



Chapter 5: Residential Furnaces and Boilers Evaluation Protocol

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

Created as part of subcontract with period of performance
September 2011 – September 2016

This document was republished in September 2017 after a thorough review; no substantive changes were made. This supersedes the version originally published in April 2013.

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Preface

This document was developed for the U.S. Department of Energy Uniform Methods Project (UMP). The UMP provides model protocols for determining energy and demand savings that result from specific energy-efficiency measures implemented through state and utility programs. In most cases, the measure protocols are based on a particular option identified by the International Performance Verification and Measurement Protocol; however, this work provides a more detailed approach to implementing that option. Each chapter is written by technical experts in collaboration with their peers, reviewed by industry experts, and subject to public review and comment. The protocols are updated on an as-needed basis.

The UMP protocols can be used by utilities, program administrators, public utility commissions, evaluators, and other stakeholders for both program planning and evaluation.

To learn more about the UMP, visit the website, <https://energy.gov/eere/about-us/ump-home>, or download the UMP introduction document at <http://www.nrel.gov/docs/fy17osti/68557.pdf>.

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Acronyms

AFUE	annual fuel utilization efficiency
Btu	British thermal unit
CEE	Consortium for Energy Efficiency
DOE	U.S. Department of Energy
ECM	electronically commutated motors
EFLH	equivalent full-load hours
EM&V	evaluation, measurement, and verification
HVAC	heating, ventilating, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
M&V	measurement and verification
TRM	typical technical reference manual
UMP	Uniform Methods Project

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1 Measure Description

The high-efficiency boiler and furnace measure produces gas heating¹ savings resulting from installation of more energy-efficient heating equipment in a residence. Such equipment, which ranges in size from 60 kBtu/hr to 300 kBtu/hr, is installed primarily in single-family homes and multifamily buildings with individual heating systems for each dwelling unit. This protocol does not cover integrated heating and water heating units which can be used in lieu of space heating only equipment.

¹ High-efficiency equipment can also be fueled by propane; however, for this protocol to be applied, bills must be provided on a monthly basis.

2 Application Conditions of Protocol

Table 1 shows typical mid-level efficiency program rebate offerings for this measure.²

Table 1. Mid-Level Qualifying Efficiency and Rebate Values

Measure	Efficiency Requirement	Rebate Amount
Natural gas forced-air furnace	92% to 93.9% AFUE	\$150
Natural gas forced-air furnace	94% to 95.9% AFUE	\$300
Natural gas forced-air furnace	96% or higher AFUE	\$400
Natural gas boiler	83.5% to 90.9% AFUE	\$300
Condensing natural gas boiler	91% or higher AFUE	\$500

A more aggressive program may offer the rebates shown in Table 2.³

Table 2. Higher-Level Qualifying Efficiency and Rebate Values

Measure	Efficiency Requirement	Rebate Amount
Natural gas forced-air furnace with ECM	96% or higher AFUE	\$800
Natural gas forced-air furnace without ECM	95% or higher AFUE	\$500
Natural gas hot water boiler	96% or higher AFUE	\$1,500
Natural gas hot water boiler	90% to 95.9% AFUE	\$1,000

The specific measure described in this protocol improves upon the efficiency of residential furnace and boilers in terms of the U.S. Department of Energy's (DOE's) annual fuel utilization efficiency (AFUE) rating. AFUE, the most widely used measure of seasonal thermal efficiency for residential-sized heating equipment, is defined as the amount of useful heat delivered from a unit into a heating system for distribution, compared to the amount of fuel supplied to the unit on an annual basis. Units with efficiency levels in excess of 90% generally rely on extracting additional energy—typically that lost up a flue—by condensing water vapor out of flue gas. Generally, this is accomplished using larger heat exchangers and a redesigned exhaust system to accommodate lower flue gas exit temperatures.

The measure primarily targets customers purchasing new equipment, usually for the following reasons:

- Acquiring a new home
- Converting to gas from oil or other fuel

² CenterPoint Energy's high-efficiency heating system rebate program offered in 2011. See www.centerpointenergy.com/services/naturalgas/residential/efficiencyrebatesandprograms/heatingssystemrebates/MN/.

³ MassSave/GasNetworks 2012 High Efficiency Heating and Water Heating Rebates for Residential Customers. See www.masssave.com/~media/Files/Residential/Applications%20and%20Rebate%20Forms/2012%20GN%20Rebate.ashx.

- Replacing equipment at the end of its normal life or upon failure
- Major remodeling of an existing home.

The program design assumes customers participating in a residential furnace and boiler program would purchase new equipment that meets applicable codes or standard practices. Therefore codes or standard practices provide the baseline from which savings can be calculated (rather than using the equipment being replaced as the baseline). The program seeks to encourage installation of higher-efficiency equipment by paying all or a significant portion of incremental costs for upgrading to such units.

Rebate programs, often used for such measures, are usually marketed through a utility (or other program administrator staff) and its heating and plumbing contractor partners. Typically, rebates are paid at a specified dollar amount per unit, depending on efficiency levels. (For residential equipment, size generally does not play a role, due to the narrow size range.)

Residential purchasers of new furnaces can also receive incentives for installing electronically commutated motors (ECMs) in place of standard efficiency motors on furnace fans or hot water distribution pumps. This protocol, however, does not cover ECMs, which primarily provide electricity savings. This protocol also does not cover add-on boiler control measures, such as outdoor temperature reset controls, as these often are used for retrofits of existing boilers.

Some comprehensive residential programs assist customers in determining the appropriate or “right” size of the unit to be installed relative to the predicted load of the home. As most residential boiler and furnace programs do not offer these services—and because the modeling becomes much more complex for programs that do—this protocol does not take into account the changes in capacity from such efforts.

3 Savings Calculations

Key issues in determining savings for this measure are:

- What data are collected at the time of installation or application for incentives?
- What data can be easily collected during an evaluation?
- What assumptions are made about baseline equipment-sizing practices?

As previously described, the installed unit's AFUE reflects its efficiency level. Typically, the AFUE rating is collected for each unit rebated, as incentive payments are contingent on receiving verification that the unit meets program requirements. However, the efficiency of the baseline unit is not typically tracked.

For determining unit-specific savings or overall average savings per unit, many common formulas calculating savings use unit size or "capacity" in their derivations. With air-conditioning units, the size or capacity ratings always are provided in cooling output (Btu/hr or tons) delivered from units. For heating equipment, however, both the rate of heat delivered from the system (that is, the output capacity) and the rate of energy the unit consumes (the input capacity) often are provided. Program administrators strive to be specific in their requests for the capacity ratings of incented heating units, however, the two ratings often are confused. Also, customers or plumbing and heating contractors sometimes fail to provide the information.

Input and output capacity ratings generally are provided as *peak* capacity and not annual average numbers represented by AFUE.

- For non-condensing boilers and for both condensing and non-condensing furnaces, the ratio of peak input and peak output come very close to the AFUE. Thus, nameplate data can approximate relative annual performance.
- For condensing boilers, peak capacity does not indicate annual performance well because units perform better at part-load conditions.

Thus, for the most efficient boilers (usually condensing units), it is not valid to assume the approximation of the ratio of rated peak input to output capacities is proportional to the AFUE. This difference carries implications regarding which formulas can be used to calculate savings.

Capacity values are needed for unit-specific calculations of gross savings, but when they are not supplied on rebate forms, program administrators often use the manufacturer-provided capacity information embedded in specific model numbers.⁴ However, the capacity indicated in model number nomenclature usually provides the input capacity in kBtu/hr rather than the output capacity. Due to differences in the capacity information provided by program participants—and how this affects derivation of formulas for calculating savings—the recommended formula is presented in two forms; which one is used depends on the capacity value provided. (The

⁴ For example, the York YP9C060B12MP12C is 60,000 Btu/hr input capacity, and the York YP9C100C12MP12C is rated at 100,000 Btu/hr input capacity.

Appendix to this chapter provides derivations for calculating savings through these two methods.)

- The first derivation assumes data collected regarding unit size is input capacity.
- The second derivation assumes size data collected is output heating capacity.

Generally, input capacity (rather than output capacity) is more readily available, and the recommended formula for calculating savings is based on the following assumptions:

- Input capacity (Btu/hr) remains the same for the baseline unit and the installed unit.
- Annual full-load operating hours, operating hours, and output capacity differ for each unit. (This is a reasonable assumption, given that if input energy remains the same, and the installed unit more efficiently converts input energy to output energy, the more efficient unit will run for fewer hours.)

In these circumstances, use Equation 1 to calculate savings from a high-efficiency unit replacing a baseline-efficiency unit:

Equation 1

$$\text{Savings}_{b-e} = \text{Capacity}_{\text{input-e}} * \text{EFLH}_{\text{e-installed}} * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

where:

$\text{Capacity}_{\text{input-e}}$ = peak heating input capacity of both the baseline and installed unit

$\text{EFLH}_{\text{e-installed}}$ = equivalent full-load hours of the installed high-efficiency unit

In some cases, program managers collect the output capacity (or what program managers interpret as output capacity).⁵ The alternative formula for calculating savings has been based on an assumption that runtimes (and, therefore, output capacities) are the same for high-efficiency units and baseline units. However, input capacities of baseline units differ for base- and high-efficiency units.^{6,7} That formula, based on the rated output capacity, is shown in Equation 2:

Equation 2

$$\text{Savings}_{b-e} = \text{Capacity}_{\text{output}} * \text{EFLH} * (1 / \text{AFUE}_b - 1 / \text{AFUE}_e)$$

where:

$\text{Capacity}_{\text{output}}$ = heating output capacity of both the baseline and installed high-efficiency unit

⁵ On some rebate forms, the field simply says the “capacity”; it does not specify whether it is input or output capacity.

⁶ This implies the same annual heating load on the home for the base and the installed unit.

⁷ This assumes input capacities for the base and high-efficiency units are different (that is, the installer, knowing the unit is more efficient—or relying on the ratings—will install a unit with smaller input requirements for the higher-efficiency unit). This makes engineering sense but, again, it depends on whether input or output ratings are used.

- EFLH = full-load equivalent hours of the baseline and installed high-efficiency unit
- AFUE_b = annual fuel utilization efficiency of the baseline code compliant/standard practice unit
- AFUE_e = annual fuel utilization efficiency of the high-efficiency unit

Note that the Capacity_{output} * EFLH equals the annual heating (Btu or therms) loss of a home to be met by the furnace or boiler. It does not represent the peak design load (Btu/hr) used by HVAC contractors to size a system to meet the peak heating load.

An alternative formula for calculating savings uses results from multiplying Equation 2 by AFUE_b/AFUE_b and noting Capacity_{output} / AFUE_b = Capacity_{input-b}.

Equation 3

$$\text{Savings} = \text{Capacity}_{\text{input-b}} * \text{EFLH} * [1 - (\text{AFUE}_b / \text{AFUE}_e)]$$

where:

$$\text{Capacity}_{\text{input-b}} = \text{heating input of the baseline unit}$$

As the baseline unit's input heating capacity rarely is known, this equation is seldom used correctly. The equation is discussed here because it is sometimes used incorrectly, in that the output heating capacity is substituted for the base unit's input capacity. Given the issues discussed above regarding rated peak output capacity of condensing boilers not being related to the AFUE, do not use Equation 2 or Equation 3 when calculating the savings from condensing boilers.

4 Measurement and Verification Plan

When choosing an option, consider the following factors:

- The equation variables used to calculate savings
- The uncertainty in the claimed estimates of each parameter
- The cost, complexity, and uncertainty in measuring each of those variables.⁸

4.1 IPMVP Option

As gas energy efficiency programs have shorter histories than electric energy efficiency programs, considerably fewer impact evaluations have been conducted for either gas programs as a whole or for specific measures (such as replacements of boilers and furnaces). A thorough literature search for detailed evaluations of furnace replacement and boiler efficiency programs resulted in a very limited number of studies (NMR and Cadmus 2010) (KEMA 2009) (KEMA 2008). Thus, less information is available to inform the development of a recommended protocol, compared to many other measures.

Given the large sample sizes required and the high costs of gas submetering, it is not feasible to conduct direct gas submetering of a sufficiently large sample to represent varying types of equipment (boilers and furnaces with varying efficiency levels) and different home and homeowner characteristics. Fortunately, the possible end uses for gas in homes are limited, making disaggregation of whole-house gas billing data into heating and non-heating components very reliable. Consequently, the methods used to evaluate this program to date have involved whole-house gas billing data.

Option C is the recommended International Performance Measurement and Verification Protocol (IPMVP) option for this measure: whole-facility regression analysis combined with site-level data on the capacity and efficiency of an installed unit. The methods of Option C entail combining a billing analysis with the equations presented above, which produces the most useful results at a reasonable expense. The methodologies can provide updated deemed savings results or updated parameters for use in typical technical reference manual (TRM) equations, as listed in equations 1 through 3. This is based on:

- The potential variables in the equations used to calculate savings (as previously discussed)
- The cost and complexity in measuring each of those variables
- The availability and relevance of billing data.

The primary variables for determining savings for high-efficiency boiler and furnaces are:

1. The installed unit size or capacity in Btu/hr (either input or output)

⁸ As discussed under the section *Considering Resource Constraints* of the “Introduction” chapter to this UMP report, small utilities (as defined under the U.S. Small Business Administration (SBA) regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

2. The AFUE rating of baseline unit
3. The AFUE rating of the installed unit
4. The annual equivalent full-load operating hours, determined from methods discussed below.

The key issue for evaluating time-of-replacement/replace-on-burnout/new construction programs is that baseline equipment cannot be measured or assessed for the same customer installing new equipment, as only high-efficiency units have been installed. Thus, the key challenges presented in evaluating this measure entail determining (1) what a customer would have installed in the program's absence and (2) how much energy the baseline equipment would have used.

The methods described below combine whole-building billing analysis with the savings equations provided above to calculate the evaluated gross savings for this measure.

4.2 Verification Process

The first step of the protocol entails verifying key program data collected on typical rebate forms, including the size (Btu/hr) and efficiency (AFUE) of the high-efficiency unit installed. Such data can be verified using a desk review of invoices and manufacturer specification sheets (which should be required for rebate payment) or through an on-site audit of a sample of participants to verify the quality of self-reported information. If efficiency and unit capacity are not collected for each participant, it is recommended that program application requirements be modified to include these important data.

Generally, the size and efficiency ratings for baseline units cannot be verified. However, the baseline efficiency is assumed to be the code-compliant AFUE rating in the service territory for a unit of the same size as the high-efficiency unit. Differences between the code-compliant units and the standard practice should be reflected in calculations of appropriate net-to-gross ratios. If the net-to-gross is not considered within the specific jurisdiction, use the efficiency noted in standard practice.

The standard installation practice for each category of furnaces and boilers can be determined through conducting detailed interviews with HVAC contractors and plumbers (when possible) and collecting shipment data from regional distributors.

4.3 Data Requirements

The key data to be collected for impact evaluations of furnace and boiler upgrade programs are:

- Type of unit (natural gas furnace, condensing hot water boiler, or steam boiler)
- Capacity of the unit in input or output Btu/hr, depending on the algorithm selected to calculate savings (as discussed, input capacity is preferred, and it is important to be explicit regarding whether the specified capacity is input or output)
- Efficiency of the installed unit in AFUE
- Assumed baseline efficiency for each type of equipment

- Type of housing unit (single-family, multifamily having one to four units, multifamily having more than four units)
- Location of each unit in terms of city or ZIP code and state, if multiple climate zones are analyzed (the location will be used to calculate heating degree days for weather normalization)
- Post-installation billing data for a minimum of 12 months (if available, a full 12 months of pre-installation data should be compiled for the preferred analysis method, discussed below).

4.4 Collecting Data

4.4.1 Capacity Ratings

For a unit's heating capacity, use ratings from the manufacturer's specifications, which generally are determined through Air-Conditioning, Heating, and Refrigeration Institute (AHRI)⁹ and DOE-approved standards for input and output capacity. As information already has been provided in an industry-approved manner, measuring input or output capacities through metering would be redundant. Although some variation may occur in an individual rebated unit's capacity, it is reasonable to assume that, on average, a unit's performance will be close to the manufacturer's ratings.

As noted, an issue exists regarding the capacity (input or output) captured for each unit in the program tracking system and whether this can be easily determined during an evaluation. Because input capacity is more readily available—and for high-efficiency condensing boilers, the relationship between the two capacities does not equal AFUE—use Equation 1. (The basis for the methodology is discussed below.)

4.4.2 Efficiency Levels

Similar to capacity, the efficiency levels of baseline and installed units would be extremely costly and difficult to field-verify over the heating season. Use the information on labels and the AHRI ratings for efficiency (an industry-accepted standard available in an online directory).¹⁰

4.4.3 Equivalent Full-Load Hours of Operation

Most equations use the number of equivalent full-load hours of operation as a variable for calculating savings. Depending on the evaluation methodology selected (as discussed below), this variable is either calculated as a product of the billing analysis-based evaluation, or it is not used at all in determining average savings per installation (also described below).

In some evaluations, direct measurement of operating hours has been attempted by metering furnace fans, but the technique has not been widely used. As many furnaces and boilers currently have more than one stage, the fan and pump hours do not always indicate the full-load hours needed for a calculation using full capacity as a variable.

⁹ Often listed as Gas Appliance Manufacturers Association (GAMA) in the manufacturer's literature. The Air-Conditioning and Refrigeration Institute and GAMA merged in 2007 to form AHRI.

¹⁰ www.ahridirectory.org/ahridirectory/pages/home.aspx

5 Discussion of Methodology

The methodology used to calculate savings for each unit and, if required, to calculate the corresponding EFLH, begins with Equation 1, provided here again. This assumes that the input Btu/hr would be the same for the baseline unit and the installed unit and that annual full-load operating hours, EFLH, and output capacity could be different.

Equation 1

$$\text{Savings} = \text{Capacity}_{\text{input-e}} * \text{EFLH}_{\text{e-installed}} * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

where:

$\text{Capacity}_{\text{input-e}}$ = heating input of both the baseline and installed unit in Btu/hr

$\text{EFLH}_{\text{e-installed}}$ = equivalent full-load hours of the installed high-efficiency unit

Assuming the gas used for heating = normalized annual heating consumption of the high efficiency (NAH_e), determined from a billing analysis (as discussed below), then:

Equation 4

- $\text{Savings} = \text{NAH}_e * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$

Assuming the AFUE is both available for a high percentage of units installed *and* accurately represents the efficiencies of baseline units and installed units over the year, this formula, combined with sufficient post-installation billing data, allows calculation of savings using a billing analysis.

The analysis offers an advantage over a simple deemed savings formula with estimated capacity and AFUE, in that the billing analysis has been based on actual heating consumption data. Such consumption data reflect the home's size, the unit's capacity, the building shell's efficiency and the operational schedules.

The analysis must first develop post-installation, normalized annual heating consumption (NAH_e). Chapter 8: *Whole-Building Retrofit* protocol addresses the recommended approach for this process, discussing a two-staged approach based on individual premise analysis. That approach begins by developing premise-specific estimates of overall normalized annual consumption (NAC), which is the combination of the end-use consumption of heating and other gas-baseline load (such as cooking and water heating).

Step 1 (analyzing the individual premise) and Step 2 (applying the Stage 1 model) within Chapter 8: *Whole-Building Retrofit* protocol provide guidance on models and on how to derive overall NAC from model results. (See Equation 5.)

Equation 5

$$NAC_e = \alpha * 365 + \beta_H H_0$$

NAH_e provides the equation's heating-related component, shown in Equation 6.

Equation 6

$$NAH_e = \beta_H H_0$$

Where:

β_H = heating slope in therms or hundred cubic feet (CCF) of natural gas per heating degree day

H_0 = the average normal heating degree days

α = non-heating usages in therms of CCF per day

Generally, premise-level NAH_e is aggregated to a program-average NAH_e for each category of boiler or furnace measure and then analyzed to develop an estimation of savings for each category.

Once NAH_e has been determined for each home or individual boiler or furnace studied, the savings can be easily calculated using Equation 4 *if* the AFUE is available for each installed unit *and* the assumed baseline AFUE is estimated.

Savings can be specified in a manner as granular as the participation data allow. For example, savings could be disaggregated into the following categories:

- Warm air furnaces with ECMs between 92% and 94% efficiency
- Hot water boilers between 88% and 92% efficiency and with input capacities between 60,000 and 80,000 Btu/hr
- Steam boilers more than 150,000 Btu/hr.

If an evaluation seeks to update variables in a TRM, use either Equation 1 or Equation 2:

Equation 1

$$\text{Savings} = \text{Capacity}_{\text{input-e}} * \text{EFLH}_e * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

or

Equation 2

$$\text{Savings} = \text{Capacity}_{\text{output-e}} * \text{EFLH}_e * (1/\text{AFUE}_b - 1/\text{AFUE}_e)$$

In each case, $EFLH_e$ can be determined by Equation 7:

Equation 7

$$EFLH_e = NAH_e / \text{Capacity}_{\text{input-e}}$$

The equation used is determined by:

- Whether the program collects $\text{Capacity}_{\text{input}}$, $\text{Capacity}_{\text{output}}$, or both as part of the application and data collection process
- What kind of equipment has qualified for incentives.

As previously discussed, equations using output capacity do not work for condensing boilers due to relationships between rated output capacity and AFUE.

Because these equations do not work universally for all types of equipment *and* the input capacity often is embedded in the model number's nomenclature, Equation 1 is the preferred way to calculate average savings per unit, assuming AFUE estimates accurately capture relative differences in efficiency.

Steps for calculating savings for each category of furnace and boiler are:

1. Determine the annual post-installation heating consumption NAH_e
2. Multiply the NAH_e by the percentage of increase in efficiencies of installed versus baseline units.

If using a TRM of the form Equation 1 or Equation 3, determine the EFLH for that category of equipment and then use the equation with the capacity and installed efficiency of each unit installed to determine the saving of each unit. Alternatively, use the average capacity and average installed efficiency to determine the category average savings.

5.1 More Refined Approach

The approach presented above is limited in that it does not contain (1) an analysis of pre-versus-post changes in consumption resulting from a furnace or boiler replacement or (2) actual measurement of actual efficiencies. That is, the approach is not grounded in any measurement of change in consumption resulting from the purchase of a new unit; instead, it relies on the post-consumption data and the ratio of baseline to high-efficiency AFUEs.

The post-only billing analysis also does not capture any potential “take-back” effect. In this instance, take-back could occur when participants purchase a more energy-efficient model than the baseline unit that participants otherwise would have, and then they “take” some of the actual or perceived savings to increase their comfort through higher thermostat settings.

A simple pre/post analysis is not possible because pre-replacement consumption data do not supply the appropriate baseline for a time-of-replacement program. Pre/post analysis, however, results in the consumption change between the installed high-efficiency unit and the older existing unit.

If one can reasonably determine the efficiency of the replaced unit in terms of $AFUE_{replaced}$, savings can be estimated using the three AFUEs:

- $AFUE_{replaced}$ = AFUE of the unit that was replaced
- $AFUE_e$ = AFUE of the high-efficiency unit
- $AFUE_b$ = AFUE of the baseline efficiency unit.

The difference in normalized annual heating (NAH) between the existing or replaced unit and the high-efficiency unit ($\Delta NAH_{e-replaced}$) can be determined through a billing analysis of participants.¹¹ The *Pooled Fixed-Effects* approach section of Chapter 8: *Whole-Building Retrofit* protocol discusses the model specification producing an average $\Delta NAH_{e-replaced}$. As with the premise-level modeling, the model’s heating-correlated parts capture heating consumption.

For the general pooled fixed-effects model, the key components are H_{im} (heating degree days), P_m (post-period indicator, capturing pre-post change) and I_{ki} (the measure indicator variable). These combine to estimate the change in heating consumption between pre- and post-installation periods. The change in normalized annual heating consumption is calculated as shown in Equation 8:

Equation 8

$$\Delta NAH_k = \gamma_{Hk} H_{0k} + \sum_q \gamma_{Hkq} H_{0k} X_{qk}$$

where the data, model structure, and estimation procedures are as described in Chapter 8: *Whole-Building Retrofit*.

The two-stage, site-level modeling approach discussed in Chapter 8: *Whole-Building Retrofit* can also provide a suitable estimate of average ΔNAH_k , which may be calculated as the difference in pre- and post- heating components of site-level models for participants and a comparison group. However, separate components of the site-level models are less stable than the overall NAC. Thus, for installations of furnaces and boilers without domestic hot water, ΔNAC_k should be close to ΔNAH_k and better determined than the heating-only ΔNAH_k .

Using equations for ΔNAH_{e-b} and for billing analysis-determined savings $\Delta NAH_{e-replaced}$, the following derivation provides an enhanced method for calculating savings, based on a change in consumption captured through billing analysis rather than through post-only consumption.

Assuming:

Equation 9

$$Savings_{e-replaced} = \Delta NAH_{e-replaced} = NAH_e * [(AFUE_e / AFUE_{replaced}) - 1]$$

¹¹ Again, the approach recommended for this process is discussed in the “Whole-Building Retrofit” protocol.

Equation 10

$$NAH_e = \Delta NAH_{e-replaced} / [(AFUE_e / AFUE_{replaced}) - 1]$$

Equation 4

$$Savings_{e-b} = NAH_e * [(AFUE_e / AFUE_b) - 1]$$

Equation 11

$$Savings_{e-b} = \Delta NAH_{e-replaced} * (AFUE_e / AFUE_b) - 1) / [(AFUE_e / AFUE_{replaced}) - 1]$$

Equation 12

$$Savings_{e-b} = \Delta NAH_{e-replaced} * (1/AFUE_b - 1/ AFUE_e) / (1/AFUE_{replaced} - 1/ AFUE_e)$$

The efficiency of the replaced unit, $AFUE_{replaced}$, can be determined through surveys of installation contractors. Ideally, the surveys would cover the age and efficiency of the measure. In many cases, contractors will not know the efficiency of the model replaced, however, the process of estimating the efficiencies can be helped by information regarding the age of the units, or examples of specific models, manufacturers, and capacities.¹²

The accuracy of this method is highly dependent on the quality of the $AFUE_{replaced}$ estimate. Contractors may tend to underestimate the efficiency of units replaced to justify the sale of more efficient units. This under estimate of the replaced unit efficiency would underestimate savings from going from a new baseline to high efficiency unit. When using a contractor survey, verify the responses with on-site visits in which the efficiency of the older unit being replaced can be assessed.

As with methods based exclusively on post-installation heating consumption, the savings for each unit can be determined using Equation 9, including only estimates of AFUE and post-installation billing data. Again, the average savings can be broken down as finely as participation data allow. Savings could be separated out for major equipment types (hot water boiler, steam boiler, and warm-air furnace, with or without ECM), efficiency (AFUE, condensing or non-condensing), and size categories (Btu/hr ranges), as listed in the typical program offerings above.

The preferred method does not lend itself to determining the EFLH to be used in typical TRM equations, but rather to calculating average therm or MMBtu savings by category. If use of a simplified TRM is necessary, Equation 13 or Equation 7 can be used with the average capacity of each unit to determine EFLH.

¹² Preston's guides provide a good resource for efficiency specifications on old units: www.prestonguide.com.

If average of the Capacity_{input} is known for each category, then:

Equation 13

$$\text{EFLH} = \text{Savings}_{e-b} / [\text{Capacity}_{\text{input}} * (\text{AFUE}_e / \text{AFUE}_b) - 1]$$

or

Equation 7

$$\text{EFLH} = \text{NAH}_e / \text{Capacity}_{\text{input-e}}$$

6 Sample Design

In general, the evaluator will determine the required target confidence and precision levels, subject to specific regulatory or program administrator requirements. In most jurisdictions, the generally accepted level should be designed to estimate the category-level savings or EFLH at a precision level of 10% at the 90% confidence interval. That said, as no physical measurements are involved, this protocol seeks to use data from *all* participants receiving rebates.

Consequently, sampling error will be as low as the availability of billing, capacity, and efficiency data permit. Traditional sampling will not occur, unless large data gaps emerge in efficiency or capacity. For the preferred method, using pre- and post-billing data and efficiencies only *and* assuming the installed AFUE is collected for each participant, the availability of billing data presents the only limitation.

The billing analysis itself will have errors in the development of heating consumption and changes in heating consumption, but the precision of those regression-based estimates can be calculated. The target for these estimates should be better than +/- 10% at a 90% confidence level. As the analysis generally includes *all* participants with available billing, the efficiency and capacity data-sampling errors are essentially eliminated, and the primary error results from the billing analysis and the assumptions in the development of the equations provided in this protocol.

Errors in the accuracy of efficiencies and capacities provided by manufacturers versus actual values in the field will not be determined as part of this protocol, given the costs of measurement, but they are assumed to be small, relative to errors in the billing analysis.

6.1 Program Evaluation Elements

At the study's onset, procedures need to be established for data validity. The key issues to address are:

- Clear determination whether capacity data collected are input or output
- The number of months of billing data from a site that are considered to be the minimum needed for analysis
- The procedures for filling in limited amounts of missing billing data.

6.2 Net-to Gross

A separate cross-cutting protocol to determine applicable net-to-gross is planned for Phase 2 of the Uniform Methods Project.

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9 Appendix

9.1 Simplified Formulas for Calculating Savings From Upgrading the Efficiency of a Residential Gas Furnace or Boiler

9.1.1 Constant Input Btu/hr for Baseline and Installed Units

The following applies when the input Btu/hr is available from the tracking database.

The major simplifying assumption is this: Input Btu/hr for the baseline and the high-efficiency unit would be the same, as is usually the case. Some contractors install smaller units if those units prove more efficient, but many installers use a unit with the same input Btu/hr size. For new construction, one must assume baseline and high-efficiency units would be the same size.

Assuming a building has the same annual heat loss Q_{loss} , regardless of the heating-unit efficiency, then:

$$Q_{\text{loss}} = \text{annual heat loss in Btu}$$

$$\text{Capacity}_{\text{input}} = \text{furnace or boiler input heat rate Btu/hr}$$

Then:

$$Q_{\text{loss}} = \text{Capacity}_{\text{input}} * \text{EFLH}_{\text{b}} * \text{AFUE}_{\text{b}}$$

$$Q_{\text{loss}} = \text{Capacity}_{\text{input}} * \text{EFLH}_{\text{e}} * \text{AFUE}_{\text{e}}$$

Where:

$$\text{EFLH}_{\text{b}} = \text{equivalent full-load run hours of baseline (hrs)}$$

$$\text{EFLH}_{\text{e}} = \text{equivalent full-load run hours of efficient unit (hrs)}$$

$$\text{AFUE}_{\text{b}} = \text{efficiency of baseline unit \%}$$

$$\text{AFUE}_{\text{e}} = \text{efficiency of efficient unit \%}$$

Then:

$$\text{EFLH}_{\text{b}} * \text{AFUE}_{\text{b}} = \text{EFLH}_{\text{e}} * \text{AFUE}_{\text{e}}$$

$$\text{EFLH}_{\text{b}} = \text{EFLH}_{\text{e}} * \text{AFUE}_{\text{e}} / \text{AFUE}_{\text{b}}$$

Savings result from the difference in gas heating consumption between the baseline unit and the efficient unit:

$$\begin{aligned} \text{Savings} &= \text{Capacity}_{\text{input}} * \text{EFLH}_b - \text{Capacity}_{\text{input}} * \text{EFLH}_e \\ &= \text{Capacity}_{\text{input}} * \text{EFLH}_e * (\text{AFUE}_e / \text{AFUE}_b) - \text{Capacity}_{\text{input}} * \text{EFLH}_e \\ &= \text{Capacity}_{\text{input}} * \text{EFLH}_e * ((\text{AFUE}_e / \text{AFUE}_b) - 1) \end{aligned}$$

To use the normalized annual heating (NAH) of gas for heating from billing data, via a degree day-based regression analysis or end-use metering, apply this equation:

$$\text{NAH}_e = \text{Capacity}_{\text{input}} * \text{EFLH}_e$$

Substituting the above into the savings equation produces:

$$\text{Savings} = \text{NAH}_e * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

So savings can be calculated using the above equation without the input heating capacity (if not known). Alternatively, the NAH_e can be divided by the input capacity to calculate an EFLH_e , which can be used with the efficiencies to calculate savings using:

$$\text{Savings} = \text{Capacity}_{\text{input}} * \text{EFLH}_e * (\text{AFUE}_e / \text{AFUE}_b) - 1$$

9.1.2 Constant Output Btu/hr for Baseline and Installed Units

The following applies when output Btu/hr is available from the tracking database; however, it does not apply to condensing boilers.

$$\text{AFUE} = \text{Useful Heat Delivered Out of Boiler or Furnace} / \text{Gas Input Capacity} = \text{Capacity}_{\text{output}} / \text{Capacity}_{\text{input}}$$

$$\text{Savings} = \text{Change in input for a given heating load}$$

$$\text{Input Energy}_b = \text{Annual Heating Load} / \text{AFUE}_b$$

$$\text{Input Energy}_e = \text{Annual Heating Load} / \text{AFUE}_e$$

Assuming annual heating loads served are the same for baseline and high-efficiency equipment, and *output* capacities ($\text{Capacity}_{\text{output-e}}$) of unit and hours are the same for each unit:

$$\text{Annual Heating Load} = \text{Capacity}_{\text{output-e}} * \text{EFLH}$$

Then:

$$\begin{aligned}\text{Savings} &= \text{Input Energy}_b - \text{Input Energy}_e = \text{Annual Heat Load} / \text{AFUE}_b - \text{Annual Heat Load} / \text{AFUE}_e \\ &= \text{Annual Heat Load} * (1/ \text{AFUE}_b - 1/ \text{AFUE}_e) \\ &= \text{Capacity}_{\text{output}} * \text{EFLH} * (1/ \text{AFUE}_b - 1/ \text{AFUE}_e)\end{aligned}$$

Rearranging:

$$\text{Savings} = \text{Capacity}_{\text{output}} * \text{EFLH} / \text{AFUE}_e * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

Noting that:

$$\text{Capacity}_{\text{output}} / \text{AFUE}_e = \text{Capacity}_{\text{input-e}} \text{ and } \text{NAH}_e = \text{Capacity}_{\text{input-e}} * \text{EFLH}_e$$

Yields the same equations as above:

$$\text{Savings} = \text{NAH}_e * [(\text{AFUE}_e / \text{AFUE}_b) - 1]$$

So again, savings can be calculated using the above equation, without requiring output or input heating capacity (if not known), or the NAC_e can be divided by the input capacity to calculate an EFLH, which can be used with the efficiencies and output capacity to calculate savings using:

$$\text{Savings} = \text{Capacity}_{\text{output}} * \text{EFLH}_e * (1/ \text{AFUE}_b - 1/ \text{AFUE}_e)$$