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STANDARD PRACTICE FOR STANDARDIZED QUALIFICATION OF WHOLE-HOUSE ENERGY SAVINGS PREDICTIONS BY CALIBRATION TO ENERGY USE HISTORY

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This standard is formulated under the cognizance of the BPI Data and Modeling Standards Technical Committee.

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Introduction (Informative)

Procedures described in this document are intended to increase confidence in energy savings projected by whole building simulation for single family dwellings and townhouses that undergo energy efficiency retrofits. The approach relies on setting boundaries on predicted savings by using actual pre-retrofit energy consumption (utility bills) where available, and provides an alternate approach for evaluating savings in homes where monthly utility data is available but not of sufficient quality.

The purpose of this standard is to define a procedure and the minimum requirements for calculating standardized energy savings on proposed whole house energy retrofit work based on the difference between energy usage before the energy upgrade and predicted energy use after the upgrade. Verification of meeting these modeling and calibration criteria may be performed by the approved building energy simulation tool, by the program implementer's system of record, or both.

1. Scope

This standard specifies the requirements and process for the calculation of standardized predicted savings: a difference (delta simulation) between the modeled energy usage before an energy upgrade (or set of upgrades) and modeled energy use after an upgrade (or set of upgrades), using approved building energy simulation software.

This standard applies to existing detached single-family dwellings and townhouses that have independent mechanical systems for each dwelling unit (heating, cooling, water heating, and ventilation); direct access to outdoors for each dwelling unit; and were designed to have continuous party walls with no penetrations to adjacent units, with such party walls extending from ground to roof where the dwelling unit is attached to one or more adjacent single-family dwelling units.

This standard specifies a process for using an approved building energy simulation software tool and actual energy bills to calibrate the model to the actual energy use of the home, and provides a set of criteria to be used in the final calculation of standardized estimated savings that may be considered in compliance with this standard.

2. Process Overview

This standard describes a process for generating a pre-retrofit calibrated model and a process for the calculation of energy savings based on the calibrated model.

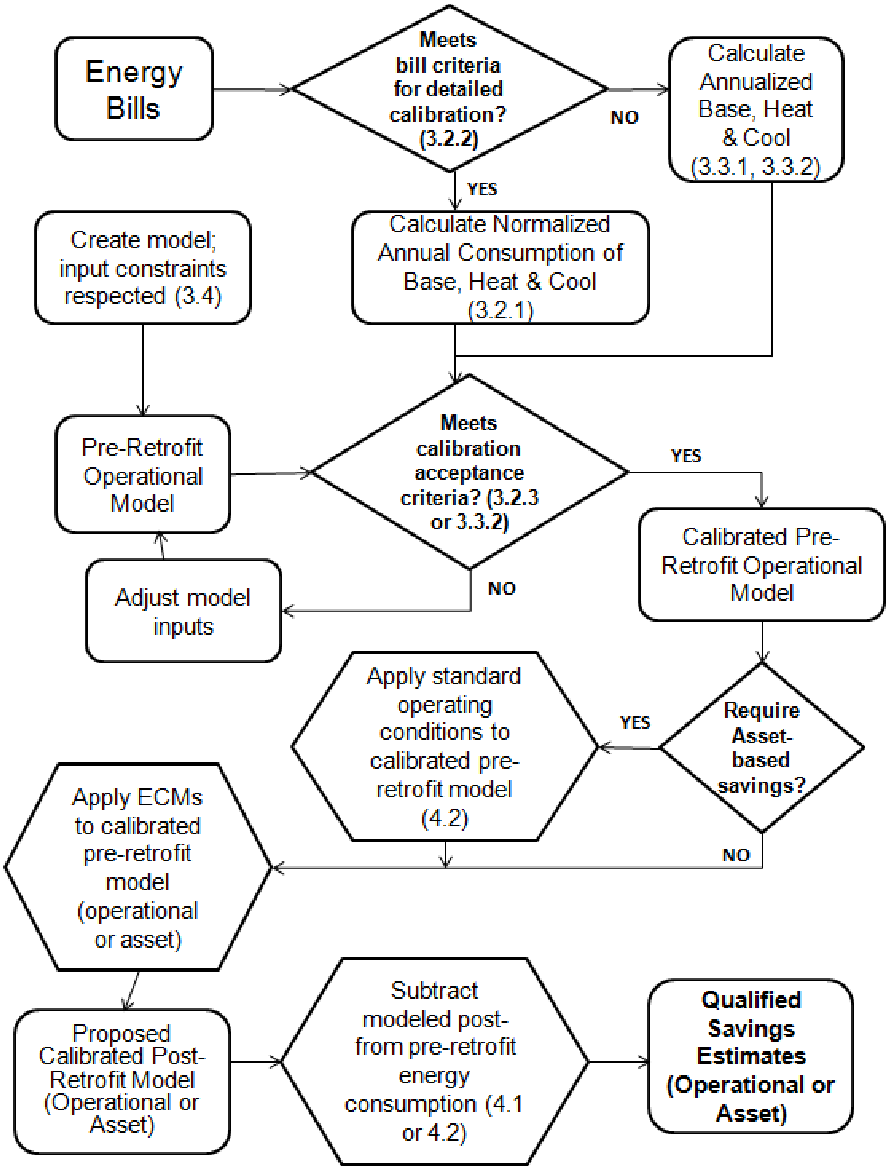
There are two paths for generating the pre-retrofit calibrated model: a detailed calibration process and a simplified calibration process. Both calibration processes have acceptance tests and criteria to determine when the pre-retrofit model is calibrated. The detailed path relies on having monthly utility bill history for each fuel using detailed calibration, while the simplified path requires only the annual consumption for each fuel. An operational model that is successfully calibrated using detailed calibration (Section 3.2.1) will typically have less uncertainty in the savings predictions than that of the simplified calibration (Section 3.3.2) and shall be used when qualified utility data are available. In the case where energy data meeting the criteria in Section 3.2.2 is available for some fuels used in the building and not others, the detailed path shall be used for the fuel(s) with qualified data. If one or more fuel(s) are used that do not meet the criteria of either Section 3.2.2 or Section 3.3.1, calibration shall not be conducted and savings shall not be reported for that fuel(s).

There are two methods for the calculation of predicted energy savings: one based on an operational model, and one based on an asset model[1]. The predicted operational savings are calculated as the difference between the

[1] Operational and asset models are defined in Annex B of this Standard.

modeled fuel usage between the calibrated pre-retrofit operational model and the post-retrofit operational model, where the post-retrofit operational model is the calibrated pre-retrofit operational model adjusted for the proposed ECMs. For programs that require an asset-based calculation of predicted energy savings, calibration is first conducted on the operational model. Then the savings are calculated as stated for the operational model, except that the pre- and post-retrofit energy models' input parameters are modified to reflect standardized (asset-based) operating conditions. (See Figure 1: Process Overview Flow Chart below.)

Figure 1: Process Overview Flow Chart



3. Energy Model Calibration Process

3.1. Energy Simulation Software Criteria

Building energy simulation software used in the analysis shall at a minimum meet the following requirements:

1. Pass the software verification tests listed in Section 4.2.1 of Procedures for Certifying Residential Energy Efficiency Tax Credits – RESNET Publication No. 06-001, Nov 7, 2011.
2. Be capable of reporting energy consumption separately, by fuel type, for the following end -uses at a minimum: space heating, space cooling, water heating, lighting, and other appliances.

Input constraints shall be enforced by the reviewing body. Compliance with input constraints shall be identifiable to software users and to the reviewing body. An example of an input constraint on the pre-retrofit model would be not to allow any opaque wall surface to have an R-value less than a certain value.

3.2. Detailed Calibration

3.2.1. Detailed Calibration Procedure

A detailed calibration of an operational model shall be used for homes with available utility bills that meet data quality requirements outlined in Section 3.2.2. If the utility data do not meet these criteria for one or more fuel(s), then simplified calibration (Section 3.3) shall be used for those fuel(s). The detailed calibration requires the following steps:

A. Determine that available utility bills meet the requirements of Section 3.2.2.

B. Conduct a pre-retrofit operational model, respecting constraints in Section 3.4.

C. Calibrate the operational model using one of two approaches: (a) weather-normalization of utility data, or (b) energy model with actual weather.

  a. Weather-normalization of utility data:
    i. Run the operational model, respecting the input constraints in Section 3.4, using normal (i.e. TMY2 or TMY3) weather assumptions.
    ii. Run a regression of energy usage against local dry bulb temperatures or Heating Degree Day/Cooling Degree Day (HDD/CDD) for the time span of the usage data. This will separate baseload usage and determine temperature or degree-day dependence of heating and cooling usage for the period of the billing data, for each energy source. The regression shall be conducted using a linear or change-point linear model in accordance with ASHRAE Guideline 14, Annex D, Section D2.
    iii. Weather-normalize the heating and/or cooling energy usage by applying the temperature -dependence of that usage determined in Step ii, to the normal weather conditions used for Step i, resulting in estimates of normalized baseload, heating, and cooling.
    iv. Compare the modeled energy usage to the weather-normalized energy usage following the criteria of Section 3.2.3.A.
    v. Input adjustments may be made to the operational model to meet the criteria of Section 3.2.3.A. This may be done by the user, or by the software, respecting all required input constraints in Section 3.4.
      1. When adjusting inputs to achieve an acceptable match between the operational model and the historical energy consumption, a systematic

approach that prioritizes inputs with higher uncertainty and larger influence on the model shall be used. However, inputs that represent actual measurements or direct observations shall not be adjusted to achieve calibration. Examples of inputs that can have high uncertainty and large influence on the model include the R-values of uninsulated assemblies, duct or shell leakage that is not measured, use intensity of miscellaneous electric loads such as dehumidifier, etc. There can be multiple ways to adjust inputs in order to achieve sufficient agreement between model predictions and utility data. Thus, it is import to carefully select which inputs are adjusted, and in cases where multiple calibration solutions are obtained, to select the solution that is believed to be the most realistic and probable match. Statistical methods to estimate probable solutions, if available, are preferred over manual adjustments. The selected operational model that achieves an acceptable match is the calibrated pre-retrofit operational model.

or:

b. Energy model with actual weather:

   i. Run the operational model, respecting the input constraints in Section 3.4, using actual weather data representing the same time span as the utility billing period (including actual dry-bulb temperatures at a minimum; "actual weather data" may include actual or normal data for other weather conditions such as solar radiation).

   ii. For each fuel, compare the modeled energy usage to the actual energy usage over the same billing period time spans, following the criteria of Section 3.2.3.B.

   iii. Input adjustments ([refer to 3.2.1(C)(a)(v)]) may be made to the pre-retrofit operational model to meet the criteria of Section 3.2.3.B. This may be done by the user, or by the software, respecting all required input constraints in Section 3.4.

   iv. Replace the actual weather data with normal (e.g., TMY2 or TMY3) weather data to generate the calibrated pre-retrofit operational model.

3.2.2. Model Calibration Utility Bill Criteria

For metered energy sources such as electricity or natural gas, billing data shall be adequate to meet the following criteria. If these acceptance criteria A through G below are not met, the simplified calibration procedure (section 3.3) may be used as an alternate.

A. The most recent meter reading or usage measurement shall be within the past year;

B. The date of each meter reading is recorded;

C. The amount of energy use measured during that utility billing period is recorded;

D. Estimated reads: For the purpose of weather-normalization of the utility bills, the date of an estimated reading shall be eliminated and the estimated energy use shall be added to the energy use corresponding to the following actual reading, over the total time span since the previous actual reading.

E. Up to 2 of the billing periods may be eliminated from the analysis to account for atypical periods such as vacations[2].

F. For fuels that provide heating or cooling, the usage data after accounting for estimated readings and vacation periods must meet either of the following criteria:

   a. Span at least 330 days or

   b. Span more than 183 days and

   - if fuel provides heating:
     - total HDDs in time span > 0.5 * $HDD65_{TMY}$
     - at least one period with HDD/day < 0.2 * $HDD65_{TMY}$ /365
     - at least one period with HDD/day > 1.2 * $HDD65_{TMY}$ /365.
   - if fuel provides cooling:
     - total CDDs in time span > 0.5 * $CDD65_{TMY}$
     - at least one period with CDD/day < 0.2 * $CDD65_{TMY}$/365
     - at least one period with CDD/day > 1.2 * $CDD65_{TMY}$/365.

Where:

$HDD65_{TMY}$ = annual heating degree-days base 65°F from normal weather data (e.g., TMY2 or TMY3) consistent with the weather data used in the operational model

$CDD65_{TMY}$ = annual cooling degree-days base 65°F from normal weather data (e.g., TMY2 or TMY3) consistent with the weather data used in the operational model

G. For fuels that provide heating or cooling, run a regression of energy usage against local dry bulb temperatures or HDD/CDD in accordance with section 3.2.1.C.a.ii. The Coefficient of Variation of the Root Mean Square Error (CVRMSE) of the regression results shall be determined using equation 3.2.2.G.i:

$$CVRMSE = 100 \times [\sum(y_i - \hat{y}_i)^2/(n-p)]^{0.5} / \bar{y} \qquad \text{Eqn. 3.2.2.G.i}$$

Where:

n = number of billing periods

y = the consumption from a single utility bill

$\hat{y}$ = the fitted value using the regression results for the same utility bill period

$\bar{y}$ = the arithmetic mean of the sample of n utility bills

p = the number of parameters in the regression analysis of the utility bills. For example, a variable-base heating degree day (change-point) analysis has 3 parameters: degree day base, slope, and baseload.

The acceptance limit for the bill regression is a CVRMSE of <=20%.

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[2] An example approach for removing abnormal billing periods is described in Annex D.

3.2.3. Detailed Model Calibration Acceptance Criteria

A. Acceptance Criteria for Simulation results using Weather-Normalized Utility Data

The Bias Error (BE) and Absolute Error (AE) shall be determined using equations 3.2.3.A.i and 3.2.3.A.ii, respectively for each end-use (baseload, heating, and cooling).

$$BE = \frac{(x_i - \hat{x}_i)}{\text{NAC}} \times 100 \qquad \text{Eqn. 3.2.3.A.i}$$

$$AE = |x_i - \hat{x}_i| \qquad \text{Eqn. 3.2.3.A.ii}$$

Where:

x =the weather-normalized consumption from the regression for an end-use

$\hat{x}$ = the simulation predicted value for the same end-use

NAC = the normalized annual consumption from the weather normalization for that end-use

The acceptance criteria for calculated simulation results using weather-normalized utility data is *either* |BE| <= 5%, *or* an AE <= 5 Mbtu (5 * 10^6 btu) (for fossil fuels) or AE <= 500 kWh (for electricity).

B. Acceptance Criteria for Energy Model with Actual Weather
The Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Square Error (CVRMSE) shall be determined using equations 3.2.3.B.i and 3.2.3.B.ii, respectively.

$$NMBE = \frac{\sum_n (y_i - \hat{y}_i)}{(n-1)\bar{y}} \times 100 \qquad \text{Eqn. 3.2.3.B.i}$$

$$CVRMSE = 100 \times \left[\sum (y_i - \hat{y}_i)^2 / (n-1)\right]^{0.5} / \bar{y} \qquad \text{Eqn. 3.2.3.B.ii}$$

Where:

n = number of billing periods

y =the consumption from a single utility bill

$\hat{y}$ = the simulation predicted value for the same utility bill period

$\bar{y}$ = the arithmetic mean of the sample of n utility bills

The acceptance limit for a calibrated energy model with actual weather is as follows: |NMBE| <= 5% *and* CVRMSE <= 20%.

3.3. Simplified Calibration

3.3.1. Model Calibration Delivered Fuel Criteria

For delivered fuel sources such as oil, LP, or pellets, minimum information shall include:

A. The date of the purchase(s) or deliveries based on receipt or delivery invoice from the fuel supplier for one year;

B. The amount of fuel purchased or delivered;

C. There shall be a minimum of 2 delivery records, and the time between the date of the first and last delivery record shall be 355 days or more.

D. If the delivery records are detailed enough to meet the criteria under 3.2.2 above, then detailed calibration shall be used for delivered fuel. Otherwise, simplified calibration shall be used.

E. If the delivery records do not meet the criteria under 3.2.2 the usage shall be calculated as the sum of all deliveries in the overall time span except for the first delivery, which assumes the tank is filled with each delivery.

3.3.2. Simplified Calibration Procedure

A simplified calibration of an operational model may be used for delivered fuels if delivery receipts providing consumption that spans at least one year are available. It may also be used if metered energy bills do not meet the criteria of Section 3.2.2 but do meet the criteria of Section 3.3.1. The simplified calibration path requires the following steps:

A. Determine that available delivery receipts or utility data meet the requirements of section 3.3.1.

B. Run a pre-retrofit operational model, respecting the input constraints in Section 3.4.

C. For each fuel used, determine the estimated annualized usage U_{ann} using equation 3.3.2.C.i.

$$U_{ann} = U_{raw} \Big/ \left(B_{fr} \times \frac{d}{365} + H_{fr} \times \frac{HDD65_{AW}}{HDD65_{TMY}} + C_{fr} \times \frac{CDD65_{AW}}{CDD65_{TMY}} \right) \qquad \text{Eqn. 3.3.2.C.i}$$

Where:

U_{raw} = total raw (unadjusted) fuel usage for the entire period

B_{fr} = modeled baseload annual usage / modeled total annual usage for the fuel. B_{fr}=0 if the fuel is not used for baseload.

d = number of days spanned by the period

H_{fr} = modeled heating annual usage / modeled total annual usage. H_{fr}= 0 if the fuel is not used for heating.

C_{fr} = modeled cooling annual usage / modeled total annual usage. C_{fr}= 0 if the fuel is not used for cooling.

$HDD65_{AW}$ = heating degree-days base 65°F from actual weather data for the entire period

$HDD65_{TMY}$ = annual heating degree-days base 65°F from normal weather data (TMY2 or TMY3) consistent with the weather data used in the operational model

$CDD65_{AW}$ = cooling degree-days base 65°F from actual weather data for the entire period

$CDD65_{TMY}$ = annual cooling degree-days base 65°F from normal weather data (TMY2 or TMY3) consistent with the weather data used in the operational model

D. Next, calculate the normalized heating, cooling, and baseload consumption using equations 3.3.2.D.i, 3.3.2.D.ii, and 3.3.2.D.iii:

$$NABU = U_{ann} \times B_{fr} \qquad \text{Eqn. 3.3.2.D.i}$$
$$NAHU = U_{ann} \times H_{fr} \qquad \text{Eqn. 3.3.2.D.ii}$$
$$NACU = U_{ann} \times C_{fr} \qquad \text{Eqn. 3.3.2.D.iii}$$

Where:

NAHU = Normalized Annual Heating Usage

NACU = Normalized Annual Cooling Usage

NABU = Normalized Annual Baseload Usage

E. For fuels using this calibration option, compare the modeled annual energy consumption for each end - use, to the applicable NAHU, NACU, and NABU from Step D above, as follows:

$$BE = \frac{(\mathrm{NAxU} - \hat{x}_i)}{\mathrm{NAxU}} \times 100 \qquad \text{Eqn. 3.3.2.A.i}$$

$$AE = |\mathrm{NAxU} - \hat{x}_i| \qquad \text{Eqn. 3.3.2.A.ii}$$

Where:

$\hat{x}$ = the simulation predicted value for the same end-use

NAxU = the normalized annual consumption from the weather normalization for that end-use as defined above

The acceptance criteria for calculated simulation results using the simplified method is either |BE| <= 5%, or an AE <= 5 Mbtu (5 * 10^6 Btu) (for fossil fuels) or AE <= 500 kWh (for electricity).

F. Input adjustments ([refer to 3.2.1.(C)(a)(v)]) may be made to the pre-retrofit operational model until the modeled consumption by end-use meets the acceptance criteria. This may be done by the user, or by software, respecting all required input constraints in Section 3.4.

3.4. Model Input Constraints

Tables 3.4.i and 3.4.ii indicate the limits that shall be used for input values or intermediate calculation results for physical parameters of the building. If the approved software does not enforce these input constraints at the user input level, then the software shall provide the value used in the energy simulation, either as an explicit input or a displayed value, so that the user can ensure compliance with these constraints, or provide appropriate warnings to the user. These constraints directly apply to the pre-retrofit model; they apply implicitly to the post-retrofit model because the post-retrofit model shall only vary from the pre-retrofit model in the details of specifically modeled ECMs. Therefore, elements of the home that are not part of the package of ECMs shall be modeled identically in the pre-retrofit and post-retrofit models. In addition to the values in Table 3.4.i, distribution system efficiency (DSE) shall be calculated by the software based on user description of the physical duct system, whether measured or estimated (location, insulation levels, leakage) and not directly input as DSE. Enclosure air leakage values, if measured, shall be input as CFM at 50 Pa, or ACH at 50 Pa, and not as estimated “natural” CFM or ACH.

Table 3.4.i Input Constraints

Input	Minimum Value	Maximum Value
Heating thermostat setpoint	58° F	76° F
Cooling thermostat setpoint	68° F	86° F
Domestic hot water setpoint	110° F	N/A
Forced-air furnace AFUE*	72%	N/A
Hot water / steam boiler AFUE*	60%	N/A
Heat Pump HSPF*	6.5	N/A
Heat Pump SEER*	9.0	N/A
Central air conditioner SEER*	9.0	N/A
Room air conditioner EER*	8.0	N/A
Gas-fired storage water heater EF*	0.50	N/A
Oil-fired storage water heater EF*	0.45	N/A
Electric storage water heater EF*	0.86	N/A
Interior lighting hours/day (average for home)	N/A	5
U-factor†: uninsulated wood-frame wall	N/A	0.222
U-factor†: uninsulated masonry wall	N/A	0.250
U-factor†: uninsulated wood-frame ceiling with attic (R-value from interior to attic space)	N/A	0.286
U-factor†: uninsulated unfinished roof	N/A	0.400
U-factor†: uninsulated wood-frame floor	N/A	0.222
U-factor†: single-pane window, wood frame	N/A	0.714
U-factor†: Single-pane window, metal frame	N/A	0.833

* **Exception:** Where the labeled equipment efficiency exists for the specified piece of existing equipment, the labeled or measured steady state efficiency may be used in lieu of the applicable minimum input constraints.

†U-factor includes air films.

Calculated distribution system efficiency (DSE) for ducted distribution systems shall be limited to the values in Table 3.4.ii for heating and/or cooling as applicable. For software that does not calculate an annual DSE, the DSE may be approximated by equation 3.4.i:

$$DSE \approx \frac{Building\ Load}{Equipment\ Efficiency \times Consumption} \qquad \text{Eqn. 3.4.i}$$

Where:

Building Load = the modeled annual heating or cooling load of the building (as applicable)

Equipment Efficiency = the modeled efficiency of the equipment, independent of distribution system

For software that models equipment efficiency on an hourly basis, manufacturer's equipment performance rating (MEPR), converted to dimensionless units, may be substituted.

Consumption = the modeled total energy consumption for heating or cooling (as applicable), in the same units as Building Load

Table 3.4.ii Constraints on Ducted Distribution System Efficiency

Duct location	Minimum DSE
Conditioned Space	88%
Unconditioned basement or crawlspace (no insulation in walls or ceiling, or insulated walls)	85%
Unconditioned Basement or crawlspace (insulated ceiling)	75%
Vented crawlspace	70%
Garage	60%
Attic: heating DSE	60%
Attic: cooling DSE	50%

4. Savings Calculations

4.1. Operational Savings Calculation

Operational energy savings for existing home retrofits shall be determined by comparing a pre-retrofit calibrated operational model with a post-retrofit operational model. To create the post-retrofit operational model, ECMs shall be applied to the calibrated pre-retrofit operational model. Any input adjustments made to the pre-retrofit model to calibrate to the normalized annual usage shall be duplicated in the post-retrofit model, with the exception of inputs altered specific to application of the ECMs. The difference in modeled fuel usage between the calibrated pre-retrofit operational model and the post-retrofit operational model is the operational savings for the proposed ECMs.

During the comparison, both the modeled and measured energy consumption shall be based either on actual weather, or "normal" weather. Although actual weather data may be used in the model when comparing to measured consumption that has not been weather-normalized, the final calibrated model shall use normal weather data for making savings predictions.

4.2. Asset-Based Savings Calculation

Asset-based energy savings for existing home retrofits shall be determined by taking the difference between a pre-retrofit calibrated model and a post-retrofit calibrated model, as described in Section 4.1, and additionally in accordance with the provisions of this section.

4.2.1. Pre-Retrofit Asset Model

The pre-retrofit asset model for the purposes of determining the asset-based energy savings of a set of ECMs shall be the original configuration of the existing home, as calibrated in accordance with Sections 3.2.1 and/or 3.3.2, with the following exceptions:

A. The pre-retrofit asset model shall include the full complement of lighting, appliances, and residual miscellaneous energy use as specified by Tables 303.4.1.7.1(1) and 303.4.1.7.1(2) of the 2006 Mortgage Industry National Home Energy Rating System Standards dated November 15, 2011 (hereinafter "the RESNET HERS Standards").

B. Where multiple appliances of the same type exist in the original configuration of the existing home, the same number of those appliance types shall be included in the pre-retrofit asset model.

C. Where a standard appliance, as shown in Tables 303.4.1.7.1(1) and 303.4.1.7.1(2) of the RESNET HERS Standards, does not exist in the original configuration of the existing home, the standard default energy use and internal gains as specified by Table 303.4.1(3) of the RESNET HERS Standards for that appliance shall be included in the pre-retrofit asset model.

    a. Large permanently-installed end-uses that are not covered by the RESNET Standards (e.g., swimming pool, spa, driveway/sidewalk snowmelt system) shall be included in the asset model as configured in the calibrated operational model.

D. Standard operating conditions in accordance with Section 3.4 of this standard shall be applied to the pre-retrofit asset model.

4.2.2. Post-Retrofit Asset Model

The post-retrofit asset model for the purpose of determining the asset-based energy savings of a set of ECMs shall be the existing home's configuration in accordance with Section 4.2.1 of this standard, including all ECMs, and including the full complement of lighting, appliances, and residual miscellaneous energy use contained in the home after all energy improvements have been implemented.

A. Where an appliance has been upgraded but the existing appliance is not removed from the existing home property, both the new and existing appliance shall be included in the post-retrofit model.[3]

B. Where a standard appliance as shown in Tables 303.4.1.7.1(1) and 303.4.1.7.1(2) of the RESNET HERS Standards does not exist in the improved configuration of the existing home, the standard default energy use and internal gains as specified by Table 303.4.1(3) of the RESNET HERS Standards for that appliance shall be included in the post-retrofit asset model.

C. Improvements in lighting and appliance energy use in the post-retrofit model shall be calculated in accordance with Section 303.4.1.7.2 of the RESNET HERS Standards.

    a. Large permanently-installed end-uses that are not covered by the RESNET Standards (e.g., swimming pool, spa, driveway/sidewalk snowmelt system) shall be included in the post-retrofit asset model as configured in the calibrated operational model. Where a pool pump is replaced

[3] For example, if a refrigerator is upgraded to a more efficient model and the original refrigerator is kept on property for potential use as a second refrigerator; both refrigerators shall be included in the post-retrofit asset model.

as part of the ECMs, the reduced electric consumption of the new pump may be included in the post-retrofit asset model.

D. Standard operating conditions in accordance with Section 4.2.3 of this standard shall be applied to the post-retrofit asset model.

4.2.3. Standard Operating Conditions

A. Both the pre- and post-retrofit asset models shall be configured in accordance with the Rated Home specifications of Table 303.4.1(1) of the RESNET HERS Standards, where "same as rated home" shall be taken to mean "same as the pre- and post-retrofit home being modeled" for the purpose of this standard.
Exceptions:
   a. Both the pre- and post-retrofit asset model configurations shall not violate the input constraints specified in Section 3.4 of this standard;
   b. Roofs shall be "same as rated home" as modeled in the calibrated operational model;
   c. Crawlspaces shall be "same as rated home" as modeled in the calibrated operational model;
   d. Glazing/external shading may include exterior, fixed, non-architectural shading (trees, buildings, etc), as modeled in the calibrated operational model;
   e. Air exchange rate shall be "same as rated home" as modeled in the calibrated operational model;
   f. Internal mass shall be "same as rated home" as modeled in the calibrated operational model;
   g. Thermal distribution systems shall be "same as rated home" as modeled in the calibrated operational model.

4.3. Total Equivalent Energy Savings Calculation

4.3.1. Equivalent Energy Use

Energy units used in the calculation of *total equivalent energy savings* and *equivalent energy savings percentage* shall be in units of Equivalent Electric Energy, using equivalent electric energy for all fossil fuels.[4] Equivalent electric energy use shall be calculated using Equation 4.3.1.i:

$$kWh_{eq} = kWh_{elec} + \frac{Btu_{fossil} * 0.4}{3412} \qquad \text{Eqn. 4.3.1.i}$$

4.3.2. Total Equivalent Energy Savings

Total equivalent energy savings shall be calculated as the difference between the whole-house projected equivalent energy use of the pre-retrofit model and the whole-house projected equivalent energy use of the post-retrofit model. Total equivalent energy savings shall be calculated for the calibrated operational model, except when a client, sponsor, lender, or other interested third party requires an asset-based total energy savings, in which case the asset-based model is used.

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[4] The total equivalent energy savings calculation provides a standardized method to combine multiple fuel types and end-uses in a home to represent the energy consumption and whole-house savings in consistent units. The use of equivalent energy savings does not preclude the reporting of specific estimated savings in appropriate fuel units for specific end-uses or recommended measures, or other metrics such as source or site energy savings that may apply to individual measures or a full project workscope.

4.3.3. Equivalent Energy Savings Percentage

The equivalent energy savings percentage of the retrofit shall be calculated as the whole-house equivalent energy savings, as determined in Section 4.3.1 above, divided by the whole-house equivalent energy use of the pre-retrofit model, multiplied by 100. Equivalent energy savings percentage shall be calculated for the calibrated operational model, except when a client, sponsor, lender, or other interested third party requires an asset-based energy savings percentage in which case the asset-based model is used.

Annex A: Referenced Documents (Normative)

Procedures for Certifying Residential Energy Efficiency Tax Credits – RESNET Publication No. 06-001, Revised Nov 7, 2011. Residential Energy Services Network, Inc., P.O. Box 4561, Oceanside, CA 92052-4561; www.resnet.us.

2006 Mortgage Industry National Home Energy Rating Systems Standards, November 15, 2011. Residential Energy Services Network, Inc., P.O. Box 4561, Oceanside, CA 92052-4561; www.resnet.us.

ASHRAE Guideline 14-2014, Measurement of Energy, Demand and Water Savings American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA 30329; www.ashrae.org.

Annex B: Terms and Definitions (Normative)

Approved building energy simulation software
Software tools meeting the minimum requirements of Section 3.1

Asset model
Whole-building energy simulation in which occupancy-related factors are configured to represent a standardized set of operating conditions

Asset-based savings
Savings estimate produced from the delta simulation using the same standard operating conditions and standard weather conditions in both the pre-retrofit and post-retrofit models to eliminate occupant behavior and weather variations. (Note: Asset-based savings may be required for the purpose of real estate listing or financing.)

Baseload
Energy or fuel that is consumed by household devices that has little to no dependence on outside air temperature including, but not limited to, lighting, kitchen and cleaning appliances, domestic hot water, and electronics

Calibrated model
Whole-building energy simulation in which the inputs are adjusted so that the modeled pre-retrofit energy consumption is within an acceptable range of the measured energy consumption

Coefficient of variation of the root mean square error: CVRMSE
Measures variability (or spread) in the data

Delivered fuels
Fuel that is delivered to and stored on the site including, but not limited to, fuel oil, LP gas, wood, coal, and pellets

Delta simulation
Difference in energy consumption estimates between a pre-retrofit model and a post-retrofit model, using the same operating conditions and weather assumptions, where the difference between the modeled energy consumption of the two models is considered the estimated savings (for each fuel used)

Energy conservation measures (ECM)
Proposed improvement or a package of proposed improvements to a building intended to reduce energy consumption

Input constraints
Limitations to certain inputs used in the pre-retrofit model which provide reasonable limits on savings estimates for particular ECMs

Metered energy
Energy or fuel for which consumption data is collected over time using a metering device or devices including, but not limited to, electricity and natural gas

Normal weather data
A statistically-derived, standardized description of weather representing a typical year. (Examples include TMY2, TMY3.) As applicable, normal weather data shall be approved by the Authority Having Jurisdiction

Normalized mean bias error (NMBE)
Verifies that energy usage estimated by the energy model is within acceptable range from the annual average usage based on utility bills for each energy source

Operational model
Whole-building energy simulation in which major occupancy-related factors are configured to represent actual operating conditions as accurately as practical

> (Note: For example, thermostat settings/schedule, occupancy schedule, frequency/intensity of lighting and appliance usage, window shading, and energy consumption of other amenities (including seasonal uses) are represented to the extent possible in the simulation software.)

Operational-based savings
Savings estimate produced from the delta simulation using the same operating conditions and standard weather conditions in both the pre-retrofit and post-retrofit models, to simulate occupant behavior, while eliminating weather variations

> (Note: Operational savings may be used to demonstrate estimated performance improvements to current building owners or occupants.)

Post-retrofit model
Simulation based on a physical description of the house's state after the ECMs are installed, based on the projected installation of ECMs, or (when available) a post-installation inspection of the home

Pre-retrofit model
Simulation based on a physical description of the house as it exists prior to installation of ECMs

Reviewing body
Agent identified as the implementer of a quality assurance process. This may be an accrediting body or a third party identified by a program sponsor or the accrediting body

Townhouse
A single-family dwelling unit which was designed to have continuous party walls with no penetrations to adjacent units, with such party walls extending from ground to roof where the dwelling unit is attached to one or more adjacent single-family dwelling units

Annex C: Quality Assurance (Informative)

[This Annex is not part of the standard. It is merely informative and does not contain requirements necessary for the conformance to the standard. It may contain material that has not been subject to ANSI requirements regarding public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at BPI or ANSI.]

This Annex is written in normative language so that a user of this standard may choose to include one of the quality assurance procedures listed in this Annex. The user shall specify which level (1 – 4) of quality assurance they require.

Quality Assurance (QA) as applied to this standard is a system for verification that the modeling was conducted in accordance with the criteria established by this Standard. A quality assurance program helps ensure that the software-based savings predictions are accurate and reduces bias and other sources of error. There are several areas in which the overall quality assurance process helps assure that the projected savings will be realized with a high degree of confidence:

1. Self-enforcement of requirement that the auditor meet the criteria of this Standard
2. Third party review that the submitted model and analysis meet the criteria of this Standard
3. Third party detailed hand review through the model and analysis
4. Third party field review based on the outcome of the model review

C.1 Self-Enforcement of Meeting this Standard

The first step in quality assurance is self-review and self-enforcement by the auditor conducting the energy audit as per the requirements of this Standard. The auditor shall review his or her work prior to submitting it to the program administrator to ensure that it is in full compliance with the Standard.

In cases in which the audit is not in full compliance with BPI-2400-S-2012, the auditor shall submit documentation regarding the reasons for the lack of compliance, together with the energy model(s). For example, if the auditor believes there is reason for an exception to the minimum R-value of an uninsulated wall required by Section 3.4(Input Constraints), then they shall supply documentation stating their rationale.

C.2 Third Party Minimum Model QA

The program administrator or other reviewing entity conducting QA shall verify that the submitted model and analysis meets the criteria of this standard by reviewing the energy audit and asking the following questions:

1. Is the model within acceptable calibration limits?
2. Were all constraints listed in Section 3.4 met?
3. If asset-based savings are being reported, were the standardized operating conditions applied correctly?

If any criteria of this standard are not met by the submitted model and analysis, the submission shall be returned to the auditor for correction and re-submission.

Additionally, the reviewing body should check that the workscope and/or report shows evidence of testing health and safety issues and addresses them as necessary in accordance with BPI draft standard 1100-S.

C.3 Third Party Detailed Model QA

A detailed model QA shall be done on the first 3 submissions from an auditor or contractor and then on 5% of their submission thereafter. The detailed review shall include, but not be limited to, the following actions:

1. Checking that the inputs and outputs from the model are reasonable for the house described in the report;
2. Checking that the parameters used for each ECM in the workscope are reasonable and conservative;
3. Performing the utility analysis from the raw metered or delivered energy data to determine whether or not the submitted results match, especially regarding the elimination of any energy data called out in Section 3.2.2.E.

C.4 Third Party Field Review Based on Model QA

Field-based quality assurance is more robust and more expensive. The analysis of energy model performance will be an enhancement of that process. Field inspections shall be performed for jobs identified through the random and automated review processes, based on criteria developed by the reviewing body.

C.5 Enforcement

Adverse results will require enforcement. The criteria developed by the reviewing body shall define progressive disciplinary action, up to and including suspension and loss of accreditation, based on the results of quality assurance reviews. Such process shall include mechanisms for appeal and a due process to provide for reinstatement of accreditation.

Annex D: Examples

(Informative)

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This Annex contains informative examples to support users in the implementation of the Standard.

A. Removing Abnormal Billing Periods

The following is one potential mathematical approach for identifying and removing abnormal billing periods, per Section 3.2.2.E:

1. Remove up to two billing periods that are known to be abnormal based on information provided by the homeowner. If two billing periods are removed in this step, do not proceed to Step 2 because no additional billing periods may be removed.
2. Create a regression model using all remaining data (e.g., a three-parameter heating model for natural gas usage).
3. For each billing period, calculate the regression model-predicted energy use, Er.
4. For each billing period, calculate the difference (residual, R) between the regression model-predicted energy use, Er, and the measured energy use, Em: R = Er – Em.
5. Calculate the arithmetic mean and sample standard deviation of the residuals. Identify any billing periods where the residual value does not fall within the interval: (mean of residuals) ± 3 × (standard deviation of residuals). A total of two billing periods may be removed from the analysis, counting any billing periods that were removed in Step 1. If more abnormal billing periods are identified than can be removed, remove the period(s) where the residuals are farthest from the mean residual.
6. Do NOT repeat. This approach should only be applied once to the data.