Equation 13 $$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1)$$

Where:

$Q_{fan}$ = fan flow rate in cubic feet per minute (cfm),

$A_{floor}$ = floor area in square feet ($ft^2$),

$N_{br}$ = number of bedrooms (not less than one).

The minimum ventilation rate for continuous ventilation of each multi-family dwelling unit is given in Equation 14.

Equation 14 $$Q_{fan} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

Where:

$Q_{fan}$ = fan flow rate in cubic feet per minute (cfm),

$A_{floor}$ = floor area in square feet ($ft^2$),

$N_{br}$ = number of bedrooms (not less than one).

#### *PROPOSED DESIGN*

The proposed design shall incorporate a mechanical ventilation system fan. This requirement is a mandatory measure. The compliance software allows the user to specify the IAQ ventilation type (see Table 16) and the cfm of outdoor ventilation air which must be equal to or greater than what is required by ASHRAE Standard 62.2. The default is a standalone exhaust system meeting standard 62.2.

#### STANDARD DESIGN

The mechanical ventilation system in the standard design is the same as the proposed design. The air flow rate is equal to the proposed design. The apparent heat or enthalpy recovery efficiency is the same as the proposed design. For standalone IAQ fan systems, the fan power ratio is equal to the proposed design value or 1.2 W/cfm, whichever is smaller. For central air handler fans, the fan power ratio is 0.58 W/cfm of central system airflow in ventilation mode.

#### VERIFICATION AND REPORTING

The required ventilation rate to comply with ASHRAE Standard 62.2 and the means to achieve compliance are indicated on the CF1R. The IAQ system characteristics are reported in the HERS required verification listing on the CF1R. The diagnostic testing procedures are in RA3.7.

**Table 16: IAQ Fans**

| Type | Description | Inputs |
|---|---|---|
| Standalone IAQ Fan<br>(exhaust, supply or balanced) | Dedicated fan system that provides indoor air quality ventilation to meet or exceed the requirements of ASHRAE Standard 62.2. | cfm, Watts/cfm, recovery effectiveness for balanced only |
| Central Fan Integrated (CFI)<br>(variable or fixed speed) | Automatic operation of the normal furnace fan for IAQ ventilation purposes. Ventilation type uses a special damper to induce outdoor IAQ ventilation air and distribute it through the HVAC duct system. Mixing type distributes and mixes IAQ ventilation air supplied by a separate standalone IAQ fan system. | cfm, Watts/cfm |

**Table 17: CF1R Report – Indoor Air Quality**

| IAQ System Name | IAQ System Type | Whole Building IAQ Airflow Rate (cfm) | Standalone IAQ Fan Power Ratio (W/cfm) |
|---|---|---|---|
| SFam IAQVentRpt | Default | 28.5 | 0.25 |

## 2.4.10 Ventilation Cooling System

Ventilation cooling systems operate at the dwelling-unit level using fans to bring in outside air to cool the house when this can reduce cooling loads and save cooling energy. Ventilation cooling systems such as whole house fans involve window operation and attic venting. Central fan ventilation cooling systems use the HVAC duct system to distribute ventilation air. Ventilation cooling systems operate according to the schedule and setpoints shown in Table 19. Ventilation cooling systems that exhaust air through the attic require a minimum of the larger of 1 $ft^2$ of free attic ventilation area per 750 cfm of rated capacity for relief or the manufacturer specifications (see Section 150.1(c)12 of the standards).

#### PROPOSED DESIGN

Software allows the user to specify whether a ventilation cooling system is included in conditioned and living zones (see Table 18). The user can specify the actual fan specifications or a default prescriptive whole house fan with a capacity of 1.5 CFM/ft² of conditioned floor area when there is a ventilated attic.

#### STANDARD DESIGN

The standard design building for a newly constructed building or for an addition greater than 1,000 square feet has a whole house fan in climate zones 8 through 14 and no ventilation cooling in other climate zones (see Section 150.1(c) and Table 150.1-A). The whole house fan has 1.5 CFM/ft² of conditioned floor area with 1 square foot of attic vent free area for each 750 CFM of rated whole house fan air-flow CFM.

#### VERIFICATION AND REPORTING

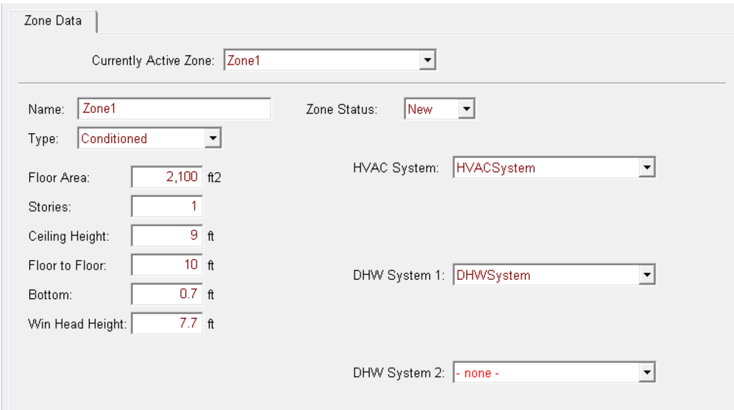
A ventilation cooling system is a special feature and the size and type is reported on the CF1R.

**Table 18: Ventilation Cooling Fans**

| Measure | Description |
|---|---|
| Whole House Fan | Traditional whole house fan mounted in the ceiling to exhaust air from the house to the attic, inducing outside air in through open windows. Whole house fans are assumed to operate between dawn and 11 PM only at 25 percent of rated cfm to reflect manual operation of fan and windows by occupant. Fans must be listed in the California Energy Commission's Whole House Fan directory. If multiple fans are used, enter the total cfm. |
| Central Fan Ventilation Cooling<br><br>Variable or fixed speed | Central fan ventilation cooling system. Ventilation type uses a special damper to induce outdoor air and distribute it through the HVAC duct system. |

## 2.5 Conditioned Zones

Figure 6: Zone Data



The software requires the user to enter the characteristics of one or more conditioned zones. Subdividing single-family dwelling units into conditioned zones for input convenience or increased accuracy is optional.

## 2.5.1 Zone Type

**PROPOSED DESIGN**

The zone is defined as conditioned, living or sleeping. Other zone types include garage, attic and crawl space.

**STANDARD DESIGN**

The standard design is conditioned.

**VERIFICATION AND REPORTING**

When the zone type is living or sleeping, this is reported as a special feature on the CF1R.

### 2.5.1.1 Heating Zonal Control Credit

With the heating zonal control credit, the sleeping and living areas are modeled separately for heating, each with its own separate thermostat schedule and internal gain assumptions. Zonal control cannot be modeled with heat pump heating. The total non-closable opening area between zones cannot exceed 40 $ft^2$. Other eligibility criteria for this measure are presented in the *Residential Compliance Manual, Chapter 4*.

**PROPOSED DESIGN**

The user selects zonal control as a building level input with separate living and sleeping zones.

**STANDARD DESIGN**

The standard design building is not zoned for living and sleeping separately.

**VERIFICATION AND REPORTING**

Zonal control is reported as a special feature on the CF1R.

## 2.5.2 Conditioned Floor Area

The total conditioned floor area (CFA) is the raised floor as well as the slab-on-grade floor area of the conditioned spaces measured from the exterior surface of exterior walls. Stairs are included in conditioned floor area as the area beneath the stairs and the tread of the stairs.

**PROPOSED DESIGN**

The compliance software requires the user to enter the total conditioned floor area of each conditioned zone.

***STANDARD DESIGN***

The standard design building has the same conditioned floor area and same conditioned zones as the proposed design.

***VERIFICATION AND REPORTING***

The conditioned floor area of each conditioned zone is reported on the CF1R.

## *2.5.3 Number of Stories*

### 2.5.3.1 *Number of Stories of the Zone*

***PROPOSED DESIGN***

The number of stories of the zone.

***STANDARD DESIGN***

The standard design is the same as the proposed design.

### 2.5.3.2 *Ceiling Height*

***PROPOSED DESIGN***

The average ceiling height of the proposed design is the conditioned volume of the building envelope. The volume (in cubic feet) is determined from the total conditioned floor area and the average ceiling height.

***STANDARD DESIGN***

The volume of the standard design building is the same as the proposed design.

***VERIFICATION AND REPORTING***

The conditioned volume of each zone is reported on the CF1R.

### 2.5.3.3 *Free Ventilation Area*

Free ventilation area is the window area adjusted to account for bug screens, window framing and dividers, and other factors.

***PROPOSED DESIGN***

Free ventilation area for the proposed design is calculated as five percent of the fenestration area (rough opening), assuming all windows are operable.

***STANDARD DESIGN***

The standard design value for free ventilation area is the same as the proposed design.

***VERIFICATION AND REPORTING***

Free ventilation is not reported on the CF1R.

### 2.5.3.4 *Ventilation Height Difference*

Ventilation height difference is not a user input.

***PROPOSED DESIGN***

The default assumption for the proposed design is 2 feet for one-story buildings or one-story dwelling units and 8 feet for two or more stories (as derived from number of stories and other zone details).

***STANDARD DESIGN***

The standard design modeling assumption for the elevation difference between the inlet and the outlet is two feet for one-story dwelling unit and eight feet for two or more stories.

### 2.5.3.5 *Zone Elevations*

The elevation of the top and bottom of each zone is required to set up the air-flow network.

***PROPOSED DESIGN***

The user enters the height of the top surface the lowest floor of the zone relative to the ground outside as the "Bottom" of the zone. The user also enters the ceiling height (the floor to floor height (ceiling height plus the thickness of the intermediate floor structure) is calculated by the software).

Underground zones are indicated with the number of feet below grade (for example -8).

***STANDARD DESIGN***

The standard design has the same vertical zone dimensions as the proposed design.

### 2.5.3.6 *Mechanical Systems*

***PROPOSED DESIGN***

The software requires the user to specify a previously defined HVAC system to provide heating and cooling for the zone and an indoor air quality (IAQ) ventilation system. The user may also specify a ventilation cooling system that applies to this and other conditioned zones.

***STANDARD DESIGN***

The software assigns standard design HVAC, IAQ ventilation, and ventilation cooling systems based on Section 150.1(c) and Table 150.1-A for the applicable climate zone.

### 2.5.3.7 *Natural Ventilation*

Natural ventilation (from windows) is available during cooling mode when needed and available as shown in Table 19. The amount of natural ventilation used by computer software for natural cooling is the lesser of the maximum potential amount available and the amount needed to drive the interior zone temperature down to the natural cooling setpoint. When natural cooling is not needed or is unavailable no natural ventilation is used.

Computer software shall assume that natural cooling is needed when the building is in "cooling mode" and when the outside temperature is below the estimated zone temperature and the estimated zone temperature is above the natural cooling setpoint temperature. Only the amount of ventilation required to reduce the zone temperature down to the natural ventilation setpoint temperature is used and the natural ventilation setpoint temperature is constrained by the compliance software to be greater than the heating setpoint temperature.

**Table 19: Hourly Thermostat Setpoints**

| | | | Standard Heating | Zonal Control Heating | |
|---|---|---|---|---|---|
| **Hour** | **Cooling** | **Venting** | **Single Zone** | **Living** | **Sleeping** |
| 1 | 78 | Off | 65 | 65 | 65 |
| 2 | 78 | Off | 65 | 65 | 65 |
| 3 | 78 | Off | 65 | 65 | 65 |
| 4 | 78 | Off | 65 | 65 | 65 |
| 5 | 78 | Off | 65 | 65 | 65 |
| 6 | 78 | 68* | 65 | 65 | 65 |
| 7 | 78 | 68 | 65 | 65 | 65 |
| 8 | 83 | 68 | 68 | 68 | 68 |
| 9 | 83 | 68 | 68 | 68 | 68 |
| 10 | 83 | 68 | 68 | 68 | 65 |
| 11 | 83 | 68 | 68 | 68 | 65 |
| 12 | 83 | 68 | 68 | 68 | 65 |
| 13 | 83 | 68 | 68 | 68 | 65 |
| 14 | 82 | 68 | 68 | 68 | 65 |
| 15 | 81 | 68 | 68 | 68 | 65 |
| 16 | 80 | 68 | 68 | 68 | 65 |
| 17 | 79 | 68 | 68 | 68 | 68 |
| 18 | 78 | 68 | 68 | 68 | 68 |
| 19 | 78 | 68 | 68 | 68 | 68 |
| 20 | 78 | 68 | 68 | 68 | 68 |
| 21 | 78 | 68 | 68 | 68 | 68 |
| 22 | 78 | 68 | 68 | 68 | 68 |
| 23 | 78 | 68 | 68 | 68 | 68 |
| 24 | 78 | Off | 65 | 65 | 65 |

**Venting starts in the hour the sun comes up.*

## 2.5.4 Conditioned Zone Assumptions

### 2.5.4.1 *Internal Thermal mass*

Internal mass objects are completely inside a zone so that they do not participate directly in heat flows to other zones or outside. They are connected to the zone radiantly and convectively and participate in the zone energy balance by passively storing and releasing heat as conditions change.

Table 20 shows the standard interior conditioned zone thermal mass objects and the calculation of the simulation inputs that represent them.

**Table 20: Conditioned Zone Thermal Mass Objects**

| Item | Description | Simulation Object |
|---|---|---|
| Interior walls | The area of one side of the walls completely inside the conditioned zone is calculated as the conditioned floor area of the zone minus ½ of the area of interior walls adjacent to other conditioned zones. The interior wall is modeled as a construction with 25 percent 2x4 wood framing and sheetrock on both sides. | Wall exposed to the zone on both sides |
| Interior floors | The area of floors completely inside the conditioned zone is calculated as the difference between the CFA of the zone and the sum of the areas of zone exterior floors and interior floors over other zones. Interior floors are modeled as a surface inside the zone with a construction of carpet, wood decking, 2x12 framing at 16 in. o.c. with miscellaneous bridging, electrical and plumbing and a sheetrock ceiling below. | Floor/ceiling surface exposed to the zone on both sides |
| Furniture and heavy contents | Contents of the conditioned zone with significant heat storage capacity and delayed thermal response, for example heavy furniture, bottled drinks and canned goods, contents of dressers and enclosed cabinets. These are represented by a 2 in. thick slab of wood twice as large as the conditioned floor area, exposed to the room on both sides. | Horizontal wood slab exposed to the zone on both sides |
| Light and thin contents | Contents of the conditioned zone that have a large surface area compared to their weight, for example, clothing on hangers, curtains, pots and pans. These are assumed to be 2 BTU per square foot of conditioned floor area | Air heat capacity ($C_{air}$) = CFA * 2 |

#### *PROPOSED DESIGN*

The proposed design has standard conditioned zone thermal mass objects that are not user editable and are not a compliance variable. If the proposed design includes specific interior thermal mass elements that are significantly different from what is included in typical wood frame production housing, such as masonry partition walls, the user may include them. See also 2.5.6.4.

#### *STANDARD DESIGN*

The standard design has standard conditioned zone thermal mass objects.

#### 2.5.4.2 *Thermostats and Schedules*

Thermostat settings are shown in Table 19. The values for cooling, venting, and standard heating apply to the standard design run and are the default for the proposed design run. See the explanation later in this section regarding the values for zonal control.

Systems with no setback required by Section 110.2(c) (gravity gas wall heaters, gravity floor heaters, gravity room heaters, non-central electric heaters, fireplaces or decorative gas appliances, wood stoves, room air conditioners, and room air-conditioner heat pumps) are assumed to have a constant heating set point of 68 degrees and the same value as in column 1 of Table 19 for the cooling set point in both the proposed design and standard design runs.

***PROPOSED DESIGN***

The proposed design assumes a mandatory setback thermostat meeting the requirements of Section 110.2(c). Systems exempt from the requirement for a setback thermostat are assumed to have no setback capabilities.

***STANDARD DESIGN***

The standard design has setback thermostat conditions based on the mandatory requirement for a setback thermostat. For equipment exempt from the setback thermostat requirement, the standard design has no setback thermostat capabilities.

***VERIFICATION AND REPORTING***

When the proposed equipment is exempt from setback thermostat requirements this is shown as a special feature on the CF1R.

#### 2.5.4.3 *Determining Heating Mode vs. Cooling Mode*

When the building is in the heating mode, the heating setpoints for each hour are set to the "heating" values in Table 19, the cooling setpoint is a constant 78°F and the ventilation setpoint is set to a constant 77°F. When the building is in the cooling mode the heating setpoint is a constant 60°F, and the cooling and venting setpoints are set to the values in Table 19.

The mode is dependent upon the outdoor temperature averaged over hours one through 24 of eight days prior to the current day through two days prior to the current day (for example: if the current day is June 21, the mode is based on the average temperature for June 13 through 20). When this running average temperature is equal to or less than 60°F, the building is in a heating mode. When the running average is greater than 60°F, the building is in a cooling mode.

### 2.5.5 *Internal Gains*

Internal gains assumptions are included in Appendix C and consistent with the CASE report on plug loads and lighting (Rubin 2016, see Appendix D).

### 2.5.6 Exterior Surfaces

The user enters exterior surfaces to define the envelope of the proposed design. The areas, construction assemblies, orientations, and tilts modeled are consistent with the actual building design and shall equal the overall roof/ceiling area with conditioned space on the inside and unconditioned space on the other side.

#### 2.5.6.1 Ceilings Below Attics

Ceilings below attics are horizontal surfaces between conditioned zones and attics. The area of the attic floor is determined by the total area of ceilings below attics defined in conditioned zones.

##### PROPOSED DESIGN

The software allows the user to define ceilings below attic, enter the area, and select a construction assembly for each.

##### STANDARD DESIGN

The standard design for new construction has the same ceiling below attic area as the proposed design. The standard design is a high performance attic with a ceiling constructed with 2x4 framed trusses, and insulated with the R-values specified in Section 150.1(c) and Table 150.1-A for the applicable climate zone assuming Option B with a 10 lb/ft$^2$ tile roof with an air space when the proposed roof slope is steep, and a lightweight roof when the proposed roof is low slope.

Climate zones 1-3 and 5-7 have R-0 and climate zones 4 and 8-16 have R-13 insulation between the roofing rafters in contact with the roof deck. Climate zones 1, 2, 4, and 8-16 have R-38 insulation on the ceiling. Climate zones 3 and 5-7 have R-30 insulation on the ceiling. Climate zones 2, 3, 5-7 have a radiant barrier. Climate zones 1, 4, and 8-16 have no radiant barrier.

##### VERIFICATION AND REPORTING

Ceiling below attic area and constructions are reported on the CF1R. Metal frame or SIP assemblies are reported as a special feature on the CF1R.

#### 2.5.6.2 Non-Attic (Cathedral) Ceiling and Roof

Non-Attic Ceilings, also known as cathedral ceilings, are surfaces with roofing on the outside and finished ceiling on the inside but without an attic space.

##### PROPOSED DESIGN

The software allows the user to define cathedral ceilings and enter the area and select a construction assembly for each. The user also enters the roof characteristics of the surface.

##### STANDARD DESIGN

The standard design has the same area as the proposed design cathedral ceiling modeled as ceiling below attic with the features of Option B from Section 150.1(c) and Table 150.1-A for the applicable climate zone.

The standard design building has an area of ceiling below attic equal to the non-attic ceiling/roof areas of the proposed design. The standard design roof and ceiling surfaces are modeled with the same construction assembly and characteristics as Package A. The aged reflectance and emittance of the standard design are determined by Section 150.1(c) and Table 150.1-A for the applicable climate zone.

##### VERIFICATION AND REPORTING

Non-attic ceiling/roof area and constructions are reported on the CF1R. Metal frame or SIP assemblies are reported as a special feature on the CF1R.

#### 2.5.6.3 *Exterior Walls*

##### PROPOSED DESIGN

The software allows the user to define walls, enter the gross area and select a construction assembly for each. The user also enters the plan orientation (front, left, back or right) or plan azimuth (value relative to the front, which is represented as zero degrees) and tilt of the wall.

The wall areas modeled are consistent with the actual building design and the total wall area is equal to the gross wall area with conditioned space on the inside and unconditioned space or exterior conditions on the other side. Underground mass walls are defined with inside and outside insulation and the number of feet below grade. Walls adjacent to unconditioned spaces with no solar gains (such as knee walls or garage walls) are entered as an interior wall with the zone on the other side specified as attic, garage, or another zone and the compliance manager treats that wall as a demising wall. An attached unconditioned space is modeled as an unconditioned zone.

##### STANDARD DESIGN

The standard design building has high performance walls modeled with the same area of framed walls as is in the proposed design separating conditioned space and exterior or unconditioned space, with a U-factor equivalent to that as specified in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone. Walls have 2”x6” wood framing with R-19 insulation between framing and R-5 continuous insulation in climate zones 1-5, 8-16 or 2”x4” wood framing with R-15 insulation between framing and R-4 continuous insulation in climate zones 6-7.

The standard design building is modeled with the same area of above grade mass walls with interior and exterior insulation equivalent to the requirements in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone.

The standard design building is modeled with the same area of below grade mass walls with interior insulation equivalent to the requirements in Section 150.1(c)1.B. and Table 150.1-A for the applicable climate zone.

The gross exterior wall area in the standard design is equal to the gross exterior wall area of the proposed design. If the proposed wall area is framed wall, the gross exterior wall area of framed walls in the standard design (excluding knee walls) contains wood framing and is equally divided between the four main compass points, north, east, south, and west.

Wall construction shall match wall construction and thermal characteristics of Section 150.1(c), Table 150.1-A. Window and door areas are subtracted from the gross wall area to determine the net wall area in each orientation. Walls adjacent to unconditioned space (garage walls) for all climate zones are wood framed, 2"x4", 16-in. on center, R-15 cavity insulation.

##### VERIFICATION AND REPORTING

Exterior wall area and construction details are reported on the CF1R. Metal frame or SIP assemblies are reported as a special feature on the CF1R.

#### 2.5.6.4 *Exterior Thermal Mass*

Constructions for standard exterior mass is supported but not implemented beyond the assumptions for typical mass.

The performance approach assumes that both the proposed design and standard design building have a minimum mass as a function of the conditioned area of slab floor and non-slab floor (see Section 2.5.4.1).

Mass such as concrete slab floors, masonry walls, double gypsum board and other special mass elements can be modeled. When the proposed design has more than the typical assumptions for mass in a building then each element of heavy mass is modeled in the proposed design, otherwise, the proposed design is modeled with the same thermal mass as the standard design.

##### PROPOSED DESIGN

The proposed design may be modeled with the default 20 percent exposed mass / 80 percent covered mass, or with actual mass areas modeled as separate covered and exposed mass surfaces. Exposed mass surfaces covered with flooring materials that is in direct contact with the slab can be considered as exposed mass. Examples of such materials are tile, stone, vinyl, linoleum, and hard wood.

##### STANDARD DESIGN

The conditioned slab floor in the standard design is assumed to be 20 percent exposed slab and 80 percent slab covered by carpet or casework. Interior mass assumptions as described in Section 2.5.4.1 are also assumed. No other mass elements are modeled in the standard design. The standard design mass is modeled with the following characteristics.

- The conditioned slab floor area (slab area) shall have a thickness of 3.5 inches; a volumetric heat capacity of 28 Btu/ft$^3$-°F; a conductivity of 0.98 Btu-in/hr-ft$^2$-°F. The exposed portion shall have a surface conductance of 1.3 Btu/h-ft$^2$-°F (no thermal resistance on the surface) and the covered portion shall have a surface conductance of 0.50 Btu/h-ft$^2$-°F, typical of a carpet and pad.

- The "exposed" portion of the conditioned non-slab floor area shall have a thickness of 2.0 inches; a volumetric heat capacity of 28 Btu/ft$^3$-°F; a conductivity of 0.98 Btu-in/hr- ft$^2$-ºF; and a surface conductance of 1.3 Btu/h- ft$^2$-°F (no added thermal resistance on the surface). These thermal mass properties apply to the "exposed" portion of non-slab floors for both the proposed design and standard design. The covered portion of non-slab floors is assumed to have no thermal mass.

##### VERIFICATION AND REPORTING

Exposed mass greater than 20 percent exposed slab on grade and any other mass modeled by the user shall be reported as a special feature on the CF1R.

#### 2.5.6.5 *Doors*

##### PROPOSED DESIGN

The compliance software shall allow users to enter doors specifying the U-factor, area, and orientation. Doors to the exterior or to unconditioned zones are modeled as part of the conditioned zone. For doors with less than 50 percent glass area, the U-factor shall come from *JA4, Table 4.5.1* (default U-factor 0.50), or from NFRC certification data for the entire door. For unrated doors, the glass area of the door, calculated as the sum of all glass surfaces plus two inches on all sides of the glass (to account for a frame), is modeled under the rules for fenestrations; the opaque area of the door is considered the total door area minus this calculated glass area. Doors with 50 percent or more glass area are modeled under the rules for fenestrations using the total area of the door.

When modeling a garage zone, large garage doors (metal roll-up or wood) are modeled with a 1.0 U-factor.

##### STANDARD DESIGN

The standard design has the same door area for each dwelling unit as the proposed design. The standard design door area is distributed equally between the four main compass points—north, east, south and west. All doors are assumed to have a U-factor of 0.50. The net opaque wall area is reduced by the door area in the standard design.

##### VERIFICATION AND REPORTING

Door area and U-factor are reported on the CF1R.

#### 2.5.6.6 *Fenestration*

Fenestration is modeled with a U-factor and solar heat gain coefficient (SHGC). Acceptable sources of these values are National Fenestration Rating Council (NFRC), default tables from Section 110.6 of the standards, and *Reference Appendix NA6*.

In limited cases for certain site-built fenestration that is field fabricated the performance factors (U-factor, SHGC) may come from *Nonresidential Reference Appendix NA6* as described in exception 4 to Section 150.1(c)3A.

There is no detailed model of chromogenic fenestration available at this time. As allowed by exception 3 to Section 150.1(c)3A, the lower rated labeled U-factor and SHGC may be used only when installed with automatic controls as noted in the exception. Chromogenic fenestration cannot be averaged with non-chromogenic fenestration.

***PROPOSED DESIGN***

The compliance software allows users to enter individual skylights and fenestration types, the U-factor, SHGC, area, orientation, and tilt.

Performance data (U-factors and SHGC) is from NFRC values or from the Energy Commission default tables from Section 110.6 of the standards. In spaces other than sunspaces, solar gains from windows or skylights use the California simulation engine (CSE) default solar gain targeting.

Skylights are a fenestration with a slope of 60 degrees or more. Skylights are modeled as part of a roof.

***STANDARD DESIGN***

If the proposed design fenestration area is less than 20 percent of the conditioned floor area, the standard design fenestration area is set equal to the proposed design fenestration area. Otherwise, the standard design fenestration area is set equal to 20 percent of the conditioned floor area. The standard design fenestration area is distributed equally between the four main compass points—north, east, south and west.

The standard design has no skylights.

The net wall area on each orientation is reduced by the fenestration area and door area on each facade. The U-factor and SHGC performance factors for the standard design are taken from Section 150.1(c) and Table 150.1-A (Package A). Where Package A has no requirement, the SHGC is set to 0.50.

***VERIFICATION AND REPORTING***

Fenestration area, U-factor, SHGC, orientation, and tilt are reported on the CF1R.

#### 2.5.6.7 *Overhangs and Sidefins*

***PROPOSED DESIGN***

Software users enter a set of basic parameters for a description of an overhang and sidefin for each individual fenestration or window area entry. The basic parameters include fenestration height, overhang/sidefin length, and overhang/sidefin height. Compliance software user entries for overhangs may also include fenestration width, overhang left extension and overhang right extension. Compliance software user entries for sidefins may also include fin left extension and fin right extension for both left and right fins. Walls at right angles to windows may be modeled as sidefins.

Figure 7: Overhang Dimensions

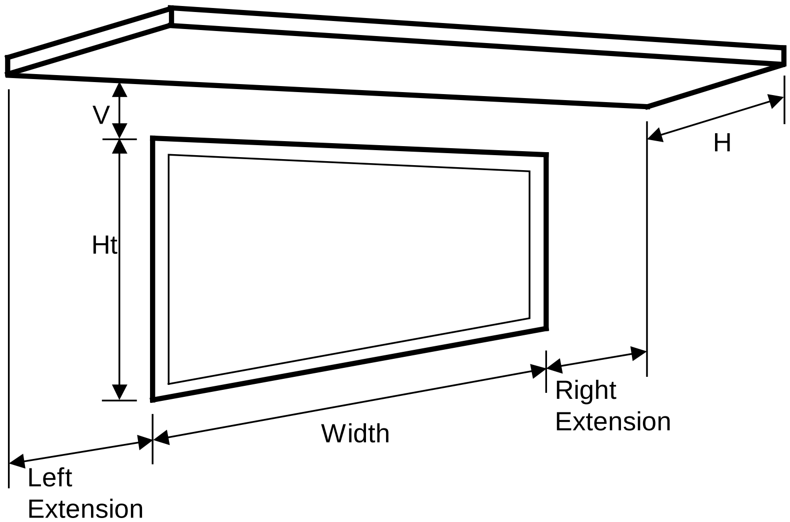
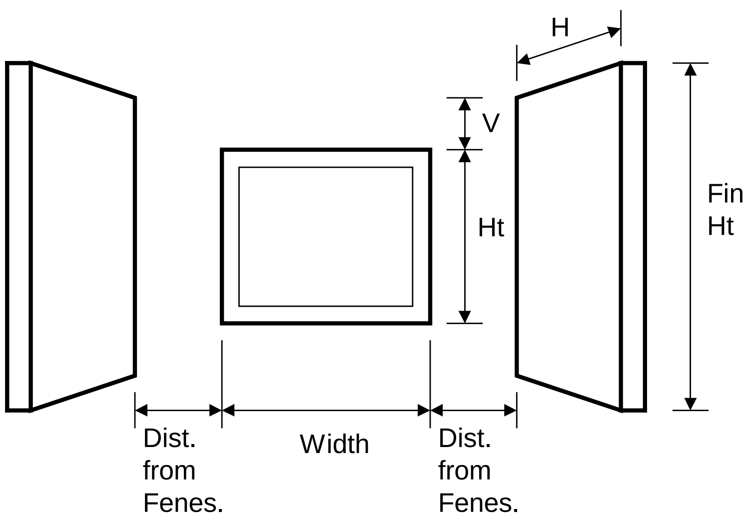



Figure 8: Sidefin Dimensions




***STANDARD DESIGN***

The standard design does not have overhangs or sidefins.

***VERIFICATION AND REPORTING***

Overhang and fin dimensions are reported on the CF1R.

### 2.5.6.8 *Interior Shading Devices*

For both the proposed and standard design, all windows are assumed to have draperies and skylights are assumed to have no interior shading. Window medium drapes are closed at night and half open in the daytime hours. Interior shading is not a compliance variable and is not user editable.

#### 2.5.6.9 *Exterior Shading*

For both the proposed and standard design, all windows are assumed to have bug screens and skylights are assumed to have no exterior shading. Exterior shading is modeled as an additional glazing system layer using the ASHWAT calculation.

***PROPOSED DESIGN***

The compliance software shall require the user to accept the default exterior shading devices, which are bug screens for windows and none for skylights. Credit for shading devices that are allowable for prescriptive compliance are not allowable in performance compliance.

***STANDARD DESIGN***

The standard design shall assume bug screens. The standard design does not have skylights.

#### 2.5.6.10 *Slab on Grade Floors*

***PROPOSED DESIGN***

The software allows users to enter areas and exterior perimeter of slabs that are heated or unheated, covered or exposed, and with or without slab-edge insulation. Perimeter is the length of wall between conditioned space and the exterior, but it does not include edges that cannot be insulated, such as between the house and the garage. The default condition for the proposed design is that 80 percent of each slab area is carpeted or covered by walls and cabinets, and 20 percent is exposed. Inputs other than the default condition require that carpet and exposed slab conditions are documented on the construction plans.

When the proposed heating distribution is radiant floor heating (heated slab), the software user will identify that the slab is heated and model the proposed slab edge insulation. The mandatory minimum requirement is R-5 insulation in climate zones 1-15 and R-10 in climate zone 16 (Section 110.8(g), Table 110.8-A).

***STANDARD DESIGN***

The standard design perimeter lengths and slab on grade areas are the same as the proposed design. Eighty percent of standard design slab area is carpeted and 20 percent is exposed. For the standard design, an unheated slab edge has no insulation with the exception of climate zone 16, which assumes R-7 to a depth of 16 inches. The standard design for a heated slab is a heated slab with the mandatory slab edge insulation of R-5 in climate zones 1-15 and R-10 in climate zone 16.

***VERIFICATION AND REPORTING***

Slab areas, perimeter lengths and inputs of other than the default condition are reported on the CF1R.

### 2.5.6.11 *Raised Floors*

**PROPOSED DESIGN**

The software allows the user to input floor areas and constructions for raised floors over a crawl space, over exterior (garage or unconditioned), over a controlled ventilation crawl space, and concrete raised floors. The proposed floor area and constructions are consistent with the actual building design.

**STANDARD DESIGN**

The standard design has the same area and type of construction as the proposed design. The thermal characteristics meet Section 150.1(c) and Table 150.1-A. For floor areas that are framed construction, the standard design floor has R-19 in 2x6 wood framing, 16" on center. For floor areas that are concrete raised floor, the standard design floor is 6 inches of normal weight concrete with R-8 continuous insulation in climate zones 1, 2, 11, 13, 14, 16, R-4 in climate zoned 12 and 15, and R-0 in climate zones 3-10.

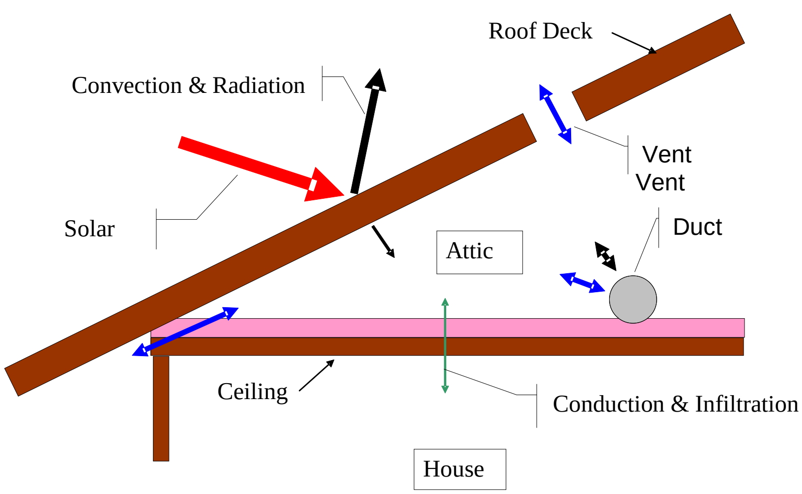
**VERIFICATION AND REPORTING**

Raised floor areas and constructions are reported on the CF1R.

## 2.6 Attics

The compliance software models attics as a separate thermal zone and includes the interaction with the air distribution ducts, infiltration exchange between the attic and the house, the solar gains on the roof deck and other factors. These interactions are illustrated in Figure 9.

Figure 9: Attic Model Components



## 2.6.1 Attic Components

### 2.6.1.1 Roof Rise

This is the ratio of rise to run (or pitch), and refers to the number of feet the roof rises vertically for every 12 feet horizontally. For roofs with multiple pitches the roof rise that makes up the largest roof area is used.

### 2.6.1.2 Vent Area

This value is the vent area as a fraction of attic floor area. This value is not a compliance variable and is assumed to be a value equal to attic floor area/300.

### 2.6.1.3 Fraction High

The fraction of the vent area that is high due to the presence of ridge, roof or gable end mounted vents. Soffit vents are considered low ventilation. Default value is zero for attics with standard ventilation. Attics with radiant barriers are required to have a vent high fraction of at least 0.3.

### 2.6.1.4 Roof Deck/Surface Construction

Typical roof construction types are concrete or clay tile, metal tile or wood shakes, or other high or low sloped roofing types.

### 2.6.1.5 Solar Reflectance

This input is a fraction that specifies the certified aged reflectance of the roofing material or 0.1 default value for uncertified materials. The installed value must be equal to or higher than the value specified here. Roof construction with a roof membrane mass of at least 25 lb/ft$^3$ or a roof area that has integrated solar collectors is assumed to meet the minimum solar reflectance.

### 2.6.1.6 Thermal Emittance

The certified aged thermal emittance (or emissivity) of the roofing material, or a default value. The installed value must be equal to or greater than the value modeled here. Default value is 0.85 if certified aged thermal emittance value is not available from the Cool Roof Rating Council (www.coolroofs.org). Roof construction with a roof membrane mass of at least 25 lb/ft$^2$ or roof area incorporated integrated solar collectors are assumed to meet the minimal thermal emittance.

**PROPOSED DESIGN**

The conditioning is either ventilated or unventilated. Each characteristic of the roof is modeled to reflect the proposed construction. Values for solar reflectance and thermal emittance shall be default or from the Cool Roof Rating Council.

Roofs with solar collectors or with thermal mass over the roof membrane with a weight of at least 25 lb/ft$^2$ may model the Package A values for solar reflectance and thermal emittance.

#### STANDARD DESIGN

The standard design depends on the variables of the climate zone and roof slope. Low-sloped roofs (with a roof rise of 2 feet in 12 or less) in climate zones 13 and 15 will have a standard design aged solar reflectance of 0.63 and a thermal emittance of 0.85.

Steep-sloped roofs in climate zones 10 through 15 will have a standard design roof with an aged solar reflectance of 0.20 and a minimum thermal emittance of 0.85.

Roofs with solar collectors or with thermal mass over the roof membrane with a weight of at least 25 lb/ft$^2$ are assumed to meet the standard design values for solar reflectance and thermal emittance.

#### VERIFICATION AND REPORTING

A reflectance of 0.20 or higher is reported as a cool roof, a value higher than the default but less than 0.20 is reported as a non-standard roof reflectance value.

### 2.6.2 Ceiling Below Attic

#### PROPOSED DESIGN

For each conditioned zone, the user enters the area and construction of each ceiling surface that is below an attic space. The compliance software shall allow a user to enter multiple ceiling constructions. Surfaces that tilt 60 degrees or more are treated as knee walls and are not included as ceilings. The sum of areas shall equal the overall ceiling area with conditioned space on the inside and unconditioned attic space on the other side.

The compliance software creates an attic zone whose floor area is equal to the sum of the areas of all of the user input ceilings below an attic in the building. The user specifies the framing and spacing, the materials of the frame path and the R-value of the insulation path for each ceiling construction.

The user inputs the proposed insulation R-value rounded to the nearest whole R-value. For simulation, all ceiling below attic insulation is assumed to have nominal properties of R-2.6 per inch, a density of 0.5 lb/ft$^3$ and a specific heat of 0.2 Btu/lb.

#### STANDARD DESIGN

The standard design shall have the same area of ceiling below attic as the proposed design. The ceiling/framing construction is based on the Package A prescriptive requirement and standard framing is assumed to be 2x4 wood trusses at 24 inches on center.

#### VERIFICATION AND REPORTING

The area, insulation R-value, and layer of each construction are reported on the CF1R.

### 2.6.3 Attic Roof Surface and Pitch

#### PROPOSED DESIGN

The roof pitch is the ratio of rise to run, (for example: 4:12 or 5:12). If the proposed design has more than one roof pitch, the pitch of the largest area is used.

The compliance software creates an attic zone roof. The roof area is calculated as the ceiling below attic area divided by the cosine of the roof slope where the roof slope is an angle in degrees from the horizontal. The roof area is then divided into four equal sections with each section sloping in one of the cardinal directions (north, east, south and west). Gable walls, dormers or other exterior vertical surfaces that enclose the attic are ignored.

If the user specifies a roof with a pitch less than 2:12, the compliance software creates an attic with a flat roof that is 30 inches above the ceiling.

#### STANDARD DESIGN

The standard design shall have the same roof pitch, roof surface area and orientations as the proposed design.

#### VERIFICATION AND REPORTING

The roof pitch is reported on the CF1R.

### 2.6.4 Attic Conditioning

Attics may be ventilated or unventilated. Insulation in a ventilated attic is usually at the ceiling level but could also be located at the roof deck. Unventilated attics usually have insulation located at the roof deck and sometimes on the ceiling (Section 150.0(a)).

In an unventilated attic, the roof system becomes part of the insulated building enclosure. Local building jurisdictions may impose additional requirements.

#### PROPOSED DESIGN

A conventional attic is modeled as ventilated. When an attic will not be vented, attic conditioning is modeled as unventilated.

#### STANDARD DESIGN

Attic ventilation is set to ventilated for the standard design.

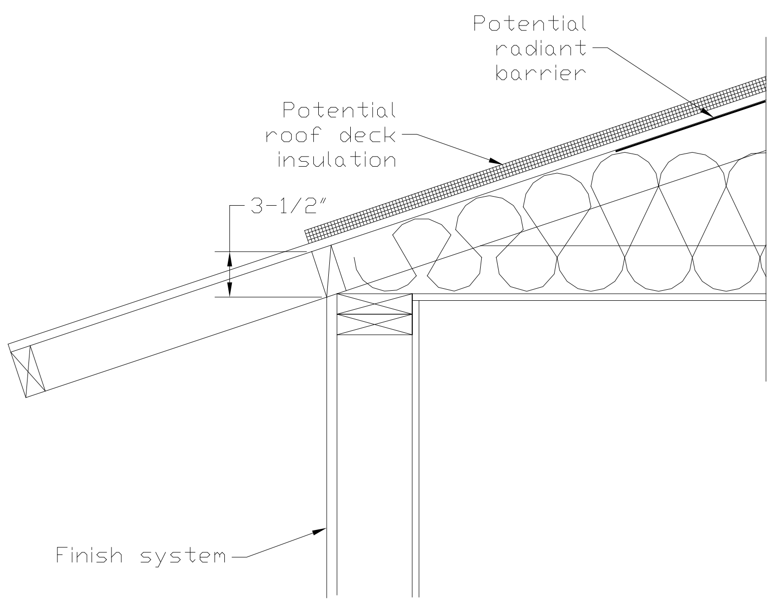
#### VERIFICATION AND REPORTING

The attic conditioning (ventilated or unventilated) is reported on the CF1R.

### 2.6.5 Attic Edge

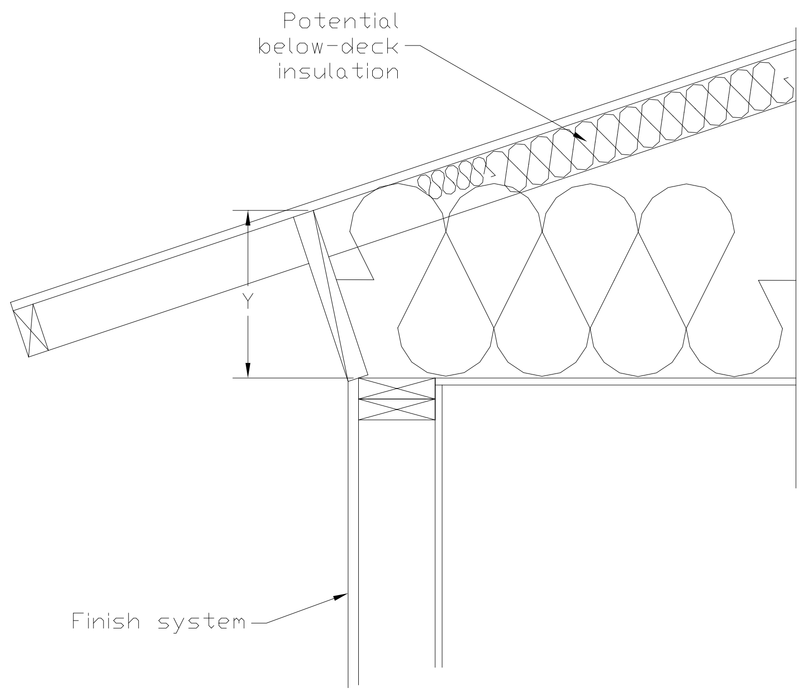
With a standard roof truss (Figure 10), the depth of the ceiling insulation is restricted to the space left between the roof deck and the wall top plate for the insulation path and the space between the bottom and top chord of the truss in the framing path. If the modeled insulation completely fills this space, there is no attic air space at the edge of the roof. Heat flow through the ceiling in this attic edge area is directly to the outside both horizontally and vertically, instead of to the attic space. Measures that depend on an attic air space, such as radiant barriers or ventilation, do not affect the heat flows in the attic edge area.

Figure 10: Section at Attic Edge with Standard Truss



A raised heel truss (Figure 11) provides additional height at the attic edge that, depending on the height Y and the ceiling insulation R, can either reduce or eliminate the attic edge area and its thermal impact.

Figure 11: Section at Attic Edge with a Raised Heel Truss




For cases where the depth of insulation (including below deck insulation depth) is greater than the available height at the attic edge, the compliance software automatically creates cathedral ceiling surfaces to represent the attic edge area and adjusts the dimensions of the attic air space using the algorithms contained in the document *2016 Residential Alternative Calculation Method Algorithms*. If above deck insulation is modeled, it is included in the attic edge cathedral ceiling constructions, but radiant barriers below the roof deck are not.

#### PROPOSED DESIGN

The compliance software shall allow the user to specify that a raised heel truss will be used (as supported by construction drawings), with the default being a standard truss as shown in Figure 10. If the user selects a raised heel truss, the compliance software will require the user to specify the vertical distance between the wall top plate and the bottom of the roof deck (Y in Figure 11).

#### STANDARD DESIGN

The standard design shall have a standard truss with the default vertical distance of 3.5 in. between wall top plate and roof deck.

#### VERIFICATION AND REPORTING

A raised heel truss is a special feature and its vertical height above the top plate will be included on the CF1R.

### 2.6.6 The Roof Deck

The roof deck is the construction at the top of the attic and includes the solar optic properties of the exterior surface, the roofing type, the framing, insulation, air gaps and other features. These are illustrated in Figure 12, which shows a detailed section through the roof deck.

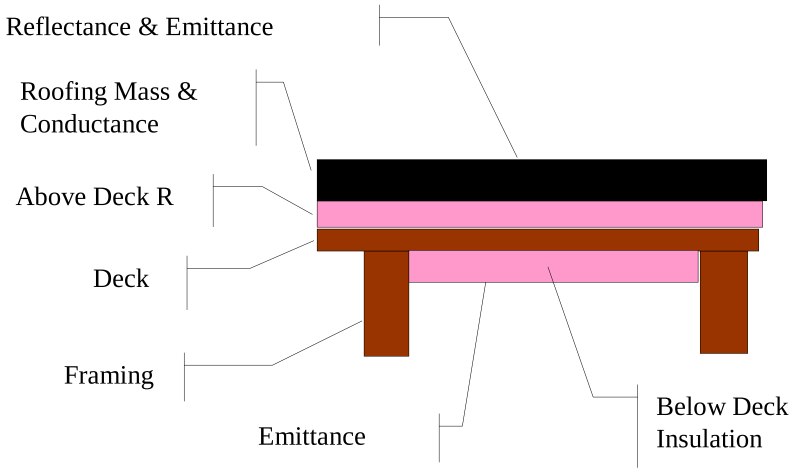



Figure 12: Components of the Attic Through Roof Deck

#### 2.6.6.1 *Radiant Barrier*

Radiant barriers are used to reduce heat flow at the bottom of the roof deck in the attic. A 0.05 emittance is modeled at the bottom surface of the roof deck if radiant barriers are used. If no radiant barrier is used, the value modeled is 0.9. If radiant barrier is installed over existing skip sheathing in a reroofing application, 0.5 is modeled.

***PROPOSED DESIGN***

The user shall specify whether or not the proposed design has a:

- Radiant Barrier
- No Radiant Barrier

***STANDARD DESIGN***

The standard design shall have a radiant barrier if required by the prescriptive standards (Section 150.1(c) and Table 150.1-A) for the applicable climate zone with Option B.

***VERIFICATION AND REPORTING***

Radiant barriers are reported as a special feature on the CF1R.

#### 2.6.6.2 *Below Deck Insulation*

Below deck insulation is insulation that will be installed below the roof deck between the roof trusses or rafters.

##### *PROPOSED DESIGN*

The compliance software shall allow the user to specify the R-value of insulation that will be installed below the roof deck between the roof trusses or rafters. The default is no below deck roof insulation.

##### *STANDARD DESIGN*

The standard design has below deck insulation.

##### *VERIFICATION AND REPORTING*

The R-value of any below deck insulation is reported as a special feature on the CF1R.

#### 2.6.6.3 *Roof Deck and Framing*

The roof deck is the structural surface that supports the roofing. The compliance software assumes a standard wood deck and this is not a compliance variable. The size, spacing and material of the roof deck framing are compliance variables.

##### *PROPOSED DESIGN*

The roof deck is wood siding/sheathing/decking. The compliance software shall default the roof deck framing to 2x4 trusses at 24 in. on center. The compliance software shall allow the user to specify alternative framing size, material and framing spacing.

##### *STANDARD DESIGN*

The standard design is 2x4 trusses at 24 in. on center.

##### *VERIFICATION AND REPORTING*

Non-standard roof deck framing or spacing is reported as a special feature on the CF1R.

#### 2.6.6.4 *Above Deck Insulation*

Above deck insulation represents the insulation value of the air gap in “concrete or clay tile” or “metal tile or wood shakes.” The R-value of any user modeled insulation layers between the roof deck and the roofing is added to the air gap value.

##### *PROPOSED DESIGN*

This input defaults to R-0.85 for “concrete or clay tile” or for “metal tile or wood shakes” to represent the benefit of the air gap, but no additional insulation. The compliance software shall allow the user to specify the R-value of additional above deck insulation in any roof deck construction assembly.

##### *STANDARD DESIGN*

The standard design accounts for the air gap based on roofing type, but has no additional above deck insulation.

##### *VERIFICATION AND REPORTING*

Above deck insulation R-value is reported as a special feature on the CF1R.

#### 2.6.6.5 *Roofing Type and Mass*

***PROPOSED DESIGN***

The choice of roofing type determines the air gap characteristics between the roofing material and the deck, and establishes whether other inputs are needed, as described below. The choices for roof type are shown below.

- **Concrete or clay tile.** These have significant thermal mass and an air gap between the deck and the tiles.
- **Metal tile or wood shakes.** These are lightweight, but have an air gap between the tiles or shakes and the deck. Note that tapered cedar shingles do not qualify and are treated as a conventional roof surface.
- **Other high slope roofing types.** This includes asphalt and composite shingles and tapered cedar shingles. These products have no air gap between the shingles and the structural roof deck.
- **Low slope membranes.** These are basically flat roofs with a slope of 2:12 or less.
- **Above deck mass**. The above deck mass depends on the roofing type. The mass is 10 lb/ft² for concrete and clay tile and 5 lb/ft² for metal tile, wood shakes or other high slope roofing types. For low slope roofs the additional thermal mass is assumed to be gravel or stone and the user chooses one of the following inputs that is less than or equal to the weight of the material being installed above the roof deck:

    - No mass
    - 5 lb/ft²
    - 10 lb/ft²
    - 15 lb/ft²
    - 25 lb/ft²

***STANDARD DESIGN***

The roof slope shall match the proposed design. The roof type for a steep slope roof is 10 lb/ft² tile. The roof type for low-slope roof is lightweight roof.

***VERIFICATION AND REPORTING***

The roof type is reported on the CF1R.

#### 2.6.6.6 *Solar Reflectance and Thermal Emittance*

***PROPOSED DESIGN***

The compliance software shall allow the user to default the solar reflectance and thermal emittance of the roofing. The solar reflectance default is 0.10 for all roof types. The thermal emittance default is 0.85.

The compliance software shall allow the user to input aged solar reflectance and thermal emittance of roofing material that are rated by the Cool Roof Rating Council. The installed value must be equal to or higher than the value specified here. Roof construction with a roof membrane mass of at least

25 lb/ft$^2$ or roof area incorporated integrated solar collectors are assumed to meet the minimal solar reflectance.

#### STANDARD DESIGN

The solar reflectance and thermal emittance of the standard design roofing are as specified in the prescriptive Standards.

#### VERIFICATION AND REPORTING

Thermal emittance and solar reflectance shall be reported on the CF1R. A reflectance of 0.20 or higher is reported as a cool roof, a value higher than the default but less than 0.20 is reported as a non-standard roof reflectance value.

## 2.7 Crawl Spaces

The crawl space type is either a (1) normal vented crawl space (has a conditioned space above with raised floor insulation), (2) insulated with reduced ventilation [as used in the Building Code], or (3) sealed and mechanically ventilated crawl space (also called a controlled ventilation crawl space or CVC).

#### PROPOSED DESIGN

The software user will model the crawl space as a separate unconditioned zone, selecting the appropriate crawl space type, with the perimeter of the crawlspace (in linear feet) and the height of the crawl space.

#### STANDARD DESIGN

The standard design has a typical vented crawlspace when a crawl space is shown. Otherwise the raised floor is assumed to be over exterior or unconditioned space.

#### VERIFICATION AND REPORTING

The crawl space zone type and characteristics shall be reported on the CF1R. A controlled ventilation crawl space shall be reported as a special feature on the CF1R.

## 2.8 Garage/Storage

An attached unconditioned space is modeled as a separate unconditioned zone. While the features of this space have no effect on compliance directly, it is modeled to accurately represent the building. The modeling of the garage will shade the walls adjacent to conditioned space and will also have a lower air temperature (than the outside) adjacent to those walls. The walls and door that separate the conditioned zone from the garage are modeled as part of the conditioned zone.

#### PROPOSED DESIGN

The software user will model the area and type for the floor, exterior walls (ignore windows), large metal roll-up or wood doors (assume a 1.0 U-factor), and roof/ceiling (typically an attic or the same as the conditioned zone).

#### STANDARD DESIGN

The standard design building has the same features as the proposed design.

#### VERIFICATION AND REPORTING

The presence of an attached garage or unconditioned space is reported as general information on the CF1R. The general characteristics of the unconditioned zone are reported on the CF1R.

## 2.9 Domestic Hot Water (DHW)

Water heating energy use is based on the number of dwelling units, number of bedrooms, fuel type, distribution system, water heater type, and conditioned floor area. Detailed calculation information is included in Appendix B.

#### PROPOSED DESIGN

The water heating system is defined by the element type (gas, electric resistance or heat pump), tank type, distribution type, multi-family central water heating distribution, efficiency (either energy factor or recovery efficiency with the standby loss), tank volume, exterior insulation R-value (only for indirect), rated input, and tank location (for electric resistance only).

Heat pump water heaters are defined by their energy factor, volume, and tank location or, for Northwest Energy Efficiency Alliance (NEEA) rated heat pumps, by selecting the specific heater type and tank location.

Tank types include:

- Small storage: ≤ 75,000 Btu/h gas/propane, ≤105,000 Btu/h oil, ≤ 12 kW electric, or ≤ 24 amps heat pump.
- Small tankless: gas or propane with an input of 200,000 Btu/h or less, oil with an input of 210,000 Btu/h or less, or electric with an input of 12 kW or less. Tankless water heater is a water heater with an input rating of ≥ 4,000 Btu/h/gallon of stored water. Rated with an energy factor.
- Large storage: > 75,000 Btu/h gas/propane, >105,000 Btu/h oil, or > 12 kW electric. Rated with thermal efficiency and standby loss.
- Large tankless: gas or propane with an input of >200,000 Btu/h, oil with an input of >210,000 Btu/h, or electric with an input of >12 kW. Tankless water heater is a water heater

with an input rating of ≥ 4,000 Btu/h per gallon of stored water. Rated with thermal efficiency.

- Mini-tank (only modeled in conjunction with an instantaneous gas water heater): a small electric storage buffering tank that may be installed downstream of an instantaneous gas water heater to mitigate delivered water temperatures (e.g. cold water sandwich effect). If the standby loss of this aftermarket tank is not listed in the Energy Commission appliance database, a standby loss of 100 W must be assumed.

- Indirect: a tank with no heating element or combustion device used in combination with a boiler or other device serving as the heating element.

- Boiler: a water boiler that supplies hot water, rated with thermal efficiency or AFUE.

Heater element type includes:

- Electric resistance,
- Gas, or
- Heat pump.

For water heating systems serving a single dwelling unit, a dwelling unit distribution type must be specified. Dwelling unit dDistribution system types for systems serving an individual dwelling units include:

- Standard (the full length of the line from the water heater to the kitchen fixtures and all piping of nominal ¾" or larger diameter insulated with 1 inch of insulation
- Pipe insulation, all lines
- Point of use
- Central parallel piping
- Recirculation with non-demand control (continuous pumping)
- Recirculation with demand control push button
- Recirculation with demand control occupancy/motion sensor
- HERS required pipe insulation, all lines
- HERS required central parallel piping
- HERS required recirculation, demand control push button
- HERS required recirculation with demand control occupancy/motion sensor
- HERS required compact distribution system

When a multi-family building has central water heating, both a dwelling unit and a central system distribution type must be specified. Dwelling unit distribution types for this case include:

- Standard (the full length of the line from the water heater to the kitchen fixtures and all piping of nominal ¾" or larger diameter insulated with 1 inch of insulation
- Pipe insulation, all lines

- HERS required pipe insulation, all lines

Distribution types for mMulti-family central hot water heating central system distribution types include:

- No loops or centralrecirculation system pump
- Recirculation with no control (continuous pumping)
- Recirculation demand control (standard design for new construction)
- Recirculation with temperature modulation control
- Recirculation with temperature modulation and monitoring
- Dual loop design for buildings with 8 or more dwelling units w/HERS verification (can be combined with any of the re-circulating conditions)
- Increased pipe insulation w/HERS verification (can be combined with any of the re-circulating conditions).

Some distribution systems have an option to increase the amount of credit received if the option for HERS verification is selected. See Appendix B for the amount of credit and *Reference Appendices, Residential Appendix Table RA2-1* for a summary of inspection requirements.

#### STANDARD DESIGN

The standard design is based on Section 150.1(c)8.

## 2.9.1 Individual dwelling units

For systems serving individual dwelling units the standard design is a single gas or propane small instantaneous water heater for each dwelling unit. The standard design is natural gas except if the proposed water heater is propane; then the standard is modeled as propane. The small instantaneous water heater is modeled with an input of 200,000 Btu/h, a tank volume of zero gallons, and an energy factor meeting federal standards. The current federal standard for an instantaneous water heater is (0.82 – (0.0019*vol)) or 0.82 energy factor for the standard system.

## 2.9.2 Multiple dwelling units

When the proposed design is a central water heating system, the standard design consists of the water heating devices, a recirculation system and solar systems as follows:

**Water heating device.** The standard design consists of the same number of water heating devices as the proposed design using the efficiencies required in the Appliance Efficiency Standards. The standard design is natural gas except if the proposed water heater is propane, then the standard is modeled as propane. Each water heating device in the proposed system is examined separately. If the proposed water heating device is gas or propane, the standard design is set to the same type and characteristics as the proposed design. If the proposed water heating device is not natural gas or propane, then the standard design is converted to a gas or propane water heater of a similar type and characteristics as the proposed design. The appropriate efficiencies and standby losses for each standard water heating device are then assigned to match the minimum requirements of the definitions and Tables F-2 and F-3 of the 2015 Appliance Efficiency Standards.

**Recirculating system.** The standard design includes a recirculation system with controls that regulate pump operation based on measurement of hot water demand and hot water return temperature, and capable of turning off the system as described in Appendix B4 Hourly Recirculation Distribution Loss for Central Water Heating Systems. When a building has more than eight dwelling units, the standard design has ~~two~~one recirculation loop~~s~~. When a building with eight or fewer dwelling units includes a recirculation system, the standard design has one recirculation loop.

**Solar.** The standard design has a solar water heating system meeting the installation criteria specified in *Reference Residential Appendix RA4* and with a minimum solar savings fraction of 0.20 in climate zones 1 through 9, or 0.35 in climate zones 10 through 16.

#### VERIFICATION AND REPORTING

All modeled features and the number of devices modeled for the water heating system are reported on the CF1R. Electric resistance and heat pump water heaters indicate the location of the water heater. NEEA-rated heat pumps are identified by the heater type, which must be verified by the building inspector.

Where distribution systems specify HERS verification, those features are listed in the HERS required verification listings on the CF1R.

### 2.9.3 Solar Thermal Water Heating Credit

When a water heating system has a solar thermal system to provide part of the water heating, the Solar Fraction (SF) is determined using an F-chart program, OG-100 or OG-300 calculation method (see www.gosolarcalifornia.org). The calculation method requires that the user specify the climate zone and conditioned floor area, in addition to published data for the solar thermal water heating system.

## 2.10 Additions/Alterations

Addition and alteration compliance is based on standards Section 150.2. Alterations must model the entire dwelling unit. When there is no addition, Section 150.2(b)2 requires at least two components of the residence must be altered. Additions may be modeled as an entirely new building (whole building), addition alone, or as “existing+addition+alteration”.

### 2.10.1 Whole Building

The entire proposed building, including all additions and/or alterations, is modeled the same as a newly constructed building. The building complies if the proposed design uses equal or less energy than the standard design. This is a difficult standard to meet as the existing building usually does not meet current standards and must be upgraded.

## 2.10.2 Addition Alone Approach

The proposed addition alone is modeled the same as a newly constructed building except that the internal gains are prorated based on the size of the dwelling. None of the exceptions included for prescriptive additions, which are implemented in the existing plus addition compliance approach (see Section 2.10.3) are given to the addition alone approach (see Standards Section 150.2(a)2.B.) The addition complies if the proposed design uses equal or less space heating, space cooling, and water heating TDV energy than the standard design.

The addition alone approach shall not be used when alterations to the existing building are proposed. Modifications to any surfaces between the existing building and the addition are part of the addition and are not considered alterations.

#### PROPOSED DESIGN

The user shall indicate that an addition alone is being modeled and enter the conditioned floor area of the addition. Any surfaces that are between the existing building and the addition are either not modeled or are treated as adiabatic surfaces. All other features of the addition shall be modeled the same as a newly constructed building.

When an existing HVAC system is extended to serve the addition, the proposed design shall assume the same efficiency for the HVAC equipment as the standard design (see Sections 2.4.1 and 2.4.5).

When a dual-glazed greenhouse or garden window is installed in an addition or alteration, the proposed design U-factor can be assumed to be 0.32.

#### STANDARD DESIGN

The addition alone is modeled the same as a newly constructed building, with the following exceptions:

A. When roofing requirements are included in Table 150.1-A, they are included in the standard design if the added conditioned floor area is greater than 300 $ft^2$.

B. When ventilation cooling (whole-house fan) is required by Table 150.1-A, it is included in the standard design when the added conditioned floor area is greater than 1,000 $ft^2$. The capacity shall be based on 1.5 $cfm/ft^2$ of conditioned floor area for the entire dwelling unit conditioned floor area.

C. When compliance with indoor air quality requirements of Section 150.0(o) apply to an addition with greater than 1,000 $ft^2$ added, the conditioned floor area of the entire dwelling unit shall be used to determine the required ventilation airflow. For additions with 1,000 $ft^2$ or less of added conditioned floor area, no indoor air quality requirements shall apply.

### 2.10.3 Existing + Addition + Alteration Approach

Standards Sections 150.2(a)2 and (b)2 contain the provisions for additions and alterations to be modeled by including the existing building in the calculations. This is called the "Existing + Addition + Alteration" (or "E+A+A") performance approach.

#### PROPOSED DESIGN

The proposed design is modeled by identifying each energy feature as part of the existing building, the addition or an alteration. The compliance software uses this information to create an E+A+A standard design using the rules in the standards that take into account whether altered components meet or exceed the threshold at which they receive a compliance credit and whether any measures are triggered by altering a given component.

For building surfaces and systems designated below, all compliance software must provide an input field with labels for the proposed design which define how the standard design requirements are established, based on the option selected by the software user:

- **Existing:** remains unchanged within the proposed design (both standard design and proposed design have the same features and characteristics).
- **Altered:** the surface or system is altered in the proposed design. No verification of existing conditions is assumed.
- **Verified Altered**: the surface or system is altered in the proposed design and the original condition is verified by a HERS rater (an optional selection).
- **New:** a new surface or system is added in the proposed design (may be in the existing building or the addition).

Features removed are not included in the proposed design.

The user chooses whether an altered feature includes "Third Party Verification" of an existing condition (see Section 150.2, Table 150.2-B):

**Altered** with no third party verification of existing conditions (the default selection). This compliance path does not require an on-site inspection of existing conditions prior to the start of construction. The attributes of the existing condition is undefined, with the standard design for altered components based on Section 150.2, Table 150.2-B and the climate zone. Energy compliance credit or penalty is a function of the difference between the value for that specific feature allowed in Table 150.2-B and the modeled/installed efficiency of the feature.

**Verified Altered** existing conditions. This compliance path requires that a HERS rater perform an on-site inspection of pre-alteration conditions prior to construction. If an altered component or system meets or exceeds the prescriptive alteration requirements, the compliance software uses the user-defined existing condition as the standard design value. Energy compliance credit is then based on the difference between the verified existing condition for that altered feature and the modeled/installed efficiency of the proposed design.

### 2.10.3.1 *Roof/Ceilings*

***STANDARD DESIGN***

The standard design roof/ceiling construction assembly is based on the proposed design assembly type as shown in Table 21**.** For additions less than or equal to 700 square feet, radiant barrier requirements follow Option C (Section 150.1(c)9B). The standard design for unaltered ceilings and roofs is the existing condition.

**Table 21: Addition Standard Design for Roofs/Ceilings**

| Proposed Design Roof/Ceiling Types | Standard Design Based on Proposed Roof/Ceiling Status | | | | |
|---|---|---|---|---|---|
| | Add ≤ 300 ft$^2$ | Add > 300 ft$^2$ and ≤ 700 ft | Addition > 700 ft$^2$ | Altered | Verified Altered |
| Roof Deck Insulation | NR | NR | CZ 4, 8-16 = R-13 below deck | NR | Existing |
| Ceilings Below Attic | R-22 / U-0.043 | R-22 / U-0.043 | CZ 1, 2, 4, 8-16 = R-38 ceiling<br>CZ 3, 5-7 = R-30 ceiling | R-19 / U-0.054 | Existing |
| Non-Attic (Cathedral) Ceilings and Roofs | R-22 / U-0.043 | R-22 / U-0.043 | Same as above | R-19 / U-0.054 | Existing |
| Radiant Barrier | CZ 2-15 REQ<br>CZ 1, 16 NR | CZ 2-15 REQ<br>CZ 1, 16 NR | CZ 2, 3, 5-7 REQ<br>CZ 1, 4, 8-16 NR | NR | Existing |
| Roofing Surface (Cool Roof) Steep Slope | NR | CZ 10-15 >0.20 Reflectance, >0.75 Emittance | CZ 10-15 >0.20 Reflectance, >0.75 Emittance | CZ 10-15 >0.20 Reflectance >0.75 Emittance | Existing |
| Roofing Surface (Cool Roof) Low Slope | NR | CZ 13, 15 > 0.63 Reflectance, >0.75 Emittance | CZ 13, 15 > 0.63 Reflectance, >0.75 Emittance | CZ 13, 15 > 0.63 Reflectance >0.75 Emittance | Existing |

### 2.10.3.2 *Exterior Walls*

***PROPOSED DESIGN***

Existing structures with R-11 insulation that are being converted to conditioned space using an E+A+A approach are allowed to show compliance using R-11 wall insulation, without having to upgrade to R-13 mandatory insulation requirements. The walls are modeled as an assembly with R-11 insulation.

***STANDARD DESIGN***

The areas, orientation and tilt of existing, new and altered net exterior wall areas (with windows and doors subtracted) are the same in the existing and addition portions of standard design as the proposed design.

If the proposed wall area is framed, the gross exterior wall area (excluding knee walls) is equally divided between the four building orientations: front, left, back and right. The gross exterior wall area of any unframed walls is also equally divided between the four orientations in the standard design.

The standard design exterior wall construction assembly is based on the proposed design assembly type as shown in Table 22. Framed walls are modeled as 16-inch on center wood framing. The standard design for unaltered walls is the existing condition. The software does not implement the prescriptive provision that allows eliminating continuous insulation for walls being extended to an addition.

**Table 22: Addition Standard Design for Exterior Walls**

| Proposed Design Exterior Wall Assembly Type | Standard Design Values Based on Proposed Wall Status | | |
|---|---|---|---|
| | Addition | Altered | Verified Altered |
| Framed Walls | CZ 1-5, 8-16 = R19+R5 in 2x6 (U0.051)<br>CZ 6-7 = R15+R4 in 2x4 (U-0.065) | R-13 in 2x4<br>R-19 in 2x6 | Existing |
| Framed Wall Adjacent to Unconditioned (Garage Wall) | R-15 in 2x4<br>R-19 in 2x6 | R-13 in 2x4<br>R-19 in 2x6 | Existing |
| Mass Interior Insulation | CZ 1-15 = R-13<br>CZ 16 = R-17 | Mandatory requirements have no insulation for mass walls | Existing |
| Mass Exterior Insulation | CZ 1-15 = R-8<br>CZ 16 = R-13 | | Existing |
| Below Grade Mass Interior Insulation | CZ 1-15 = R-13<br>CZ 16 = R-15 | | Existing |

#### 2.10.3.3 *Fenestration*

**Table 23: Addition Standard Design for Fenestration (in Walls and Roofs)**

| Proposed Design Fenestration Type | Standard Design Based on Proposed Fenestration Status | | | | |
|---|---|---|---|---|---|
| | Add ≤ 400 ft² | Add > 400 and ≤ 700 ft² | Add > 700 ft² | Altered | Verified Altered |
| Vertical Glazing: Area and Orientation | 75 ft² or 30% | 120 ft² or 25% | 175 ft² or 20% | See full description below. | Existing |
| West Facing Maximum Allowed | CZ2, 4, 6 -16=60 ft² | CZ2, 4, 6 -16=60 ft² | CZ2, 4, 6 -16=70 ft² or 5% | NR | NR |
| Vertical Glazing: U-Factor | 0.32 | 0.32 | 0.32 | 0.40 | See below |
| Vertical Glazing: SHGC | CZ2, 4, 6 -16=0.25 CZ1,3 & 5=0.50 | CZ2, 4, 6 -16=0.25 CZ1,3 & 5=0.50 | CZ2, 4, 6 -16=0.25 CZ1,3 & 5=0.50 | CZ2, 4 & 6-16=0.35 CZ1,3 & 5=0.50 | Existing |
| Skylight: Area and Orientation | No skylight area in the standard design | No skylight area in the standard design | No skylight area in the standard design | NR | Existing |
| Skylight: U-Factor | 0.32 | 0.32 | 0.32 | 0.55 | Existing |
| Skylight: SHGC | CZ2, 4, 6 -16=0.25 CZ1,3 & 5=0.50 | CZ2, 4, 6 -16=0.30 CZ1,3 & 5=0.50 | CZ2, 4, 6 -16=0.30 CZ1,3 & 5=0.50 | CZ2, 4, 6 -16=0.30 CZ1,3 & 5=0.50 | Existing |

***PROPOSED DESIGN***

Fenestration areas are modeled in the addition as new. In the existing building they may be existing, altered or new. Altered (replacement) fenestration is defined in Section 150.2(b)1.B as "*existing fenestration area in an existing wall or roof [which is] replaced with a new manufactured fenestration product…Up to the total fenestration area removed in the existing wall or roof….*" Added fenestration area in an existing wall or roof is modeled as new.

***STANDARD DESIGN***

Standard design fenestration U-factor and SHGC are based on the proposed design fenestration as shown in Table 23. Vertical glazing includes all fenestration in exterior walls such as windows, clerestories and glazed doors. Skylights include all glazed openings in roofs and ceilings.

New fenestration in an alteration is modeled with the same U-factor and SHGC as required for an addition.

West-facing limitations are combined with maximum fenestration allowed and are not an additional allowance.

The standard design is set for fenestration areas and orientations as shown in Table 23:

- ***Proposed design ≤ allowed % total fenestration area:***

In the existing building, the standard design uses the same area and orientation of each existing or altered fenestration area (in its respective existing or altered wall or roof.)

In the addition, new fenestration is divided equally between the four project compass points similar to new gross wall areas in the addition described above.

- ***Proposed design > allowed % total fenestration area:***

The standard design first calculates the allowed total fenestration area as the total existing and altered fenestration area in existing or altered walls and roofs + % of the addition conditioned floor area.

#### 2.10.3.4 *Overhangs, Sidefins and Other Exterior Shading*

***STANDARD DESIGN***

The standard design for a proposed building with overhangs, sidefins and/or other exterior shades are shown in Table 24. Treated differently than fixed overhangs and sidefins, exterior shading includes such features as exterior woven or louvered sunscreen, or roll-down awnings or slats as explained in Section 2.5.6.9.

**Table 24: Addition Standard Design for Overhangs, Sidefins and Other Exterior Shading**

| Proposed Design Shading Type | Standard Design Based on Proposed Shading Status | | |
|---|---|---|---|
| | **Addition** | **Altered** | **Verified Altered** |
| **Overhangs and Sidefins** | No overhangs or sidefins | Proposed altered condition | Same as Altered |
| **Exterior Shading** | Standard (bug screens on fenestration, none on skylights) | Proposed altered condition | Existing exterior shading |
| **Window Film** | No window film | Proposed altered condition | Existing exterior shading |

#### 2.10.3.5 *Window Film*

***PROPOSED DESIGN***

A window film must have at least a 10-year warranty and is treated as a window replacement. The values modeled are either the default values from Tables 110.6-A and 110.6-B or the NFRC Window Film Energy Performance Label.

#### 2.10.3.6 *Floors*

***STANDARD DESIGN***

Table 150.2-C requires that the standard design is based on the mandatory requirements from Section 150.0(d). The standard design for floors is shown in Table 25.

**Table 25: Addition Standard Design for Raised Floor, Slab-on-Grade and Raised Slab**

| Proposed Design Floor Type | Standard Design Based on Proposed Floor Status (Tag) | | |
|---|---|---|---|
| | **Addition** | **Altered (mandatory)** | **Verified Altered** |
| **Raised Floor Over Crawl Space or Over Exterior** | R-19 in 2x6 16" o.c. wood framing | R-19 in 2x6 16" o.c. wood framing | If proposed U ≤ 0.037, standard design = existing raised; if proposed U > 0.037, standard design = Altered |
| **Slab-on-Grade: Unheated** | CZ1-15: R-0<br>CZ16: R-7 16" vertical | Proposed design | Existing unheated slab-on-grade |
| **Slab-on-Grade: Heated** | CZ1-15: R-5 16" vertical<br>CZ 16: R-10 16" vertical | Proposed design | Existing heated slab-on-grade |
| **Raised Concrete Slab** | CZ1,2,11,13,14,16: R-8<br>CZ3-10: R-0<br>CZ12,15: R-4 | Proposed design | Existing raised concrete slab |

### 2.10.3.7 *Thermal Mass*

***STANDARD DESIGN***

The standard design for thermal mass in existing plus addition plus alteration calculations is the same as for all newly constructed buildings as explained in Section 2.5.4.1.

### 2.10.3.8 *Air Leakage and Infiltration*

***STANDARD DESIGN AIR LEAKAGE AND INFILTRATION***

The standard design for space-conditioning systems is shown in Table 26.

**Table 26: Addition Standard Design for Air Leakage and Infiltration**

| Proposed Air Leakage and Infiltration | Standard Design Air Leakage Based on Building Type | | |
|---|---|---|---|
| | **Addition** | **Altered** | **Verified Altered** |
| **Single Family Buildings** | 5 ACH50 | 5 ACH50 | Diagnostic testing of existing ACH50 value by HERS rater or 7.0 ACH50, whichever is less |
| **Multi-Family Buildings** | 7 ACH50 | 7 ACH50 | 7 ACH50 |

### 2.10.3.9 *Space Conditioning System*

***STANDARD DESIGN***

The standard design for space-conditioning systems is shown in Table 27.

When cooling ventilation is required by Sections 150.1 and 150.2, the capacity is 1.5 cfm/ft$^2$ of conditioned floor area for the entire dwelling unit.

When compliance with indoor air quality requirements of Section 150.0(o) apply to an addition with greater than 1,000 ft$^2$ added, the conditioned floor area of the entire dwelling unit is used to determine the required ventilation airflow. For additions with 1,000 ft² or less of added conditioned floor area, no indoor air quality requirements shall apply.

**Table 27: Addition Standard Design for Space Conditioning Systems**

| Proposed Design Space Conditioning System Type | Standard Design Based on Proposed Space Conditioning Status | | |
|---|---|---|---|
| | **Added** | **Altered** | **Verified Altered** |
| **Heating System:** | See Section 2.4 and 2015 Federal Appliance Stds based on fuel source and equipment type | Same as Addition. | Existing heating fuel type and equipment type/efficiency |
| **Cooling System:** | See Section 2.4 and 2015 Federal Appliance Stds based on fuel source and equipment type | Same as Addition. | Existing cooling equipment type/efficiency |
| **Refrigerant Charge** | Climate zones 2, 8-15:Yes<br>Climate zones 1, 3-7: No | Same as Addition. | Existing |
| **Whole House Fan (WHF) applies only if addition > 1,000 ft2** | Climate zones 8-14; 1.5 cfm/ft$^2$ | | Existing condition. To count as Existing the WHF must be $\geq$ 1.5 cfm/ft$^2$ and be CEC-rated |
| **Indoor Air Quality applies only if addition > 1,000 ft2** | Meet mandatory ventilation for entire dwelling | N/A | N/A |

## 2.10.3.10 *Duct System*

***STANDARD DESIGN***

**Table 28: Addition Standard Design for Duct Systems**

| Proposed Design Duct System Type | Standard Design Based on Proposed Duct System Status | |
|---|---|---|
| | **Altered** | **Verified Altered** |
| **All** | CZ 1-10, 12-13: Duct insulation R-6 and duct sealing $\leq$ 15%<br>CZ 11, 14-16: Duct insulation R-8 and duct sealing $\leq$ 15% | Existing duct R-value and duct leakage of 15%. |

Note 1: Refer to Section 150.2(b)1Diia for definition of an "Entirely New or Complete Replacement Duct System".

## 2.10.3.11 *Water Heating System*

***STANDARD DESIGN***

**Table 29: Addition Standard Design for Water Heater Systems**

| Proposed Design Water Heating System Type | Standard Design Based on Proposed Water Heating Status | | |
|---|---|---|---|
| | **Addition** | **Altered** | **Verified Altered** |
| **Single Family** | Existing fuel type, minimum efficiency, standard distribution. | Mandatory and Prescriptive requirements (excluding any solar). | Existing water heater type(s), efficiency, distribution system. |
| **Multi-family: Individual Water Heater for Each Dwelling Unit** | Package A water heating system for each dwelling unit | Mandatory and Prescriptive requirements (excluding any solar). | Existing water heater type(s), efficiency, distribution system |

| | | | |
|---|---|---|---|
| | (see Section 2.9). | | |
| **Multi-family: Central Water Heating System** | Central water heating system per Section 2.9. | Mandatory and Prescriptive requirements (excluding any solar). | Existing water heater type(s), efficiency, distribution system |

## 2.11 Documentation

The software shall be capable of displaying and printing an output of the energy use summary and a text file of the building features. These are the same features as shown on the CF1R when generated using the report manager.

See public domain software user guide or vendor software guide for detailed modeling guidelines

# 3 Energy Design Rating

The software can calculate an energy design rating (EDR) as required in the CALGreen energy provisions (Title 24, Part 11). The EDR implementation is limited to newly constructed single- and multi-family dwellings.

The EDR is an alternate way to express the energy performance of a home using a scoring system where 100 represents the energy performance of a reference design building meeting the envelope requirements of the 2006 International Energy Conservation Code (IECC). The EDR is similar to the energy rating index in the 2015 IECC and the 2014 Residential Energy Services Network (RESNET) standard. Combining high levels of energy efficiency with generating renewable energy, a score of zero or less can be achieved.

Buildings complying with the current Building Energy Efficiency Standards are more efficient than the 2006 IECC, so most newly constructed buildings will have EDR scores below 100. Buildings with renewable generation like photovoltaics (PV) can achieve a negative score. If an EDR is calculated for an older inefficient home, the score would likely be well over 100.

When the user requests an EDR calculation, additional inputs are required specifying more details about PV systems, and an EDR screen is displayed at the end of a calculation and reported on the CF1R. EDR PV inputs and calculations are not used for compliance with the Title 24, Part 6.

## 3.1 Calculation Procedure

To calculate the EDR, the user enters the proposed home with additional inputs for PV as described in Section 3.3.

The software calculates the proposed design energy use and the standard design energy use in accordance with the normal compliance rules. A third annual simulation is performed to determine the reference design energy use as described in Section 3.2.

EDR calculations are based on the total energy use with units of kTDV/ft$^2$ with an adjustment to maintain similar ratings with different fuel types. The total energy use includes the energy use associated with the space heating, space cooling and water heating used in compliance calculations plus the energy use for inside lighting, appliances, plug loads and exterior lighting.

There are adjustments made to these EDR calculations to address the issue that the 2006 IECC includes efficiency specifications that result in significantly different levels of total energy use in the reference design for gas and electric equipment and appliances. These adjustments are needed to ensure that homes using gas water heating equipment and gas appliances are not penalized in the EDR results, as compared to homes using electric water heating equipment and electric appliances. This adjustment provides EDRs for gas and electric homes that implements a fuel neutral approach in the reference design total energy use.

Four quantities are reported for the EDR ratings. The EDR of the standard design building is provided to illustrate how the 2016 standard design compares with the reference design. The EDR score of the proposed design is provided separately from the EDR value of installed PV so that the effects of efficiency and renewable energy can both be seen. The final EDR for the proposed building includes both the effects of efficiency and PV.

The EDR values are calculated for each end use and fuel type and then summed for the total EDR as follows:

Equation 15: $EDR_{standard} = EU_{standard} / EU_{adjusted} \times 100$

Equation 16: $EDR_{proposed\ without\ PV} = (EU_{proposed} - PV_{proposed}) / EU_{adjusted} \times 100$

Equation 17: $EDR_{proposed\ PV} = PV_{proposed} / EU_{adjusted} \times 100$

Equation 18: $EDR_{proposed\ final} = EU_{proposed} / EU_{adjusted} \times 100$

Where:

$EU_{standard}$ = Standard Design Energy Use (kTDV/ft$^2$)

$EU_{reference}$ = Reference Design Energy Use (kTDV/ft$^2$)

$EU_{proposed}$ = Proposed Design Energy Use (kTDV/ft$^2$)

$PV_{proposed}$ = Proposed PV Energy Generation (kTDV/ft$^2$)

$EU_{adjusted} = EU_{reference}$ / Adjustment (kTDV/ft$^2$)

Adjustment = 1 for all end uses that are electric; or

Adjustment = Ratio from Table 30 for all end uses that are gas.

**Table 30: EDR Adjustments by End Use for Gas Fuel Type**

| Climate Zone | Single Family Space Heating | Single Family Water Heating | Single Family Appliances | Multi Family Space Heating | Multi Family Water Heating | Multi Family Appliances |
|---|---|---|---|---|---|---|
| 01 | 0.84 | 0.38 | 0.57 | 0.83 | 0.42 | 0.56 |
| 02 | 0.91 | 0.42 | 0.57 | 0.90 | 0.46 | 0.56 |
| 03 | 1.00 | 0.40 | 0.57 | 1.02 | 0.44 | 0.56 |
| 04 | 0.92 | 0.41 | 0.57 | 0.91 | 0.45 | 0.56 |
| 05 | 0.90 | 0.40 | 0.57 | 0.91 | 0.43 | 0.56 |
| 06 | 1.00 | 0.45 | 0.58 | 1.00 | 0.50 | 0.57 |
| 07 | 1.07 | 0.44 | 0.58 | 1.22 | 0.48 | 0.56 |
| 08 | 1.05 | 0.47 | 0.59 | 1.07 | 0.51 | 0.57 |
| 09 | 1.02 | 0.47 | 0.59 | 1.02 | 0.52 | 0.57 |
| 10 | 0.97 | 0.49 | 0.58 | 0.96 | 0.52 | 0.57 |
| 11 | 0.89 | 0.44 | 0.57 | 0.88 | 0.48 | 0.56 |
| 12 | 0.93 | 0.43 | 0.57 | 0.92 | 0.46 | 0.56 |
| 13 | 0.91 | 0.44 | 0.57 | 0.89 | 0.46 | 0.56 |
| 14 | 0.87 | 0.48 | 0.58 | 0.85 | 0.52 | 0.57 |
| 15 | 0.97 | 0.53 | 0.58 | 0.95 | 0.59 | 0.57 |
| 16 | 0.68 | 0.35 | 0.57 | 0.65 | 0.45 | 0.56 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ~~01~~ | ~~1.05~~ | ~~0.48~~ | ~~0.59~~ | ~~1.15~~ | ~~0.51~~ | ~~0.57~~ |
| ~~02~~ | ~~1.05~~ | ~~0.50~~ | ~~0.59~~ | ~~1.10~~ | ~~0.53~~ | ~~0.57~~ |
| ~~03~~ | ~~1.18~~ | ~~0.49~~ | ~~0.59~~ | ~~1.26~~ | ~~0.53~~ | ~~0.57~~ |
| ~~04~~ | ~~1.06~~ | ~~0.51~~ | ~~0.59~~ | ~~1.11~~ | ~~0.54~~ | ~~0.57~~ |
| ~~05~~ | ~~1.07~~ | ~~0.49~~ | ~~0.60~~ | ~~1.15~~ | ~~0.53~~ | ~~0.58~~ |
| ~~06~~ | ~~1.20~~ | ~~0.54~~ | ~~0.60~~ | ~~1.32~~ | ~~0.58~~ | ~~0.58~~ |
| ~~07~~ | ~~1.23~~ | ~~0.52~~ | ~~0.59~~ | ~~1.56~~ | ~~0.54~~ | ~~0.57~~ |
| ~~08~~ | ~~1.23~~ | ~~0.55~~ | ~~0.60~~ | ~~1.39~~ | ~~0.58~~ | ~~0.58~~ |
| ~~09~~ | ~~1.20~~ | ~~0.54~~ | ~~0.60~~ | ~~1.32~~ | ~~0.60~~ | ~~0.58~~ |
| ~~10~~ | ~~1.15~~ | ~~0.56~~ | ~~0.60~~ | ~~1.26~~ | ~~0.60~~ | ~~0.58~~ |
| ~~11~~ | ~~1.02~~ | ~~0.52~~ | ~~0.59~~ | ~~1.07~~ | ~~0.57~~ | ~~0.57~~ |
| ~~12~~ | ~~1.07~~ | ~~0.51~~ | ~~0.59~~ | ~~1.12~~ | ~~0.55~~ | ~~0.57~~ |
| ~~13~~ | ~~1.05~~ | ~~0.53~~ | ~~0.59~~ | ~~1.09~~ | ~~0.57~~ | ~~0.57~~ |
| ~~14~~ | ~~1.03~~ | ~~0.56~~ | ~~0.60~~ | ~~1.07~~ | ~~0.60~~ | ~~0.58~~ |
| ~~15~~ | ~~1.18~~ | ~~0.64~~ | ~~0.60~~ | ~~1.37~~ | ~~0.69~~ | ~~0.58~~ |
| ~~16~~ | ~~0.98~~ | ~~0.52~~ | ~~0.60~~ | ~~1.02~~ | ~~0.55~~ | ~~0.58~~ |

The ratios were calculated by using a prototype analysis once with gas fuel type for space heating, water heating and appliances, and once with electric fuel types. The ratio is the end use energy for the EDR reference building run with gas (kTDV/ft$^2$) divided by the run with electric (kTDV/ft$^2$).

## 3.2 Reference Design

The reference design is calculated using the same inputs, assumptions and algorithms as the standard design except for the following requirements:

- Air handler power. The air handler power is 0.8 W/cfm.
- Air infiltration rate. The air infiltration rate is 7.2 ACH50.
- Cooling airflow. The air handler airflow is 300 CFM/ton.
- Duct R-value. The duct R-value is R-8.
- Duct leakage rate. The duct leakage rate is modeled as an HVAC distribution efficiency of 80 percent.
- Insulation Installation Quality (QII): QII is modeled as “improved”.
- Wall construction. Climate zones 2-15 have 2x4 R-13 walls. Climate zones 1 and 16 have 2x6 R-19 walls.
- Roof/ceiling construction. Climate zones 2-15 have R-30 ceiling. Climate zones 1 and 16 have R-38 ceiling. No climate zones include radiant barriers or cool roofs.
- Floor construction. Climate zones 2-15 have 2x10 R-19 floors. Climate zones 1 and 16 have 2x10 R-30 floors.
- Slab edge insulation. Climate zones 1 and 16 include R-10 insulation 24 inches deep.
- Window U-factors. Climate zones 2-15 have 0.65 U-factor. Climate zones 1 and 16 have 0.35 U-factor.
- Window SHGC. All windows have 0.4 SHGC.
- Window area. When the window area is below 18 percent of the floor area, the reference design has the same area as the proposed design. Above 18 percent, the reference design has 18 percent.
- HVAC equipment efficiencies. HVAC equipment meets NAECA requirements in effect in 2006 such as 78 percent AFUE for gas central furnace, 13 SEER for central AC.
- Water heating efficiency. Water heating modeled as a 40 gallon storage water with a 0.594 EF if gas or a 0.9172 EF if electric.
- Appliance and plug load energy use and internal gains. Energy use and internal gains for appliance and miscellaneous plug loads are modeled as specified the ANSI/RESNET/ICC 301-2014 Standard.

## 3.3 Energy Design Rating PV System Credit

The PV credit reflected in the Energy Design Rating for both single- and multi-family buildings uses calculations found in PVWatts technical documentation (see Appendix D). The PV system size and module type are required inputs. Users may select simplified or detailed inputs. With detailed inputs, the inverter efficiency must be included. The user can select either detailed installation information for the orientation and angle/tilt of the array or select California flexible installation.

Installation and verification must meet the requirements of *Residential Appendix RA4.6.1*.

# APPENDIX A – SPECIAL FEATURES

| *Measure* | *CF1R Documentation Requirement* |
|---|---|
| **GENERAL** | |
| Controlled-Ventilation Crawlspace (CVC) | Not yet implemented |
| Photovoltaic (PV) system credit | Special feature |
| Zonal heating controls | Special feature |
| **ENVELOPE** | |
| Above deck insulation | Special feature |
| Advanced wall framing | Special feature |
| Below deck insulation | Special feature |
| Building air leakage / reduced infiltration | HERS verification of reported ACH50 value |
| Cool roof | Special feature |
| Dynamic glazing | Not yet implemented |
| Exterior shading device | Not yet implemented |
| Exposed slab area greater than 20% | Special feature |
| High quality insulation installation (QII) | HERS verification |
| Metal-framed assembly | Special feature |
| Non-default spray foam insulation R-values | HERS verification |
| Overhangs and sidefins | Special feature |
| Raised heel truss (height above top plate) | Special feature |
| Spray foam insulation, closed cell >R-5.8/inch | HERS verification |
| Spray foam insulation, open cell >R-3.6/inch | HERS verification |
| Structurally insulated panel (SIP) assembly | Special feature |
| **MECHANICAL** | |
| Air handling unit fan efficacy | HERS verification |
| Airflow or System Airflow (cfm) | HERS verification |
| Central fan ventilation cooling, fixed speed | Special feature |

| | |
|---|---|
| Central fan ventilation cooling, variable speed | Special feature |
| Energy Efficiency Ratio (EER) | HERS verification |
| Evaporatively-cooled condenser | HERS verification |
| Evaporative cooling, indirect, indirect/direct | Not yet implemented. |
| Fan efficacy | HERS verification |
| High Seasonal Energy Efficiency Ratio (SEER) | HERS verification |
| Indoor air quality ventilation | HERS verification |
| No cooling | Special feature |
| Refrigerant charge or fault indicator display (FID) | HERS verification |
| Ventilation cooling system, central fan | Special feature |
| Whole-building mechanical ventilation airflow | HERS verification |
| Whole house fan | Special feature |
| **DUCTS** | |
| Buried duct | HERS verification |
| Bypass duct conditions in a zonal system | HERS verification |
| Deeply buried duct | HERS verification |
| Duct leakage testing | HERS verification |
| Ducts in conditioned space | HERS verification |
| Ducts in crawl space | Special feature |
| High R-value ducts | Special feature |
| Low leakage air handler | HERS verification |
| Low leakage ducts in conditioned space | HERS verification |
| Non-standard duct leakage target | HERS verification |
| Non-standard duct location (any location other than attic) | Special feature |
| Return duct design | HERS verification |
| Supply duct location, surface area, R-value | HERS verification |
| **WATER HEATING** | |
| Compact distribution system (HERS verified) | HERS verification |

| | |
|---|---|
| ~~Multi-family: Central water heating recirculating dual loop design~~ | ~~Special feature~~ |
| ~~Multi-family: Central water heating recirculating dual loop design (HERS verified)~~ | ~~HERS verification~~ |
| Multi-family: Recirculating demand control | Special feature |
| Multi-family: No loops or recirc pump | Special feature |
| Multi-family: Recirculating with no control (continuous pumping) | Special feature |
| Multi-family: Recirculating with temperature modulation | Special feature |
| Multi-family: Recirculating with temperature modulation and monitoring | Special feature |
| Multi-family: Solar water heating credit | Special feature and additional documentation |
| Central parallel piping | Special feature |
| Central parallel piping (HERS verified) | HERS verification |
| Pipe insulation, all lines | Special feature |
| Pipe insulation, all lines (HERS verified) | HERS verification |
| Point of use | Special feature |
| Recirculation with demand control, occupancy/ motion sensor | Special feature |
| Recirculation with demand control, occupancy/ motion sensor (HERS verified) | HERS verification |
| Recirculation with demand control, push button | Special feature |
| Recirculation with demand control, push button (HERS verified) | HERS verification |
| Recirculation with non-demand control (continuous pumping) | Special feature |
| Solar water heating credit, single family building | Special feature and additional documentation |
| **ADDITIONS/ALTERATIONS** | |
| Verified existing conditions | HERS verification |

# APPENDIX B – WATER HEATING CALCULATION METHOD

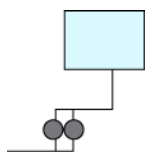
## B1. Purpose and Scope

This appendix documents the methods and assumptions used for calculating the hourly energy use for residential water heating systems for both the proposed design and the standard design. The hourly fuel and electricity energy use for water heating will be combined with hourly space heating and cooling energy use to come up with the hourly total fuel and electricity energy use to be factored by the hourly TDV energy multiplier. The calculation procedure applies to low-rise single family, low-rise multi-family, and high-rise residential.

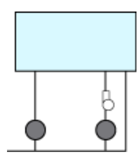
When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

The following diagrams illustrate the domestic hot water (DHW) system types recognized by the compliance software.

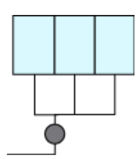
1 One distribution system with one or multiple water heaters serving a single dwelling unit. The system might include recirculation loops within the dwelling unit.



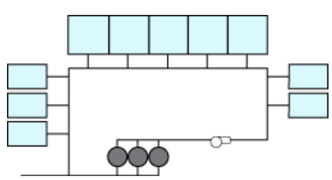
2 Two water heaters with independent distribution systems serving a single dwelling unit. One or more of the distribution systems may include a recirculation loop within the dwelling unit.



3 One distribution system without recirculation loop and with one or multiple water heaters serving multiple dwelling units.



4 One distribution system with one or multiple recirculation loops and with one or multiple water heaters serving multiple dwelling units.



## B2. Water Heating Systems

Water heating distribution systems may serve more than one dwelling unit and may have more than one water heating appliance. The energy used by a water heating system is calculated as the sum of the energy used by each individual water heater in the system. Energy used for the whole building is calculated as the sum of the energy used by each of the water heating systems. To delineate different water heating elements several indices are used.

i Used to describe an individual dwelling unit. For instance, $CFA_i$ would be the conditioned floor area of the $i^{th}$ dwelling unit. Nunit is the total number of dwelling units.

j Used to refer to the number of water heaters in a system. NWH is the total number of water heaters.

k Used to refer to a water heating system or distribution system. A building can have more than one system and each system can have more than one water heater.

l Used to refer to the $l^{th}$ unfired- or indirectly-fired storage tank in the $k^{th}$ system. $NL_k$ is the total number of unfired- or indirectly-fired storage tanks in the $k^{th}$ system. Temperature buffering tanks with electric heating (e.g., minitanks) shall not to be treated as unfired or indirectly-fired storage tanks.

| Symbol | Definition | Notes |
|---|---|---|
| CFA | Conditioned floor area, $ft^2$ | |
| NFloor | Number of floors in building | |
| Nunit | Number of units in building | |
| NK | Number of water heating systems | |
| $NWH_k$ | Number of water heaters in $k^{th}$ system | |
| $NLoop_k$ | Number of recirculation loops in kth system (multi-unit dwellings only) | |
| $CFA_i$ | Conditioned floor area of ith dwelling unit | |
| $CFAU_k$ | Average unit conditioned floor area served by kth system, $ft^2$ | |

## B3. Hot Water Consumption

The schedule of hot water use that drives energy calculations is derived from measured data as described in (Kruis, 2016). That analysis produced 365 day sets of fixture water draw events for dwelling units having a range of number of bedrooms. The draws are defined in the files DHWDUSF.TXT (for single family) and DHWDUMF.TXT (for multifamily) that ship with CBECC-Res. Each draw is characterized by a start time, duration, flow rate, and end use. The flow rates given are the total flow at the point of use (fixture or appliance). This detailed representation allows derivation of draw patterns at 1 minute intervals as is required for realistic simulation of heat pump water heaters.

The fixture flow events are converted to water heater (hot water) draws by 1) accounting for mixing at the point of use and 2) accounting for waste, distribution heat losses, and solar savings --

$$VS_k = VF_k \times f_{hot} \times f_{wh} \qquad \text{Equation 1}$$

*Where*

*$VS_k$* = Hot water draw at the k[th] water heating system's delivery point (gal)

*$VF_k$* = Mixed water draw at an appliance or fixture (gal) served by the k[th] water heating system, as specified by input schedule

*$f_{hot}$, $f_{wh}$* = End-use-specific factors from the following –

| End use | $f_{hot}$ | $f_{wh}$ |
|---|---|---|
| Shower | $\frac{105 - T_{inlet}}{T_s - T_{inlet}}$ | $WF_k \times \max\left(0, DLM_k - SSF_k\right)$ |
| Bath | | |
| Faucet | 0.50 | $1 - SSF_k$ |
| Clothes washer | 0.22 | |
| Dish washer | 1 | |

$T_s$ = Hot water supply temperature (ºF). Assumed to be 115 °F.

$T_{inlet}$ = Cold water inlet temperature (ºF) as defined in Section B3.3.

$WF_k$ = Hot water waste factor.

- $WF_k$ = 0.9 for within-dwelling-unit pumped circulation systems (see Table B-1).
- $WF_k$ = 1.0 otherwise

$DLM_k$ = Distribution loss multiplier (unitless), see *Equation 5*.

$SSF_k$ = Hourly solar savings fraction (unitless) for the k[th] water heating system, which is the fraction of the total water heating load that is provided by solar hot water heating. The annual average value for SSF is provided from the results generated by the CEC approved calculations approaches for the OG-100 and OG-300 test procedure. A CEC approved method shall be used to convert the annual average value for SSF to hourly $SSF_k$ values for use in compliance calculations.

The individual water heater draws are combined to derive the overall demand for hot water. ~~Note that this draw-based approach does not support multiple water heating systems within a dwelling unit, since that would require assignment of each draw to a specific system.~~

For each hour of the simulation, all water heater draws are allocated to 1 minute bins using each draw's starting time and duration. This yields a set of 60 $VS_{k,t}$ values for each hour that are used as input to the detailed heat pump water heating model (HPWH) as discussed in section B7.7.. For hourly efficiency-based models used for some water heater types, the minute-by-minute values are summed to give an hourly hot water requirement --

$$GPH_k = \sum_{t=1}^{60} VS_{k,t} \qquad \text{Equation 2}$$

In cases where multiple dwelling units are served by a common water heating system, the dwelling unit draws are summed.

In cases where there are multiple water heating systems within a dwelling unit, the draws are divided equally among the systems. For minute-by-minute draws (for HPWH models), this allocation is accomplished by assigning draws to systems in rotation within each end use. This ensures that some peak draw events get assigned to each system. Since heat pump water heater performance is non-linear with load (due to activation of resistance backup), allocation of entire events to systems is essential. Note that realistic assignment of draws to specific systems requires information about the plumbing layout of the residence and capturing that is deemed to impose an unacceptable user input burden.

## B4. Hourly Adjusted Recovery Load

The hourly adjusted recovery load for the kth water heating system is calculated as follows:

$$HARL_k = HSEU_k + HRDL_k + \sum_{1}^{NL_k} HJL_l \qquad \text{Equation 3}$$

*where*

$HSEU_k$ = Hourly standard end use at all use points (Btu), see *Equation 4.*

$HRDL_k$ = Hourly recirculation distribution loss (Btu), see *Equation 11*. $HDRL_k$ is non-zero only for multi-family central water heating systems.

$NL_k$ = Number of unfired or indirectly-fired storage tanks in the $k^{th}$ system

$HJL_l$ = Tank surface losses of the $l^{th}$ unfired tank of the $k^{th}$ system (Btu), see *Equation 40.*

*Equation 4* calculates the hourly standard end use (HSEU). The heat content of the water delivered at the fixture is the draw volume in gallons (GPH) times the temperature rise ΔT (difference between the cold water inlet temperature and the hot water supply temperature) times the heat required to elevate a gallon of water 1 ºF (the 8.345 constant).

$$HSEU_k = 8.345 \times GPH_k \times \left(T_s - T_{inlet}\right) \qquad \text{Equation 4}$$

*where*

$HSEU_k$ = Hourly standard end use (Btu).

$GPH_k$ = Hourly hot water consumption (gallons) from *Equation 2*

*Equation 5* calculates the distribution loss multiplier (DLM) which combines two terms: the standard distribution loss multiplier (SDLM), which depends on the floor area of the dwelling unit and the distribution system multiplier (DSM) listed in Table B-1.

$$DLM_k = 1 + (SDLM_k - 1) \times DSM_k \qquad \text{Equation 5}$$

*where*

$DLM_k$ = Distribution loss multiplier (unitless)

$SDLM_k$ = Standard distribution loss multiplier (unitless), see *Equation 6*.

$DSM_k$ = Distribution system multiplier (unitless), see Section 3.2.

Several relationships below depend on $CFA_k$, the floor area served

*Equation 6* calculates the standard distribution loss multiplier (SDLM) based on dwelling unit floor area. Note that in *Equation 6*, that floor area is capped at 2500 ft$^2$ -- without that limit, *Equation 6* produces unrealistic $SDLM_k$ values for large floor areas.

$$\begin{aligned} \mathrm{SDLM_k} &= 1.004 \\ &+ 0.000202 \times \min(2500, \mathrm{CFAU_k}) \\ &- 0.0000000231 \times \min(2500, \mathrm{CFAU_k}) \times \min(2500, \mathrm{CFAU_k}) \end{aligned} \qquad \text{Equation 6}$$

*where*

$SDLM_k$= Standard distribution loss multiplier (unitless).

$CFAU_k$= Dwelling unit conditioned floor area (ft2) served by the kth system, calculated using methods specified in *Equation 7*.

Single dwelling unit,

$$CFAU_k = CFA / NK$$

For multiple dwelling units served by a central system:

$$CFAU_k = \frac{\sum_{\text{all units served by system k}} CFA_i}{Nunit_k} \qquad \text{Equation 7, Method WH-CFAU}$$

Alternatively, if the system-to-unit relationships not known:

$$CFAU_k = \frac{\sum_{\text{all units served by any central system}} CFA_i}{\text{Number of units served by any central system}}$$

Note: "Method" designations are invariant tags that facilitate cross-references from comments in implementation code.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater, as shown in *Equation 8*.

$$HARL_j = \frac{HARL_k}{NWH_k} \quad \text{Equation 8}$$

*where*

$HARL_j$ = Hourly adjusted recovery load for the j$^{th}$ water heater of the k$^{th}$ system (Btu).

$HARL_k$ = Hourly adjusted total recovery load for the k$^{th}$ system (Btu)

$NWH_k$ = The number of water heaters in the k$^{th}$ system.

## B4.1. Distribution Losses within the Dwelling Unit

The distribution system multiplier (DSM, unitless) is an adjustment for alternative water heating distribution systems within the dwelling unit. A value of 1.00 for "standard" distribution systems, defined as a non-recirculating system with the following mandatory requirements:

The full length of the line from the water heater to the kitchen fixtures shall be insulated in accordance with Standards Section 150.0(j)2**.** All piping of nominal ¾" or larger diameter insulated in accordance with Section 150.0(j)2.

For all four system types, values for alternative distribution systems are given in Table B-1. Improved DSM values are available for cases where voluntary HERS inspections are completed, as per the eligibility criteria shown in Reference Residential Appendix RA4.4. Detailed descriptions of all of the distribution system measures are found in Residential Appendix RA 4.4.

***Table B-1. Distribution System Multipliers within a Dwelling Unit with One or More Water Heaters***

| Distribution System Types | Assigned Distribution System Multiplier | System Type 1 and 2 | System Type 3 and 4 |
|---|---|---|---|
| **No HERS Inspection Required** | | | |
| Trunk and Branch -Standard (STD) | 1.0 | Yes | Yes |
| Pipe Insulation (PIC) | 0.9 | Yes | Yes |
| Central Parallel Piping (PP) | 1.05 | Yes | |
| Point of Use (POU) | 0.3 | Yes | |
| Recirculation: Non-Demand Control Options (R-ND) | 9.0* | Yes | |
| Recirculation with Manual Demand Control (R-DRmc) | 1.6* | Yes | |
| Recirculation with Motion Sensor Demand Control (R-DRsc) | 2.4* | Yes | |
| **Optional Cases: HERS Inspection Required** | | | |
| Pipe Insulation (PIC-H) | 0.8 | Yes | Yes |
| Central Parallel Piping with 5' maximum length (PP-H) | 0.95 | Yes | |
| Compact Design (CHWDS-H) | 0.7 | Yes | |
| ~~Point of Use (POU-H)~~ | ~~0.3~~ | ~~Yes~~ | |
| Recirculation with Manual Demand Control (R-DRmc-H) | 1.45* | Yes | |
| Recirculation with Motion Sensor Demand Control (RDRsc-H) | 2.2* | Yes | |
| Non-Compliant Installation Distribution Multiplier | 1.2 | Yes | Yes |
| *Recirculation DSMs reflect impact of reduced hot water consumption associated with recirculation systems. | | | |

## B4.2. Cold Water Inlet Temperature

The water heater inlet temperature is assumed to vary on a daily basis with the following relationship defined by the data included in the climate zone weather files. For each day of the year, $T_{inlet}$ will be calculated as follows:

$$T_{inlet} = T_{ground} \times 0.65 + T_{avg31} \times 0.35 \quad \textit{Equation 9}$$

*where*

$T_{avg31}$ = outdoor dry-bulb temperature averaged over all hours of the previous 31 days (note for January days, weather data from December will be used)

$T_{ground}$ = Ground temperature (°F ) for current day of year, calculated using *Equation 10*.

For each day (θ = 1 TO 365)

$$T_{ground}(\theta) = TyrAve - 0.5 \times (TyrMax - TyrMin) \times COS(2 \times \pi \times ((\theta - 1)/PB) - PO - PHI) \times GM \quad \textit{Equation 10}$$

*where*

| | | |
|---|---|---|
| TyrAve | = | average annual temperature, °F |
| TyrMin | = | the lowest average monthly temperature, °F |
| TyrMax | = | the highest average monthly temperature, °F |
| PB | = | 365 |
| PO | = | 0.6 |
| DIF | = | 0.025 $ft^2$/hr |
| BETA | = | SQR(π/(DIF*PB*24))*10 |
| XB | = | EXP(-BETA) |
| CB | = | COS( BETA) |
| SB | = | SIN( BETA) |
| GM | = | SQR((XB*XB - 2.*XB*CB + 1)/(2.*BETA*BETA)) |
| PHI | = | ATN((1.-XB*(CB+SB)) / (1.-XB*(CB-SB))) |

## B5. Hourly Distribution Loss for Central Water Heating Systems

This section is applicable to the DHW system type 3 and 4, as defined in B1. Purpose and Scope. The distribution losses accounted for in the distribution loss multiplier (DLM), *Equation 5*, reflect distribution heat loss within each individual dwelling unit. Additional distribution losses occur outside dwelling units and they include losses from recirculation loop pipes and branch piping feeding individual dwelling units. The hourly values of these losses, HRDL, shall be calculated according to *Equation 11*. Compliance software shall provide input for specifying recirculation system designs and controls according to the following algorithms.

$$HRDL_k = NLoop_k \times HRLL_k + HRBL_k \qquad \text{Equation 11}$$

*where*

$HRDL_k$= Hourly central system distribution loss for $k^{th}$ system (Btu).

$HRLL_k$= Hourly recirculation loop pipe heat loss (Btu). This component is only applicable to system type 4. See *Equation 12*.

$HRBL_k$= Hourly recirculation branch pipe heat loss (Btu), see *Equation 20*.

$NLoop_k$= Number of recirculation loops in water heating system k. This component is only applicable to system type 4. See section 4.3.

A recirculation loop usually includes multiple pipe sections, not necessarily having the same diameter, that are exposed to different ambient conditions. The compliance software shall provide input entries for up to six pipe sections with three sections for supply piping and three sections for return piping for users to describe the configurations of the recirculation loop. For each of the six pipe sections, input entries shall include pipe diameter (inch), pipe length (ft), and ambient conditions. Ambient condition input shall include three options: outside air, underground, conditioned or semi-conditioned air. Modeling rules for dealing with recirculation loop designs are provided in Section 4.3.

Outside air includes crawl spaces, unconditioned garages, unconditioned equipment rooms, as well as actual outside air. Solar radiation gains are not included in the calculation because the impact of radiation gains is relatively minimal compared to other effects. Additionally, the differences in solar gains for the various conditions (e.g., extra insulation vs. minimum insulation) are relatively even less significant.

The ground condition includes any portion of the distribution piping that is underground, including that in or under a slab. Insulation in contact with the ground must meet all the requirements of Section 150.0(j), Part 6, of Title 24.

The losses to conditioned or semi-conditioned air include losses from any distribution system piping that is in an attic space, within walls (interior, exterior or between conditioned and unconditioned spaces), within chases on the interior of the building, or within horizontal spaces between or above conditioned spaces. It does not include the pipes within the residence. The distribution piping stops at the point where it first meets the boundaries of the dwelling unit.

## B5.1. Hourly Recirculation Loop Pipe Heat Loss Calculation

Hourly recirculation loop pipe heat loss ($HRLL_k$) is the hourly heat loss from all six pipe sections. There are two pipe heat loss modes, pipe heat loss with non-zero water flow (PLWF) and pipe heat loss without hot water flow (PLCD). The latter happens when the recirculation pump is turned off by a control system and there are no hot water draw flows, such as in recirculation return pipes.

Compliance software shall provide four options of recirculation system controls listed in Table B-2. A proposed design shall select a control type from one of the four options. The standard design shall use demand control.

**Table B-2. Recirculation Loop Supply Temperature and Pump Operation Schedule**

| Hour | No Control | | Demand Control | | Temperature Modulation | | Temperature Modulation with Continuous Monitoring | |
|---|---|---|---|---|---|---|---|---|
| | $T_{in,1}$ (°F) | $SCH_{k,m}$ | $T_{in,1}$ (°F) | $SCH_{k,m}$ | $T_{in,1}$ (°F) | $SCH_{k,m}$ | $T_{in,1}$ (°F) | $SCH_{k,m}$ |
| 1 | 130 | 1 | 130 | 0.2 | 120 | 1 | 115 | 1 |
| 2 | 130 | 1 | 130 | 0.2 | 120 | 1 | 115 | 1 |
| 3 | 130 | 1 | 130 | 0.2 | 120 | 1 | 115 | 1 |
| 4 | 130 | 1 | 130 | 0.2 | 120 | 1 | 115 | 1 |
| 5 | 130 | 1 | 130 | 0.2 | 120 | 1 | 115 | 1 |
| 6 | 130 | 1 | 130 | 0.2 | 125 | 1 | 120 | 1 |
| 7 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 8 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 9 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 10 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 11 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 12 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 13 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 14 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 15 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 16 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 17 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 18 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 19 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 20 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 21 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 22 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 23 | 130 | 1 | 130 | 0.2 | 130 | 1 | 125 | 1 |
| 24 | 130 | 1 | 130 | 0.2 | 125 | 1 | 120 | 1 |

Pipe heat loss modes are determined by recirculation control schedules and hot water draw schedules. For each pipe section, hourly pipe heat loss is the sum of heat loss from the two heat loss modes.

Hourly heat loss for the whole recirculation loop ($HRLL_k$) is the heat loss from all six pipe sections, according to the following equation:

$$HRLL_k = \sum_n \left[ PLWF_n + PLCD_n \right] \qquad \textit{Equation 12}$$

*where*

$PLWF_n$= Hourly pipe heat loss with non-zero water flow (Btu/hr), see *Equation 13*.

$PLCD_n$= Hourly pipe heat loss without water flow (Btu/hr), see *Equation 18*.

n= Recirculation pipe section index, 1 – 6

$$PLWF_n = Flow_n \times \left(1 - f_{noflow,n}\right) \times \rho \times C_p \times \left(T_{n,in} - T_{n,out}\right)$$ *Equation 13*

*where*

$Flow_n$ = $Flow_{recirc} + Flow_{n,draw}$ (gph), assuming

$Flow_{n,draw}$ = Average hourly hot water draw flow (gph). For supply sections, n=1, 2, or 3, $Flow_{n,draw} = GPH_k/NLoop_k$. For return pipes, n=4, 5, and 6, $Flow_{n,draw} = 0$.

$Flow_{recirc}$ = Hourly recirculation flow (gph). It is assumed to be 360 gallons based on the assumption that the recirculation flow rate is 6 gpm.

$f_{noflow,n}$ = Fraction of the hour for pipe section n to have zero water flow, see *Equation 14*

$\rho$ = Density of water, 8.345 (lb/gal).

$C_p$ = Specific heat of water, 1 (Btu/lb-°F).

$T_{n,in}$ = Input temperature of section n (°F). For the first section (n=1), $T_{1,in}$ shall be determined based on Table B-2. The control schedule of the proposed design shall be based on user input. The standard design is demand control. For other sections, input temperature is the same as the output temperature the proceeding pipe section, $T_{n,in} = T_{n-1,out}$

$T_{n,out}$ = Output temperature of section n (°F), see *Equation 15*

$$f_{noflow,n} = \left(1 - SCH_{k,m}\right) \times NoDraw_n$$ *Equation 14*

*where*

$NoDraw_n$ = Fraction of the hour that is assumed to have no hot water draw flow for pipe section n. $NoDraw_1 = 0.2$, $NoDraw_2 = 0.4$, $NoDraw_3 = 0.6$, $NoDraw_4 = NoDraw_5 = NoDraw_6 = 1$.

$SCH_{k,m}$ = Recirculation pump operation schedule, representing the fraction of the hour that the recirculation pump is turned off, see Table B-2. $SCH_{k,m}$ for the proposed design shall be based on proposed recirculation system controls. Recirculation system control for the standard design is demand control.

$$T_{out,n} = T_{amb,n} + \left(T_{in,n} - T_{amb,n}\right) \times e^{-\frac{UA_n}{\rho C_p Flow_n}}$$ *Equation 15*

*where*

$T_{Amb,n}$ = Ambient temperature of section n (°F), which can be outside air, underground, conditioned or semi-conditioned air. Outside air temperatures shall be the dry-bulb temperature from the weather file. Underground temperatures shall be obtained from *Equation 10*. Hourly conditioned air temperatures shall be the same as conditioned space temperature. For the proposed design, $T_{amb,n}$ options shall be based on user input. The standard design assumes all pipes are in conditioned air.

$UA_n$ = Heat loss rate of section n (Btu/hr-°F), see *Equation 16*.

$$UA_n = Len_n \times min\left(U_{bare,n}, f_{UA} \times U_{insul,n}\right) \quad \text{Equation 16}$$

*where*

$Len_n$ = Section n pipe length (ft). For the proposed design, use user input; for the standard design, see *Equation 27.*

$U_{bare,n}$, $U_{insul,n}$ = Loss rates for bare (uninsulated) and insulated pipe (Btu/hr-ft-°F), evaluated using *Equation 17* with section-specific values, as follows --

$Dia_n$ = Section n pipe nominal diameter (inch). For the proposed design, use user input; for the standard design, see *Equation 28.*

$Thick_n$ = Pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system.

$Cond_n$ = Insulation conductivity shall be assumed = 0.26 (Btu inch/h·sf·F)

$h_n$ = Section n combined convective/radiant surface coefficient (Btu/hr-ft2-F) assumed = 1.5.

$f_{UA}$ = Correction factor to reflect imperfect insulation, insulation material degradation over time, and additional heat transfer through connected branch pipes that is not reflected in branch loss calculation. It is assumed to be 2.0.

*Equation 17* defines general relationships used to calculate heat loss rates for both loop and branches using appropriate parameters.

$$Dia_o = Dia + 0.125$$

$$U_{bare} = h \times \pi \times Dia_o / 12$$

$$Dia_x = Dia_o + 2 \times Thick \quad \text{Equation 17}$$

$$U_{insul} = \frac{\pi}{\frac{ln\left(Dia_x / Dia_o\right)}{2 \times Cond / 12} + \frac{12}{h \times Dia_x}}$$

*where*

Dia = Pipe nominal size (in)

$Dia_o$ = Pipe outside diameter (in)

$Dia_x$ = Pipe + insulation outside diameter (in)

Thick = Pipe insulation thickness (in)

Cond = Insulation conductivity (Btu in/hr-ft$^2$-°F)

h = Combined convective/radiant surface coefficient (Btu/hr-ft$^2$-°F).

Pipe heat loss without water flow shall be calculated according to the following equations:

$$PLCD_n = Vol_n \times \rho \times C_p \times \left(T_{n,start} - T_{n,end}\right)$$ *Equation 18*

*where*

$Vol_n$ = Volume of section n (gal). It is calculated as $7.48 \times \pi \times \left(Dia_o/24\right)^2 \times Len_n$ where 7.48 is the volumetric unit conversion factor from cubic feet to gallons. Note that the volume of the pipe wall is included to approximate the heat capacity of the pipe material.

$T_{n,start}$ = Average pipe temperature (°F) of pipe section n at the beginning of the hour. It is the average of $T_{n,in}$ and $T_{n,out}$ calculated according to *Equation 15* and associated procedures.

$T_{n,end}$ = Average pipe temperature (°F) of pipe section n at the end of pipe cool down . See *Equation 19*

$$T_{n,end} = T_{amb,n} + \left(T_{n,start} - T_{amb,n}\right) \times e^{-\frac{UA_n \times f_{noflow,n}}{Vol_n \times \rho \times C_p}}$$ *Equation 19*

*Equation 19* calculates average pipe temperature after cooling down, so the pipe heat loss calculated by *Equation 18* is for pipe with zero flow for fraction $f_{noflow,n}$ of an hour. Recirculation pumps are usually turned off for less than an hour and there could be hot water draw flows in the pipe. As a result, recirculation pipes usually cool down for less than an hour. The factor $f_{noflow,n}$ calculated according *Equation 14* is used to reflect this effect in *Equation 19*.

## B5.2. Hourly Recirculation Branch Pipe Heat Loss Calculation

The proposed design and standard design shall use the same branch pipe heat loss assumptions. Branch pipe heat loss is made up of two components. First, pipe heat losses occur when hot water is in use (HBUL). Second, there could be losses associated with hot water waste (HBWL) when hot water was used to displace cold water in branch pipes and hot water is left in pipe to cool down after hot water draws and must be dumped down the drain.

The Total Hourly Branch Losses ($HRBL_k$) shall include both components and be calculated as:

$$HRBL_k = Nbranch_k \times \left(HBUL + HBWL\right)$$ *Equation 20*

*where*

HBUL = Hourly pipe loss for one branch when water is in use (Btu/hr), see *Equation 21*.

HBWL = Hourly pipe loss for one branch due to hot water waste (Btu/hr), see *Equation 24.*

$Nbranch_k$ = Number of branches in water heating system k, see *Equation 29*.

The hourly branch pipe loss while water is flowing is calculated in the same way as recirculation pipe heat loss with non-zero water flow (PLWF) using the following equations:

$$HBUL = \left( \frac{GPH_k}{NBranch_k} \right) \times \rho \times C_p \times \left( T_{b,in} - T_{b,out} \right) \qquad \textit{Equation 21}$$

*where*

$T_{b,in}$ = Average branch input temperature (°F). It is assumed to be equal to the output temperature of the first recirculation loop section, $T_{1,out}$

$T_{b,out}$ = Average branch output temperature (°F), see *Equation 22*.

$$T_{b,out} = T_{amb,b} + \left( T_{b,in} - T_{amb,b} \right) \times e^{-\frac{UA_b}{\rho \times C_p \times Flow_b}} \qquad \textit{Equation 22}$$

*where*

$T_{amb,b}$ = Branch pipe ambient temperature (°F) Branch pipes are assumed to be located in the conditioned or semi-conditioned air.

$UA_b$ = Branch pipe heat loss rate (Btu/hr-°F), see Equation 23

$Flow_b$ = Branch hot water flow rate during use (gal/hr). It is assumed to be 2 gpm or 120 gal/hr.

The branch pipe heat loss rate is

$$UA_b = Len_b \times U_{insul,b} \qquad \textit{Equation 23}$$

*where*

$Len_b$ = Branch pipe length (ft). See *Equation 31.*

$U_{insul,b}$ = Loss rate for insulated pipe (Btu/hr-ft-°F), evaluated using *Equation 17* with branch-specific values, as follows --

$Dia_b$ = Branch pipe diameter (inch), see *Equation 30*

$Thick_b$ = Branch pipe insulation minimum thickness (inch) as defined in the Title 24 Section 120.3, TABLE 120.3-A for service hot water system.

$Cond_b$ = Branch insulation conductivity, assumed = 0.26 Btu in/hr-ft$^2$- °F

$h_b$ = Branch combined convective/radiant surface coefficient (Btu/hr-ft$^2$-$^o$F) assumed = 1.5.

The hourly pipe loss for one branch due to hot water waste is calculated as follows.

*HBWL =*

$$N_{waste} \times SCH_{waste,m} \times f_{vol} \times 7.48 \times \pi \times \left( \frac{Dia_b + 0.125}{24} \right)^2 \times Len_b \times \rho \times C_p \times (T_{b,in} - T_{inlet})$$

*Equation 24*

*where*

$N_{waste}$ = Number of times in a day for which water is dumped before use. This depends on the number of dwelling units served by a branch. Statistically, the number of times of hot water waste is wasted is inversely proportional to the number of units a branch serves, see *Equation 25.*

$SCH_{waste,m}$ = Hourly schedule of water waste, see Table B-3.

$f_{vol}$ = The volume of hot water waste is more than just the volume of branch pipes, due to branch pipe heating, imperfect mixing, and user behaviors. This multiplier is applied to include these effects and is assumed to be 1.4.

$T_{in,b}$ = Average branch input temperature ($^o$F). It is assumed to equal to the output temperature of the first recirculation loop section, $T_{OUT,1}$.

$T_{inlet}$ = The cold water inlet temperature (ºF) according to Section 3.3 Cold Water Inlet Temperature.

$$N_{waste} = 19.84 \times e^{-0.544 \times Nunit_b}$$

*Equation 25*
*Method WH-BRWF*

*where*

$Nunit_b$= Number of dwelling units served by the branch, calculated using *Equation 26* (note that $Nunit_b$ is not necessarily integral).

$$Nunit_b = \frac{Nfloor}{2}$$

*Equation 26*
*Method WH-BRNU*

**Table B-3. Branch Water Waste Schedule**

| Hour | $SCH_{waste,m}$ |
|---|---|
| 1 | 0.01 |
| 2 | 0.02 |
| 3 | 0.05 |
| 4 | 0.22 |
| 5 | 0.25 |
| 6 | 0.22 |
| 7 | 0.06 |
| 8 | 0.01 |
| 9 | 0.01 |
| 10 | 0.01 |
| 11 | 0.01 |
| 12 | 0.01 |
| 13 | 0.01 |
| 14 | 0.01 |
| 15 | 0.01 |
| 16 | 0.01 |
| 17 | 0.01 |
| 18 | 0.01 |
| 19 | 0.01 |
| 20 | 0.01 |
| 21 | 0.01 |
| 22 | 0.01 |
| 23 | 0.01 |
| 24 | 0.01 |

## B5.3. Recirculation System Plumbing Designs

A recirculation system can have one or multiple recirculation loops. Each recirculation loop consists of many pipe sections, which are connected in sequence to form a loop. Each pipe section could have different pipe diameter, length, and location. The compliance software shall use six pipe sections, with three supply pipe sections and three return pipe sections, to represent a recirculation loop. When multiple recirculation loops exist, all recirculation loops are assumed to be identical. The compliance software shall provide default and standard recirculation system designs based on building geometry according to the procedures described in the following sections. The default design reflects typical recirculation loop design practices. The standards design is based on one or two loops and is used to set recirculation loop heat loss budget.

The first step of establishing recirculation system designs is to determine the number of recirculation loops, $Nloop_k$, in water heating system k. The standard design has one recirculation loop, $Nloop_k$ =1, when Nunit <= 8, or two recirculation loops, $Nloop_k$ =2 for buildings with Nunit > 8. The proposed design is allowed to specify more than one loop only if the design is verified by a HERS rater. Otherwise, the proposed design can only be specified to have one recirculation loop.

The standard and default recirculation loop designs are based on characteristics of the proposed building. There could be many possibilities of building shapes and dwelling unit configurations, which would determine recirculation loop pipe routings. Without requiring users to provide detailed dwelling unit configuration information, the compliance software shall assume the proposed buildings to have same dwelling units on each floor and each floor to have a corridor with dwelling units on both sides. Recirculation loops start from the mechanical room (located on the top floor), go vertically down to the middle floor, loop horizontally in the corridor ceiling to reach the dwelling units on both ends of the building, then go vertically up back to the mechanical room. At each dwelling unit on the middle floor, vertical branch pipes, connected to the recirculation loop supply pipe, are used to provide hot water connection to dwelling units on other floors above and below.

Both the standard and default recirculation loop designs are assumed to have equal length of supply sections and return sections. The first section is from the mechanical room to the middle floor. The second section serves first half branches connected to the loop and the third section serves the rest of the branches. The first and second sections have the same pipe diameter. Pipe size for the third section is reduced since less dwelling units are served. Return sections match with the corresponding supply pipes in pipe length and location. All return sections have the same diameter. For both the standard and default designs, mechanical room is optimally located so that only vertical piping is needed between the mechanical room and the recirculation pipes located on the middle floor. Pipe sizes are determined based on the number of dwelling units served by the loop, following the 2009 Uniform Plumbing Code (UPC) pipe sizing guidelines. The detailed recirculation loop configurations are calculated as following.

Pipe Length in the mechanical room (ft): $L_{mech}=8$

Height of each floor (ft): $H_{floor}$=user input floor-to-floor height (ft)

Length of each dwelling unit (ft): $L_{unit} = \sqrt{CFAU_k}$ (see *Equation 7*)

Length of recirculation pipe sections (ft):

$$Len_1 = Len_6 = L_{mech} + H_{floor} \times \frac{Nfloor}{2}$$

$$Len_2 = Len_3 = Len_4 = Len_5 = L_{unit} \times \frac{Nunit_k}{4 \times Nloop_k \times Nfloor}$$

*Equation 27*
*Method WH-LOOPLEN*

Pipe diameters for recirculation loop supply sections depend on the number of dwelling units being served and return section diameters depend only on building type, as follows --

$Dia_1$, $Dia_2$, and $Dia_3$: derived from Table B-4 based on $Nunit_1$, $Nunit_2$, and $Nunit_3$

$Dia_4 = Dia_5 = Dia_6 = 0.75$ in for low-rise multi-family building and hotel/motel less than four stories

$Dia_4 = Dia_5 = Dia_6 = 1.0$ in for high-rise multi-family and hotel/motel more than three stories

*Equation 28*
*Method WH-LOOPSZ*

*where*

$Nunit_1$ = Number of dwelling unit served by the loop section 1 = $\frac{Nunit_k}{Nloop_k}$

$Nunit_2 =$ $Nunit_1$

$Nunit_3 =$ $\frac{Nunit_1}{2}$

Note that Nunit values are not necessarily integers.

Branch pipe parameters include number of branches, branch length, and branch diameter. The number of branches in water heating system k is calculated as (note: not necessarily an integer)

$$Nbranch_k = \frac{Nunit_k}{Nunit_b}$$

*Equation 29*
*Method WH-BRN*

The branch pipe diameter shall be determined as follows:

$Dia_b$: derived from Table B-4 based on $Nunit_b$

*Equation 30*
*Method WH-BRSZ*

The branch length includes the vertical rise based on the number of floors in the building plus four feet of pipe to connect the branch to the recirculation loop.

$$Len_b = 4 + H_{floor} \times Nfloor / 2$$

*Equation 31*
*Method WH-BRLEN*

Proposed designs shall use the same branch configurations as those in the standard design. Therefore, compliance software does not need to collect branch design information.

**Table B-4. Pipe Size Schedule**

| Number of dwelling units served $NUnit_n$ or $NUnit_b$ | Loop pipe nominal size $Dia_n$ in | Branch pipe nominal size $Dia_b$ in |
|---|---|---|
| < 2 | 1.5 | 1 |
| 2 ≤ N < 8 | 1.5 | |
| 8 ≤ N < 21 | 2 | |
| 21 ≤ N < 42 | 2.5 | |
| 42 ≤ N < 68 | 3 | |
| 68 ≤ N < 101 | 3.5 | |
| 101 ≤ N < 145 | 4 | |
| 145 ≤ N < 198 | 5 | |
| N >= 198 | 6 | |

## B6. High Rise Residential Buildings, Hotels and Motels

Simulations for high rise residential buildings, hotels and motels shall follow all the rules for central or individual water heating with the following exceptions.

For central systems which do not use recirculation but use electric trace heaters the program shall assume equivalency between the recirculation system and the electric trace heaters.

For individual water heater systems which use electric trace heating instead of gas, the program shall assume equivalency.

## B7. Energy Use of Individual Water Heaters

Once the hourly adjusted recovery load is determined for each water heater, the energy use for each water heater is calculated as described below and summed.

### B7.1. Small Gas or Oil Storage Water Heaters

The hourly energy use of storage gas or oil storage water heaters is given by the following equation.

$$WHEU_j = \frac{HARL_j \times HPAF_j}{LDEF_j}$$ *Equation 32*

*where*

$WHEU_j$ = Hourly energy use of the water heater (Btu for fuel or kWh for electric). The above equation provides a value in unit of Btu. For electric water heaters, the calculation result needs to be converted to the unit of kWh by dividing 3413 Btu/kWh.

$HARL_j$ = Hourly adjusted recovery load (Btu).

$HPAF_j$ = 1 for all non-heat pump water heaters.

$LDEF_j$ = The ~~hourly~~ annual load dependent energy factor (LDEF) is given by *Equation 33*. This equation adjusts the nominal EF rating for storage water heaters for different load conditions.

~~$$LDEF_j = \min\left[LDEF_{\max}, \max\left(LDEF_{\min}, \ln\left(\frac{HARL_j \times 24}{1000}\right)\left(a \times EF_j + b\right) + \left(c \times EF_j + d\right)\right)\right]$$~~ *Equation 33*

$$LDEF_j = \min\left[LDEF_{\max}, \max\left(LDEF_{\min}, \ln\left(\frac{AAHARL_j \times 24}{1000}\right)\left(a \times EF_j + b\right) + \left(c \times EF_j + d\right)\right)\right]$$

*where*

a,b,c,d = Coefficients from the table below based on the water heater type.

**Table B-5. LDEF Coefficients**

| Coefficient | Storage Gas |
|---|---|
| a | -0.098311 |
| b | 0.240182 |
| c | 1.356491 |
| d | -0.872446 |
| $LDEF_{min}$ | .1 |
| $LDEF_{max}$ | .90 |

$AAHARL_j$ = Annual average hourly adjusted load (Btu) = $\frac{1}{8760}\sum_{1}^{8760} HARL_j$. Note that calculation of $AAHARL_j$ requires a preliminary annual simulation that sums $HARL_j$ values for each hour.

$EF_j$ = Energy factor of the water heater (unitless). This is based on the DOE test procedure. EF for storage gas water heaters with volume less than 20 gallons must be assumed to be 0.58 unless the manufacturer has voluntarily reported an actual EF to the California Energy Commission.

## B7.2. Small Gas or Oil Instantaneous Water Heater

The hourly energy use for instantaneous gas or oil water heaters is given by Equation 34, where the nominal rating is multiplied by 0.92 to reflect the impacts of heat exchanger cycling under real world load patterns.

$$WHEU_j = \frac{HARL_j}{EF_j \times 0.92}$$ *Equation 34*

*where*

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu).

$HARL_j$ = Hourly adjusted recovery load.

$EF_j$ = Energy factor from the DOE test procedure (unitless). This is taken from manufacturers' literature or from the CEC Appliance Database.

0.92 = Efficiency adjustment factor

## B7.3. Small Electric Instantaneous Water Heater

The hourly energy use for instantaneous electric water heaters is given by the following equation.

$$WHEU_{j,elec} = \frac{HARL_j}{EF_j \cdot 0.92 \cdot 3413}$$ *Equation 35*

*where*

$WHEU_{j,elec}$ = Hourly electric energy use of the water heater (kWh).

$HARL_j$ = Hourly adjusted recovery load (Btu).

$EF_j$ = Energy factor from DOE test procedure (unitless).

0.92 = Adjustment factor to adjust for overall performance.

3413 = Unit conversion factor (Btu/kWh).

### B7.4. Mini-Tank Electric Water Heater

Mini-tank electric heaters are occasionally used with gas tankless water heaters to mitigate hot water delivery problems related to temperature fluctuations that may occur between draws. If mini-tank electric heaters are installed, the installed units must be listed in the CEC Appliance Database and their reported standby loss (in Watts) will be modeled to occur each hour of the year. (If the unit is not listed in the CEC Appliance Database, a standby power consumption of 100 W should be assumed.)

$$WHEU_{j,elec} = MTSBL_j / 1000$$ *Equation 36*

*where*

$WHEU_{j,elec}$ = Hourly standby electrical energy use of mini-tank electric water heaters (kWh)

$MTSBL_j$ = Mini-tank standby power (W) for tank j (if not listed in CEC Appliance directory, assume 100 W)

### B7.5. Large Gas or Oil Storage Water Heater

Energy use for large storage gas is determined by the following equations. Note: large storage gas water heaters are defined as any gas storage water heater with a minimum input rate of 75,000 Btu/h.

$$WHEU_j = \frac{HARL_j}{EFF_j} + SBL_j$$ *Equation 37*

*where*

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu).

$HARL_j$ = Hourly adjusted recovery load (Btu)

$SBL_j$ = Total Standby Loss (Btu/hr). Obtain from CEC Appliance Database or from AHRI certification database. This value includes tank losses and pilot energy. If standby rating is not available from either of the two databases, it shall be calculated as per Table ~~F-3~~F-2 of the ~~2012~~2015 Appliance Efficiency Regulations, as follows:

SBL = Q/800 + 110 $(V)^{1/2}$, where Q is the input rating in Btu/hour, and V is the tank volume in gallons.

$EFF_j$ = Efficiency (fraction, not %). Obtained from CEC Appliance Database or from manufacturer's literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

## B7.6. Large Instantaneous, Indirect Gas, and Hot Water Supply Boilers

Energy use for these types of water heaters is given by the following equation.

$$WHEU_j = \frac{HARL_j}{EFF_j \times 0.92} + PILOT_j \qquad \text{Equation 38}$$

*where*

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section B3. .

$EFF_j$ = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

$PILOT_j$ = Pilot light energy (Btu/h) for large instantaneous. For large instantaneous water heaters, and hot water supply boilers with efficiency less than 89 percent assume the default is 750 Btu/hr if no information is provided in manufacturer's literature or CEC Appliance Database.

0.92 = Adjustment factor used when system is not supplying a storage system.

## B7.7. Small Storage Electric or Heat Pump Water Heaters

Energy use for small electric water heaters is calculated as described in the HPWHsim Project Report (Ecotope, 2015 and 2016). The HPWH model uses a detailed, physically based, multi-node model that operates on a one-minute time step implemented using a suitable loop at the time-step level within CSE. Tank heat losses and heat pump source temperatures are linked to the CSE zone heat balance as appropriate. Thus, for example, the modeled air temperature of a garage containing a heat pump water heater will reflect the heat extracted.

HPWH can model three classes of equipment:

- Specific air-source heat pump water heaters identified by manufacturer and model. These units have been tested by Ecotope and measured parameters are built into the HPWH code.
- Generic air-source heat pump water heaters, characterized by EF and tank volume. This approach provides compliance flexibility. The performance characteristics of the generic model are tuned to use somewhat more energy than any specific unit across a realistic range of EF values.

- Electric resistance water heaters, characterized by EF, tank volume, and resistance element power.

Several issues arise from integration of a detailed, short time step model into an hourly framework. HPWH is driven by water draw quantities, not energy requirements. Thus to approximate central system distribution and unfired tank losses, fictitious draws are added to the scheduled water uses, as follows:

$$V_{j,t} = \frac{VS_{k,t} + \dfrac{HRDL_k + \sum_{1}^{NL_k} HJL_l}{60 \times 8.345 \times (t_s - t_{inlet})}}{NWH_k}$$ *Equation 39*

*where*

$V_{j,t}$ = Hot water draw (gal) on j[th] water heater for minute t.

Another issue is that the HPWH hot water output temperature varies based on factors like control hysteresis and tank mixing. For compliance applications, it is required that all system alternatives deliver the same energy. To address this, the HPWH tank setup point is modeled at 125 °F and delivered water is tempered to $t_s$. If the HPWH output temperature is above $t_s$,it is assumed that inlet water is mixed with it (thus reducing $V_{i,t}$). If the output temperature is below $t_s$, sufficient electrical resistance heating is supplied to bring the temperature up to $t_s$ (preventing under capacity from being exploited as a compliance advantage).

## B7.8. Jacket Loss

The hourly jacket loss for the l[th] unfired tank or indirectly fired storage tank in the k[th] system is calculated as

$$HJL_l = \frac{TSA_l \times \Delta TS}{RTI_l + REI_l} + FTL_l$$ *Equation 40*

*where*

$HJL_l$ = The tank surface losses of the l[th] unfired tank of the k[th] system

$TSA_l$ = Tank surface area ($ft^2$), see *Equation 41.*

ΔTS = Temperature difference between ambient surrounding tank and hot water supply temperature (ºF). Hot water supply temperature shall be 124ºF. For tanks located inside conditioned space use 75ºF for the ambient temperature. For tanks located in outside conditions use hourly dry bulb temperature ambient.

$FTL_l$ = Fitting losses. This is a constant 61.4 Btu/h.

$REI_l$ = R-value of exterior insulating wrap. No less than R-12 is required.

$RTI_l$ = R-value of insulation internal to water heater. Assume 0 without documentation.

Tank surface area (TSA) is used to calculate the hourly jacket loss (HJL) for unfired or indirectly fired tanks. TSA is given in the following equation as a function of the tank volume.

$$TSA_l = \left(1.254 \times VOL_l^{0.33} + .531\right)^2$$ *Equation 41*

*where*

$VOL_l$ = Tank capacity (gal).

## B7.9. Electricity Use for Circulation Pumping

For single-family recirculation systems, hourly pumping energy is fixed as shown in Table B-6.

**Table B-6. Single Family Recirculation Energy Use (kWh) by Hour of Day**

| Hour | Non-Demand Controlled Recirculation | Demand-controlled Recirculation |
|---|---|---|
| 1 | 0.040 | 0.0010 |
| 2 | 0.040 | 0.0005 |
| 3 | 0.040 | 0.0006 |
| 4 | 0.040 | 0.0006 |
| 5 | 0.040 | 0.0012 |
| 6 | 0.040 | 0.0024 |
| 7 | 0.040 | 0.0045 |
| 8 | 0.040 | 0.0057 |
| 9 | 0.040 | 0.0054 |
| 10 | 0.040 | 0.0045 |
| 11 | 0.040 | 0.0037 |
| 12 | 0.040 | 0.0028 |
| 13 | 0.040 | 0.0025 |
| 14 | 0.040 | 0.0023 |
| 15 | 0.040 | 0.0021 |
| 16 | 0.040 | 0.0019 |
| 17 | 0.040 | 0.0028 |
| 18 | 0.040 | 0.0032 |
| 19 | 0.040 | 0.0033 |
| 20 | 0.040 | 0.0031 |
| 21 | 0.040 | 0.0027 |
| 22 | 0.040 | 0.0025 |
| 23 | 0.040 | 0.0023 |
| 24 | 0.040 | 0.0015 |
| Annual Total | 350 | 23 |

Multi-family recirculation systems typically have larger pump sizes, and therefore electrical energy use is calculated based on the installed pump size. The hourly recirculation pump electricity use (HEUP) is calculated by the hourly pumping schedule and the power of the pump motor as in the following equation.

$$HEUP_k = \frac{0.746 \times PUMP_k \times SCH_{k,m,}}{\eta_k}$$ *Equation 42*

*where*

$HEUP_k$ = Hourly electricity use for the circulation pump (kWh).

$PUMP_k$ = Pump brake horsepower (bhp).

$\eta_k$ = Pump motor efficiency.

$SCH_{k,m}$ = Operating schedule of the circulation pump, see Table B-2. The operating schedule for the proposed design shall be based on user input control method. The standard design operation schedule is demand control.