National Residential Efficiency Measures Database

Development Document, v3.0

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Executive Summary

The National Residential Efficiency Measures Database is a publicly available, centralized resource of residential building retrofit measures and costs for the U.S. building industry. With support from the U.S. Department of Energy, NREL developed this tool to help users determine the most cost-effective retrofit measures for improving energy efficiency of existing homes. This publicly accessible, centralized database of retrofit measures offers the following benefits:

- Provides information in a standardized format
- Improves the technical consistency and accuracy of the results of software programs
- Enables experts and stakeholders to view the retrofit information and provide comments to improve data quality
- Supports building science research & development
- Enhances transparency.

The primary audience for this database is a software developer who requires residential retrofit performance and cost data for applications that evaluate residential efficiency measures. In addition, a home performance contractor or manufacturer of residential materials and equipment may find this information useful.

The database is structured to store properties and costs for measure components and measure actions. A web user interface (UI) and Extensible Markup Language (XML) feeds provide user access to the data. NREL developed a set of rules to construct a list of measures based on component properties and action types. The NREL rules assemble measures from the disparate component and action data, providing details via the web UI and NREL Measures XML.

Version 1 of the Database was publically released in February 2010, v2 was released in October 2010, and v3 was released in July 2012.

This document describes the structure of the database and provides information regarding the collection and processing of underlying data and information utilized in developing and assembling the database.

Contents

List of Figures

List of Tables

Nomenclature

AC	Air-Conditioner
AFUE	Annual Fuel Utilization Efficiency
AHRI	Air-Conditioning, Heating and Refrigeration Institute
ANSI	American National Standards Institute
API	Application Programming Interface
ASHP	Air Source Heat Pump
AV	Adjusted Volume
BEopt	Building Energy Optimization Software
BLS	Bureau of Labor Statistics
Btu (kBtu)	British Thermal Unit (k = Thousand)
Btu/h (kBtu/h)	British Thermal Unit per Hour (k = Thousand)
CAC	Central Air-Conditioner
CFL	Compact Fluorescent Lamp
CHP	Central Heat Pump
CSA	Canadian Standards Association
CPI	Consumer Price Index
DHW	Domestic Hot Water
DOE	U.S. Department of Energy
EER	Energy Efficiency Ratio
EERE	DOE Office of Energy-Efficiency and Renewable Energy
EF	Energy Factor
EPA	Environment Protection Agency
ft	Foot
FHR	First-Hour Rating
GPM	Gallons Per Minute
GSHP	Ground Source Heat Pump
h	Hour
HES	Home Energy Saver
HPWH	Heat Pump Water Heater
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, Ventilating and Air-Conditioning
IECC-2009	International Energy Conservation Code - 2009
in	Inch
LBNL	Lawrence Berkeley National Laboratory
LPG	Liquid Propane Gas
MEF	Modified Energy Factor
Mil	A Thousandth of an Inch (0.001 Inch)
NEAT	National Energy Audit Tool
NG	Natural Gas
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory

O&P	Overhead and Profit
RAC	Room Air-Conditioner
R-value	A Measure of Resistance Assigned to Insulation
RE	Recovery Efficiency
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
UEC	Annual Energy Use
UL	Underwriters Laboratory
UI	User Interface
U-factor	Inverse of R-value, a Heat-Loss Coefficient.
V	Volume
WF	Water Factor
XPS	Extruded Polystyrene Continuous Insulation

1 Introduction

1.1 Purpose

This document provides a detailed explanation of the development of v3.0 of the National Residential Efficiency Measures Database. This project is sponsored by the US Department of Energy (DOE) Building Technologies Program (BTP) and designed and developed by the National Renewable Energy Laboratory (NREL).

1.2 Project Summary

The genesis of this project was a desire to integrate several existing DOE databases of residential efficiency measures and associated costs into a unified national database. Initially, measures were derived from Lawrence Berkley National Laboratory's (LBNL) Home Energy Saver (HES) software and NREL's Building Energy Optimization (BEopt) software (1) (2). The database contains information about the performance and cost of measures that improve the energy efficiency of residential buildings. It does not include energy savings estimates, which can be calculated outside the database using building energy simulation tools (such as HES or BEopt) accessing the standardized measure definitions.

The database is in the public domain and is intended to support external building science research and development organizations, improve technical accuracy, and enhance government transparency. The overall project concept is shown in Figure 1.

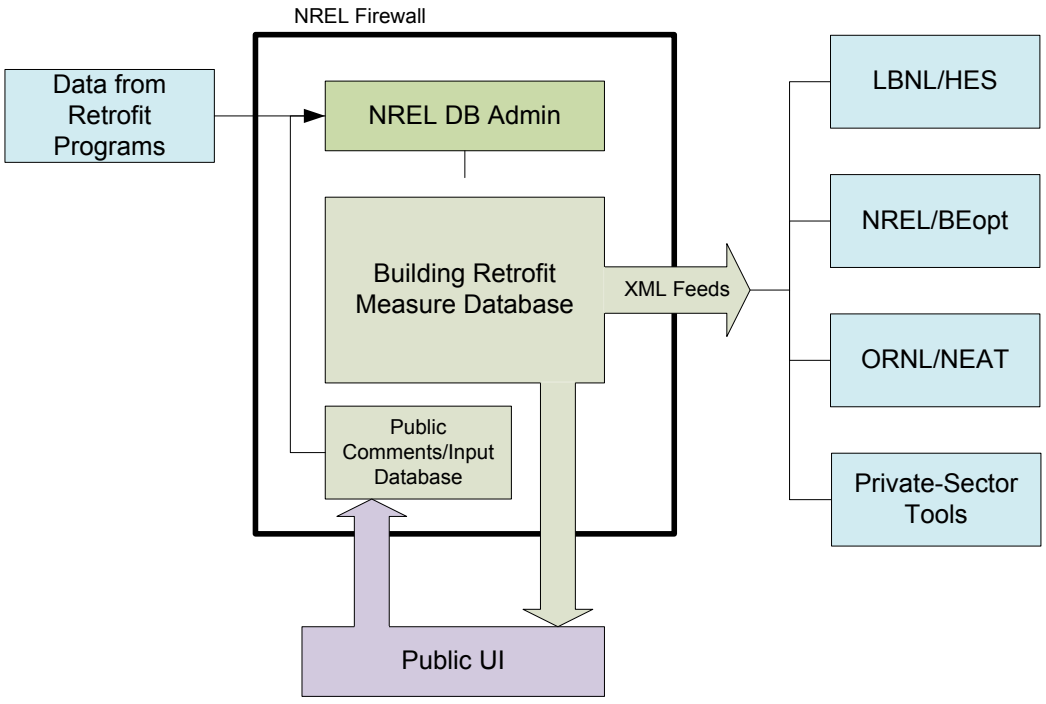

Figure 1: A diagram of overall project concept

1.3 New Features

Version 3.0 is the third release of the National Efficiency Measures Database. Key improvements in this release include:

- Additional measures and measure categories
- Expansion of performance properties for many measures
- Comprehensive update to measure cost data
- Inclusion of measure-specific lists of factors influencing installation costs
- Full integration with NREL's BEopt software
- Indication of measures meeting the 2012 International Energy Conservation Code and EPA's WaterSense Program requirements

1.4 Contact Information

The database is being developed at the National Renewable Energy Laboratory:

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2 Overview of Database

The database is structured to store properties and costs for measure components and measure actions. A web user interface (UI) and an Extensible Markup Language (XML)[1] feed provide user access to the data. NREL developed a set of rules to construct a list of measures based on component properties and action types. The NREL rules assemble measures from the disparate component and action data, providing details via the web UI and NREL Measures XML. The list of measures includes components, component properties, actions, and costs where:

- *Measures* are a combination of a before-component, an action, and an after-component;
- *Components* are unitary items (e.g., refrigerator, central air-conditioner), constructed assemblies (e.g., wood-stud wall, attic) or parts of assemblies (e.g., exterior finish);
- *Component properties* are characteristics of the component that define energy-related performance (e.g., R-value, SEER), component lifetime and other relevant descriptive attributes (e.g., siding type);
- *Actions* are specific labor operations that are required to implement the after-component; and
- *Costs* are associated with before-components, actions, and after-components.

In the following section the structure of the database is discussed, including measure construction, data hierarchy, and action types. NREL rules, cost sources, and performance level criteria are then discussed for each component type.

2.1 Data Hierarchy

The database hosts a variety of measure types. A classification schema provides a hierarchy to organize data and measures. The schema uses the following structure:

- *Group* is a classification of major house systems. Examples include “Space Conditioning,” “Windows & Doors,” “Lighting,” etc;
- *Component Type* is a sub-classification of a *Category*. Examples for the Space Conditioning - Cooling category include “Central Air Conditioner” and “Room Air Conditioner”; and
- *Component* is the lowest level descriptor; it includes some of the properties, resulting in a completely unique name for the component. Examples for the “Central Air Conditioner” *Component Type* are “CAC (SEER 13)” and “CAC (SEER 15)”.

2.2 Measure Construction

Measures are constructed utilizing a rule set developed at NREL. These rules evaluate the energy-efficiency properties of the components and combine the components to create a comprehensive, but

[1] The XML feed provides a mechanism for accessing the contents of the database electronically. Overviews of both the database schema and the XML schema are included in Appendix A, (Figure C–1 through Figure C-3).

practical list of measures. While there are nuances, the NREL measure rule set followed four major tenants:

1. The after-component must be more energy efficient than the before-component;
2. Where possible to assess, the after-component must meet energy codes and/or federal standards;
3. The after-component provides the same level of service as the before-component (e.g., same lighting level, same size refrigerator, etc.); and
4. The improvement must be practical (e.g., there is no measure to add R-3 to an attic).

Additionally, Version 3.0 includes a baseline measure, with no increase in energy-efficiency, to allow the cost-analysis of incremental energy-efficiency. To demonstrate the use of the data structure presented above, an example measure is presented:

- *Measure*: "Replace Central Air Conditioner (SEER 13) with Central Air Conditioner (SEER15)"
- *Group*: "Space Conditioning"
- *Component Type*: "Central Air Conditioner"
- *Before-Component*: "Central Air Conditioner (SEER 13)"
- *Action*: "Replace"
- *After-Component*: "Central Air Conditioner (SEER 15)"

The previous example is presented graphically in Figure 2.

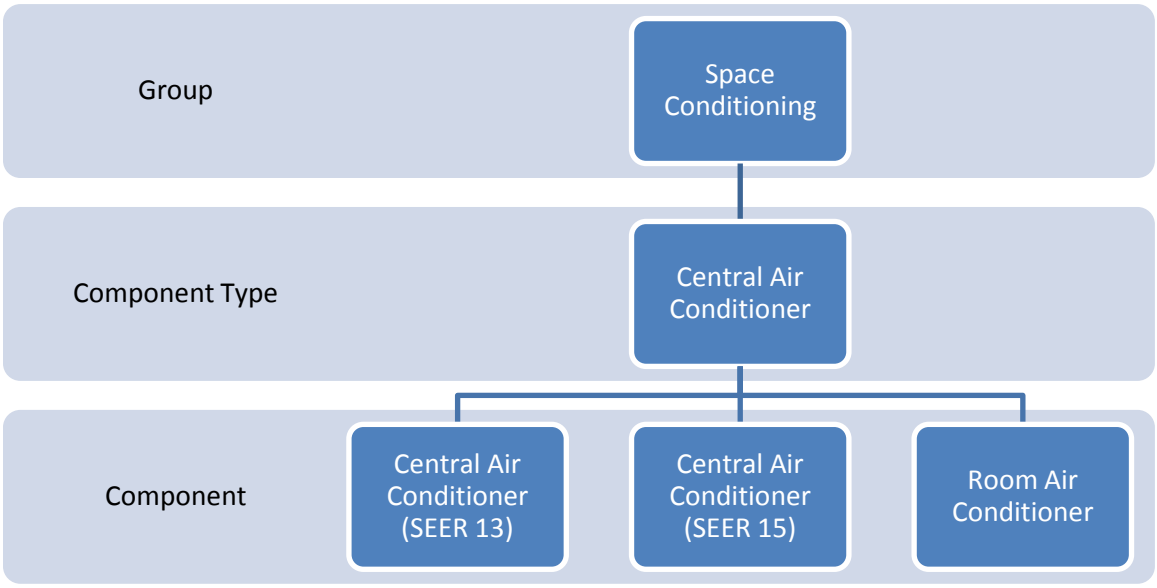

Figure 2: An example diagram database structure and hierarchy

3 Overview of Actions

3.1 Action Descriptions

The NREL rules use five different actions to form measures: *replace*, *remove*, *install*, *insulate*, and *seal*.

Replace actions substitute a before-component with a more efficient component of the same type (e.g., Seasonal Energy Efficiency Ratio [SEER] 9 central air conditioner replaced with SEER 14 central air conditioner). Replace-type measures assume an "end of useful life" scenario with respect to a particular component. The action is *required* of the homeowner if he or she wishes to maintain the existing condition of the home. Replace-type measures often provide a number of efficiency upgrade options for each before-component; including a "base-case" measure in which the component is replaced with one meeting the current federal energy standards. Typically, replace-type measures are determined using energy performance properties while other properties remain the same, maintaining similar functionality. For example, a medium size refrigerator must be replaced with a medium size refrigerator of higher energy factor.

Install actions have no "end of useful life" assumption and are actions initiated, but not required, by the homeowner. Install-type measures improve the existing condition of the home. Install-type measures have no base-case measures.

Remove actions substitute a before-component with "None". For example the "Remove Electric Furnace" measure leaves no Electric Furnace heating system with a cost figure associated with the removal of the electric furnace unit. The "Remove" action type can be used along with the "Install" action type to allow flexibility for users who wish to define measures across component types. For example, users can form a measure that replaces a central air conditioner and electric furnace with an ENERGY STAR qualified central heat pump, though these measures are not currently found on the database's web interface.

Insulate actions involve the installation of additional insulation into existing components. Measure costs are calculated as the incremental insulation material cost and the installation labor cost.

Seal actions involve a whole-house leakage reduction or a duct leakage reduction.

3.2 Rules for Action Costs

Each measure formed by the NREL rules combines a before-component, an action, and an after-component. The NREL rules account for specific costs associated with different actions. As previously noted, there are five different action types that form measures and costs are calculated based on the action type according to the following formula:

$$C_{measure} = -M_{before}C_{before} + C_{action} + M_{after}C_{after}$$

where C is a cost value, M is a cost multiplier, and the subscripts “before”, “after”, “action”, and “measure” refer to the before- and after-components, action, and total measure, respectively. Each of the action types explained below use the multipliers in Table 1: to calculate the total measure cost according to the formula above.

Table 1: Cost Multipliers for Action Types in the Database

Action Type	M_{before}	M_{after}
Replace	0	1
Install	0	1
Remove	0	0
Insulate	1	1
Seal	0	0

4 Overview of Cost Data

4.1 Cost Data Sources

Cost data for v3.0 was primarily collected, organized and processed by Navigant Consulting, Inc. (NCI) under sub-contract to NREL in 2011/2012. The sources and process used by NCI are documented in their report to NREL titled *Development of Residential Energy Efficiency Retrofit Measure Costs* which is included in Appendix B (3).

For the measures not within the scope of NCI's work, NREL collected cost data from a number of sources. Measure actions are assumed to be performed by a home performance industry professional; "Do-It-Yourself" costs are not included. NREL uses the following cost sources:

- **Construction Cost Estimation Resources**: Services provide current cost estimates for residential repair and remodeling projects. Labor and material costs for certain measures are collected separately and then combined to estimate the total measure cost. Material and labor costs may be normalized in different units, depending on the measure in question. (For example, window replacement costs are presented in $/ft^2 of window area.) The Overhead and Profit (O&P) costs are included in all material and labor costs.
- **Web-based Resources**: Cost quotes for component types that are widely available in major home improvement retail stores are included in the database. Additionally, online cost quotes are included for newer components with less market penetration.
- **Home Performance Industry Partners**: Costs from industry partners and distributors submitted to, or collected by, NREL. NREL keeps all industry cost figures submitted for use in the database confidential and encourages participation in the database from all relevant entities in the form of data sharing.[2]
- **Publications**: Data published in government, industry or academic reports are used, where compatible with cost formats.

A summary of the cost sources used for each component type is provided in Table 2.

[2] See the "Submit Data" link (https://www.nrel.gov/ap/retrofits/upload/index.cfm) on the website for information on how to submit your data.

Table 2: Summary of Measure Cost Sources and Cost Units

Group	Component Type	Cost Sources					Cost Units[3]
		NCI	NREL				
		Report	Publication	Estimation	Web	Industry	
Airflow	Air Leakage	x					$, $/(ft^2 Conditioned Floor Area), $/(ΔACH50)
Ceilings/Roofs	Radiant Barrier	x					$/(ft^2 Roof Area)
Ceilings/Roofs	Roof Material			x	x		$/(ft^2 Roof Area)
Ceilings/Roofs	Unfinished Attic	x					$/(ft^2 Attic Floor Area), $/(ΔR-value)
Foundation/Floors	Crawlspace	x					$/(ft2 Crawlspace Surface Area)
Foundation/Floors	Slab	x					$/(ft^2 Slab Edge Area)
Foundation/Floors	Unfinished Basement	x					$/(ft^2 Basement Surface Area)
Lighting	Flood Light				x		$/lumen, $/bulb
Lighting	Light Bulb	x		x	x	x	$/lumen, $/bulb
Lighting	Lighting Control			x	x		$
Lighting	Torchiere				x		$
Major Appliances	Clothes Dryer			x	x	x	$
Major Appliances	Clothes Washer		x	x			$
Major Appliances	Dishwasher			x	x		$
Major Appliances	Freezer			x	x		$
Major Appliances	Refrigerator		x	x	x		$
Miscellaneous	Water Cooler			x	x	x	$
Miscellaneous	Well Pump			x	x	x	$
Space Conditioning	Air Source Heat Pump	x					$, $/kBtu/h
Space Conditioning	Boiler	x					$, $/kBtu/h
Space Conditioning	Ceiling Fan			x	x	x	$
Space Conditioning	Central Air Conditioner	x					$, $/kBtu/h
Space Conditioning	Direct Heater		x	x		x	$, $/kBtu/h
Space Conditioning	Ducts	x	x				$/(ft^2 Duct Surface Area), $/(Δ%Leakage)

[3] Some measures have multiple components (e.g., fixed and normalized: $ + $/sf) that must be combined to get total cost for the measure.

Group	Component Type	Cost Sources					Cost Units[3]
		NCI Report	NREL				
			Publication	Estimation	Web	Industry	
Space Conditioning	Electric Baseboard		x	x		x	$/kBtu/h
Space Conditioning	Furnace	x					$, $/kBtu/h
Space Conditioning	Ground Source Heat Pump	x					$, $/kBtu/h
Space Conditioning	Room Air Conditioner		x	x	x	x	$, $/kBtu/h
Space Conditioning	Thermostat			x	x		$
Walls	CMU		x	x	x		$/(ft^2 Wall Area)
Walls	Wood Stud	x					$/(ft^2 Wall Area), $/(ΔR-value)
Water Heating	Distribution	x					$/(lf Pipe Length)
Water Heating	Showers			x	x		$
Water Heating	Sinks			x	x		$
Water Heating	Water Heater	x					$, $/Gallon
Windows & Doors	Doors (Entry)			x	x		$
Windows & Doors	Skylights		x	x	x	x	$, $/ (ft^2 Skylight Area)
Windows & Doors	Windows	x		x	x	x	$, $/(ft^2 Window Area)

4.2 Cost Processing

The database provides two cost types for each residential efficiency measure based on collected cost data: an average cost and a cost range. The average cost is the mean cost calculated from the collected raw cost data while the range represents the 10th and 90th percentile calculated costs. Factors like climate, construction, home features, local economy, contractor pricing, and geographic location affect the magnitude of the cost range. The database is not intended to provide costs for specific projects because of the wide variability in costs driven by the factors mentioned above. Rather, it is meant to provide guidance regarding the range of measures and associated costs generally available in the marketplace.[4] Additionally, the cost year is recorded for each cost data point. Historical data are considered where appropriate and adjusted for inflation using the consumer price index (CPI) inflation calculator available from the Bureau of Labor Statistics (BLS) (4).

NREL is accepting 3rd party data and/or comments regarding v3 data. Data can be submitted electronically to NREL for consideration and inclusion in the data processing for future versions of the database. Any data submitted to NREL will be treated confidentially. It will be combined with data from other sources using standardized procedures prior to inclusion in the database. Figure 3 illustrates NREL's process of aggregating and analyzing raw cost data from various sources for inclusion in the database.

[4] While NREL makes every effort to ensure accuracy of the cost figures, NREL does not assume any legal liability or responsibility for the accuracy or completeness of the information. See the Disclaimer page on the website for full details.

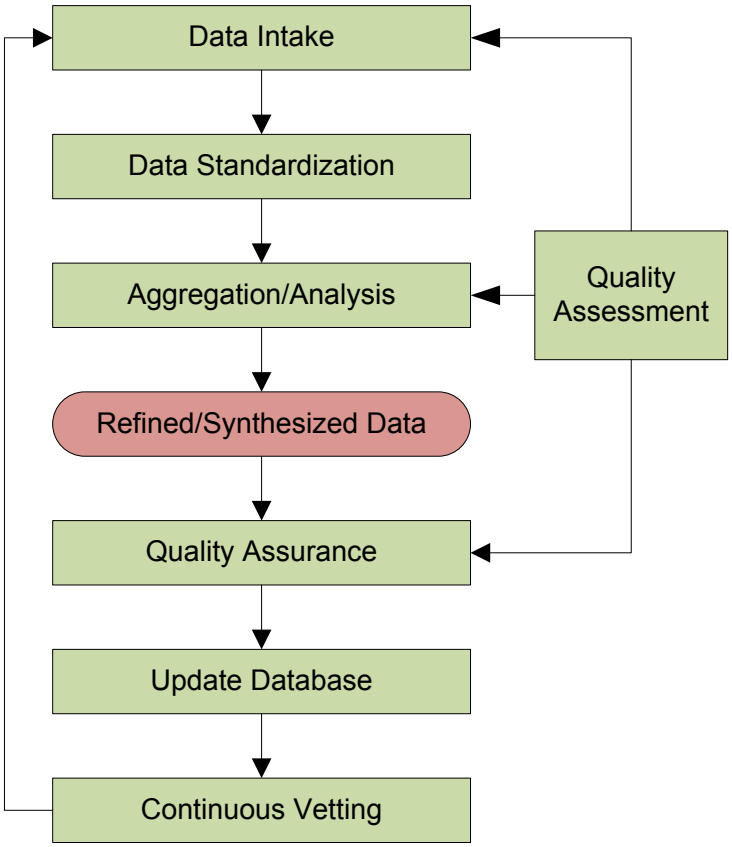

Figure 3: Schematic overview of NREL's cost data intake/processing workflow.

4.3 Cost Normalization

The measure costs are displayed as total dollars to implement the measure, or normalized to a relevant property (e.g., $/ft^2 of surface area), and in some cases both. When multiple costs are presented (e.g., a fixed cost and a normalized cost), the costs must be combined to obtain the total cost of the measure. For example, a Central Air Conditioner replacement measure may have a fixed cost of $1,000 and a variable cost of $65/kBtu/h of capacity. Applying this measure, and costs, to a 4-ton AC unit would result in a total measure cost of $4,120 ($1,000 + [4 tons]*[12 kBtu/h/ton]*[$65/kBtu/h]). Where costs are normalized, in total or in part, the property for each component type is provided in Table 2.

5 Overview of Component Types

The property data for component-types were initially populated from HES and BEopt. Federal or industry testing and labeling requirements provide the database with performance metrics for many of the components (e.g., R-value for insulation, SEER for Air Conditioners, U-factor for windows, etc.). Additional component type properties are collected from well-established sources such as the ASHRAE Fundamentals Handbook, particularly the thermophysical properties of materials. The details for properties, the measure rules and definitions, and cost details are catalogued in Section 6 by component-type.

Lifetimes for component types are gathered from a host of sources including DOE Appliance Technical Support Documents, HES documentation, and industry resources. Many component types related to the building enclosure have a lifetime of "99 years."[5] These lifetime values signify that a component's lifetime is essentially the life of the building, much greater than a typical economic analysis period of 30 years.

[5] The five exceptions are: Doors (Entry), Roof Material, Skylights, and Windows.

6 Airflow Component Types - Properties and Costs

6.1 Air Leakage

Properties

The primary property for Air Leakage is the whole-house leakage measured with a blower door, normalized by house volume, in units of air changes per hour at 50 Pascals (ACH50). The components in the database range from 20 ACH50 down to 6 ACH50.

Measure Rules and Definitions

NREL rules generate measures with varying percentage reduction from the baseline as an after-component. From a baseline of 20 ACH50, a half dozen measures are available, with fewer options as the baseline gets tighter.

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. The component and action costs include a fixed portion and portions that are normalized per square foot of conditioned floor area and the relative change in house tightness achieved by the measure.

7 Ceilings/Roofs Component Types - Properties and Costs

7.1 Radiant Barrier

Properties

Radiant Barrier measures involve the installation of a radiant barrier on the roof surface in an attic. The main energy-related property is the emissivity of the radiant barrier, which affects the radiant heat transfer in the attic cavity.

Measure Rules and Definitions

NREL rules allows the installation of a radiant barrier where no radiant barrier was installed previously.

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. Cost is normalized by square foot of roof surface area.

7.2 Roof Material

Properties

Roof Material is the exterior finishing material. The energy-related property for Roof Material is the Solar Reflectance, the fraction of solar flux reflected by a surface expressed as a percent or within the range of 0.00 and 1.00 for initial installation. The roof slope is assumed to be greater than 2”/12.

Performance standards for Roofs are included in Appendix A (Table A-17).

Measure Rules and Definitions

NREL rules allow Roof Material measures that increase the Solar Reflectance property. For Roof Sheathing measures, the before-component is assumed as “Uninsulated” and the after-component must have a greater continuous insulation R-value.

Costs

Component and action costs are imported from HES, web-based retailers, and estimation services. All costs are normalized to roof area. The removal costs for Roof Material are included in the labor costs for Roof Material.

7.3 Unfinished Attic

Properties

Attic and Ceiling measures add cellulose or fiberglass insulation, blown into an open-access attic or ceiling. Measures can be selected based on the initial insulation condition. Thermal resistance (R) values of R-3 h-ft^2-R/Btu-in (fiberglass) and R-3.2 h-ft^2-R/Btu-in (cellulose) are used. Actual results in the field, in terms of R-value, may vary from those used in the above calculations depending on the expertise of the installer and the density with which the insulation is installed. The thickness of added insulation is calculated for a given change in R-value for each measure.

Performance standards for Attics and Ceilings are included in Appendix A (Table A-1).

Measure Rules and Definitions

NREL rules require a minimum of R-19 equivalent to be installed. Also, measures must add the same insulation type as the before-component insulation type.

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. Costs are normalized per square foot of attic floor insulated and per R-value of insulation in installed.

8 Foundations/Floors Component Types - Properties and Costs

8.1 Crawlspace

Properties

Crawlspace measures include two retrofit options that are often used: insulating the ceiling above the crawlspace (the floor of the space above the crawlspace, and insulating the interior crawlspace wall, which is usually done in conjunction with sealing the crawlspace and making it a semi-conditioned space inside the thermal boundary of the home. The energy-related property is the R-value of the insulation.

Performance standards for Crawlspace Walls are included in Appendix A (Table A-6).

Measure Rules and Definitions

For Crawlspace Walls, NREL rules allow uninsulated vented crawls to either receive 1) insulation in the ceiling, or 2) be sealed and insulated on the walls. All insulation is assumed to be installed on the crawlspace interior. The before-component is assumed to be "Uninsulated".

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. Costs are normalized by the surface area of the component being insulated, either the crawlspace ceiling or the crawlspace wall.

8.2 Slab

Properties

Slab Edge insulation measures consist of adding exterior continuous insulation to the slab edge at depths of 2' or 4'. Additionally, metal flashing is added an exterior finish to protect the insulation. Measures require a foundation exposure of either 2 or 4 feet below grade, which is achieved by excavation around the exterior of the building. 1" XPS (R-5) or 2" XPS (R-10) exterior sheathing can be installed. The energy-related property is the continuous insulation R-value.

Performance standards for Slab Edges are included in Appendix A (Table A-21).

Measure Rules and Definitions

Slab Edge insulation measure rules assume an "Uninsulated" before-component.

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. Costs are normalized per square foot of slab edge surface area insulated.

8.3 Unfinished Basement

Properties

Basement Wall insulation measures include insulating the basement walls and insulating the ceiling above the basement (the floor of the space above the basement). Wall insulation measures include half- or whole-wall applications. The energy-related properties are R-values for continuous and batt

insulation. Continuous insulation is assumed to be either polyisocyanurate or extruded polystyrene (XPS). Batt insulation is assumed to be fiberglass. The half-wall measure is 1" or 2" polyisocyanurate (R-6/R-12) attached to the basement wall with fasteners. Full-wall measures are combinations of the materials listed in Table 3. Wall insulation is assumed installed on the interior and covered with drywall.

Table 3: List of Components for Basement Wall Measures

Continuous Insulation [h-ft^2-R/Btu]	Wall Furring or Framing	Cavity Insulation [h-ft^2-R/Btu]	Finish Material
None	Furring Strips	None	½-inch Gypsum
1-inch Extruded Polystyrene (XPS) [R-5]			
2-inch XPS [R-10]	Frame Wall	R-13	
3-inch XPS [R-15]		R-19	

Performance standards for Basement Walls are included in Appendix A (Table A-2).

Measure Rules and Definitions

NREL rules assume an "Uninsulated" before-component.

Costs

Costs were developed by Navigant Consulting as detailed in Appendix B. Costs are normalized per square foot of surface area insulated.

9 Lighting Component Types - Properties and Costs

9.1 Flood Lights, Light Bulbs, and Torchieres

Properties

Flood lights, light bulbs, and torchieres are included in the database. The energy-related property is luminous efficacy. Luminous efficacy is the ratio of luminous flux to power input. Compact Fluorescent Lamps (CFLs) and Light Emitting Diodes (LEDs) are available in an almost continuous range of wattages and the accepted equivalent wattages are given by ENERGY STAR (5). The database defines components across the full range of wattages but certain equivalent wattages are more common in the marketplace than others. Lamp types for Torchieres include Halogen and Fluorescent. Lamp types for Flood Lights include Incandescent, CFL, and LED. The function property for Light Bulbs defines the dimmable feature, where necessary.

Performance standards for Flood Lights, Light Bulbs, and Torchieres are included in Appendix A.

Measure Rules and Definitions

Flood light measures within the database include a baseline replacement of an incandescent flood light with a similar incandescent flood light and an upgrade replacement with a CFL flood light. CFL replacements are allowed only if the replacement bulb produces the same amount of lumens as the existing flood light to within $\pm$ 20%. This is calculated by multiplying the luminous efficacy (lm/W) by the wattage (W) to obtain the lumens output. The replacement of halogen torchiere lamps with fluorescent torchiere lamps is also included.

Costs

Costs for LED lamps were developed by Navigant Consulting as detailed in Appendix B. Cost figures for other lamps were developed by NREL, acquired from both online retailers and national retail chains. Costs are recorded on a per lamp basis; the range of costs captures the economies of scale when purchasing multiple lamp packages as well as the cost premium for purchasing a single lamp. Actions costs are reflective of relamping fees charged by home performance contractors. Component costs are normalized by lumen output of the lamps; action costs are normalized per lamp.

9.2 Lighting Controls

Properties

Lighting control components within the database include a manually switched system and a motion sensor.

Measure Rules and Definitions

Lighting control measures within the database include the replacement of a manually switched system with a motion sensor.

Costs

Measure costs include a range of product offerings and one hour of electrician labor for installation from estimation services.

10 Major Appliances Component Types - Properties and Costs

10.1 Clothes Dryer

Properties

Clothes Dryer component properties include fuel type, drying energy and machine energy. The database does not feature Clothes Dryers with a range of energy-related properties due to a small difference in energy use between models.

Measure Rules and Definitions

NREL rules allow all combinations of the listed Clothes Dryers, including a replacement that involves a change in fuel-type.

Costs

Clothes Dryer component costs are gathered from estimation services, web-based retailers, and home performance industry sources. A base-case measure is included (electric-to-electric). Action costs include shipping and installation. In the case of a change in fuel-type, it is assumed that gas hookups and venting currently are not in place at time of dryer replacement and are included in the action costs.

10.2 Clothes Washer

Properties

Clothes Washer component properties are formed from the Life-Cycle Cost and Payback Period Spreadsheets: Scenario A provided by DOE (6). The two types of Clothes Washers included are front-loading and top-loading. The major energy-related properties listed are energy factor (EF), modified energy factor (MEF), and water factor (WF).

Performance standards for Clothes Washers are included in Appendix A (Table A-3).

Measure Rules and Definitions

NREL rules allow measures where the MEF increases and the replacement Clothes Washer meets the federal energy standard.

Costs

Clothes Washer component and action costs are gathered from Life-Cycle Cost and Payback Period Spreadsheets: Scenario A (provided by DOE) and are acquired from estimation services (6).

10.3 Dishwasher

Properties

Dishwasher component properties are imported from HES and BEopt. The two capacities of Dishwashers included are compact (<8 place settings + six serving pieces) and standard (≥8 place settings + six serving pieces). The major energy-related properties listed are Annual kWh (UEC), Energy Factor (EF), and Water Usage.

Performance standards for Dishwashers are included in Appendix A (Table A-7).

Measure Rules and Definitions

NREL rules allow measures where the capacity does not change and both the Annual kWh (UEC) and Water Usage decrease. Also, the replacement Dishwasher must meet the federal energy standard, provided in Appendix A. The ENERGY STAR specifications are also included in Appendix A.

Costs

Dishwasher component costs are gathered from web-based retailers, major home improvement retail outlets, and estimation services. While energy performance is one factor that can influence cost, factors such as style and design have a large influence on the retail price. The database provides average cost values for each performance level across a range of styles, options and manufacturers. Action costs for Dishwashers are acquired from estimation services.

10.4 Freezer & Refrigerator

Properties

Refrigerator and freezer components include a standalone freezer, a standalone refrigerator, or a combined refrigerator-freezer. Properties are imported from HES and BEopt, are created based on manufacturers' specifications, and are gathered from the ENERGY STAR database of rated products (5). The major energy-related properties are Adjusted Volume (AV), Configuration, Energy Factor (EF), Rated Annual Energy Consumption (UEC), Defrost, and Ice Dispenser.

Performance standards for Freezers and Refrigerators included in Appendix A (Table A-13).

Measure Rules and Definitions

NREL rules allow measures where:

- The Configuration property does not change;
- The Adjusted Volume does not change more than ±10%;
- The Energy Factor increases; and
- The Freezer or Refrigerator after-component meets the federal energy standard.

Costs

Freezer and Refrigerator component costs are gathered from *Analytical Tools under the Notice of Proposed Rulemaking, September 2010* (7). While component costs for refrigerators and freezers are readily available across a range of configuration and performance options, there is a very large cost scatter when energy performance is used as an independent variable. Action costs are collected from estimation services.

11 Miscellaneous Component Types - Properties and Costs

11.1 Water Cooler

Properties

Water Cooler properties within the database include hot and cold water service and standby energy consumption.

Performance standards for Water Coolers are included in Appendix A (Table A-26).

Measure Rules and Definitions

Water Cooler measures within the database allow the replacement of an existing water cooler with water cooler with lower standby energy consumption.

Costs

Costs are calculated from HES data and data collected from national retail chains.

11.2 Well Pump

Properties

Well Pump components within the database include a standard Well Pump and a high efficiency Well Pump. The energy-related property is Combined Pump and Motor Efficiency.

Measure Rules and Definitions

Well Pump measures within the database allow all replacement combinations of the components.

Costs

Costs are calculated from HES data and data collected from national retail chains.

12 Space Conditioning Component Types - Properties and Costs

12.1 Ceiling Fans

Properties

Two ceiling fan components are included in the database: a standard-efficiency model and a high-efficiency model. The energy-related properties are fan efficiencies at low, medium, and high speed, as defined by the Environmental Protection Agency (EPA) (5).

Performance standards for Ceiling Fans are included in Appendix A.

Measure Rules and Definitions

NREL rules allow installation of a ceiling fan where none existed previously and allow replacement of an existing ceiling fan. A baseline replacement of a standard efficiency ceiling fan is included.

Costs

Ceiling fan component costs are assembled from HES and major home improvement retail outlets. Action costs are gathered from estimation services.

12.2 Cooling Equipment

Properties

Cooling equipment measures within the database include Central Air Conditioners (CAC), Room Air Conditioners (RAC), Air-Source Heat Pumps (ASHP), and Ground Source Heat Pumps (GSHP). The energy-related properties are Seasonal Energy Efficiency Ratio (SEER) for CAC and CHP systems and Energy Efficiency Ratio (EER) for RAC and GSHP systems. All cooling components are normalized to cooling capacity in kBtu/h (1ton = 12kBtu/h).

Performance standards for Cooling Equipment are included in Appendix A (Table A-4 and Table A-5).

Measure Rules and Definitions

Three measure types are defined within Cooling Equipment:

1. *Replacing* an existing component with a more efficient component of the same component type (i.e. SEER 9 CAC replaced with SEER 14 CAC);
2. *Installing* a component where none existed previously (i.e. installing a SEER 13 ASHP); and
3. *Removing* a component, leaving no cooling system (i.e. removing a 9.7 EER RAC).

The measure rules are structured in this manner to allow flexibility for users who wish to define measures across component types (i.e. SEER 9 CAC replaced with SEER 13 ASHP). The total measure costs for this example would include the removal costs of the SEER 9 CAC unit and the component and installation costs of the SEER 13 ASHP.

For CAC systems, all units are assumed to be single-package. Measures allow a replacement of an existing CAC unit with a higher SEER unit at a SEER 13 minimum. For CHP systems, all units are assumed

to be single-package. Measures allow a replacement of an existing ASHP system with a higher SEER. For RAC systems, all units are assumed to have louvered sides and casement-only construction without a slider. Measures allow a replacement of an existing RAC unit with a higher EER unit, provided both units have identical cooling capacities.

Costs

CAC, ASHP and GSHP measure costs were developed by Navigant Consulting as detailed in Appendix B. RAC costs were developed by NREL using information from online retailers, industry estimates and published reports.

12.3 Ducts

Properties

Duct measures include insulating exterior duct surfaces and sealing ducts to reduce leakage. The energy-related properties are the insulation R-value (Duct Insulation) and Leakage Percentage (Duct Sealing).

Performance standards for Ducts are included in Appendix A (Table A-10).

Measure Rules and Definitions

NREL rules allow Duct Insulation measures where R-value increases and the before-component is assumed to be "Uninsulated". For Duct Sealing measures, Leakage Percentage must decrease.

Costs

Duct sealing costs were developed by Navigant Consulting as detailed in Appendix B. Duct insulation costs were developed by NREL from HES, home performance industry partners, estimation services, and publications. Duct Insulation and Duct Sealing measures are normalized to exterior duct surface area and percent reduction in leakage.

12.4 Heating Equipment

Properties

Heating equipment measures within the database include central Boilers, Direct Heaters, Electric Baseboards, Furnaces, Air Source Heat Pumps (ASHP), and Ground Source Heat Pumps (GSHP). The energy-related property for central Boilers, Direct Heaters, and central Furnaces is Annual Fuel Utilization Efficiency (AFUE). The energy-related property for ASHPs is the Heating Seasonal Performance Factor (HSPF), Efficiency for Electric Baseboard and Coefficient of Performance (COP) for GSHPs. For central Boilers, two fuel types are available: gas and oil. The central Furnace components include four fuel types: electricity, natural gas, fuel oil, and propane. Similar to Cooling Equipment properties all heating components are normalized to heating capacity in kBtu/h.

Direct heaters are defined as "vented home heating equipment and unvented home heating equipment" (8). Several designs are included in the database, including: wall-mounted, floor, room, and hearth types. The database does not contain unvented direct heaters. To achieve air circulation, some types have fans included; otherwise a gravity type is assumed.

Performance standards for Heating Equipment are included in Appendix A (Table A-15 and Table A-16).

Measure Rules and Definitions

Two measure types are defined within Heating Equipment:

1. *Replacing* an existing component with a more efficient component of the same component type (e.g., 80% AFUE central Furnace replaced with 92% AFUE central Furnace) and
2. *Installing* a component where none existed previously (e.g., installing a 9.3 HSPF Air Source Heat Pump).
3. *Removing* a component where one existed previously (e.g., removing an Electric Furnace)

The measure rules are structured in this manner to allow flexibility for users who wish to define measures across component types (e.g., electric central Furnace replaced with 9.3 HSPF Air Source Heat Pump). Measures allow a replacement of existing heating equipment with a higher AFUE unit, provided the replacement unit meets the federal standard listed in Appendix A (Table A-15 and Table A-16).

Costs

ASHP, GSHP and Furnace costs were developed by Navigant Consulting as detailed in Appendix B. Direct heater and electric baseboard measure costs were developed by NREL from HES, home performance industry partners, estimation services, and web-based retailers. Heating equipment measure costs are normalized to heating capacity (kBtu/h).

12.5 Thermostat

Properties

The energy property for Thermostat component type is Control Type. Two values are possible Proportional (i.e., manual) and Programmable.

Measure Rules and Definitions

Two measures are included in the database: a baseline replacement of a proportional thermostat or a replacement with a programmable thermostat.

Costs

Thermostat measure costs are assembled from HES, home performance industry partners, estimation services, and web-based retailers.

13 Walls Component - Properties and Costs

13.1 CMU

Properties

CMU measures consist of adding an exterior insulation and finish system (EIFS). The principal energy related property associated with this measure is the R-value of the insulation added to the exterior of the wall.

Measure Rules and Definitions

NREL rules assume EIFS systems are being installed to uninsulated CMU walls.

Costs

Component and Action costs are drawn from home performance industry partners, estimation services, and web-based retailers. Data from industry sources for Wood Stud Wall insulation distinguishes between siding and brick because the exterior finish drives the cost. The cost figures for wall sheathing do not include the cost of siding replacement. All wall-type measures are normalized to the exterior wall area.

13.2 Wood Stud

Properties

Wood stud wall measures within the database include “drill-and-fill” cavity insulation and exterior insulating sheathing. The energy-related properties are stud spacing, stud size, and R-value for cavity insulation and continuous exterior insulating sheathing. Wood Stud Wall cavity insulation measures are assumed to be “drill-and-fill” where there is minimal damage to interior walls or exterior siding/sheathing. The types of cavity insulation are fiberglass or cellulose. Wood Stud Wall actions are specified as “through interior,” “through brick exterior” and “through non-brick exterior” due to the installation cost variation. The database includes two stud spacing values, 16”o.c. and 24”o.c, and two stud size values, 2x4 and 2x6. The installation of cavity batt insulation, which would require the removal of drywall or exterior siding, is not included.

Wall Sheathing measures should only be considered at the time of siding replacement. Costs associate with siding removal and replacement are not included in the database.

Performance standards for Walls are included in Appendix A (Table A-25).

Measure Rules and Definitions

NREL rules allow Wood Stud Wall measures where:

- The R-value increases;
- The same insulation type is used (unless start-component is “Uninsulated”);
- The stud spacing remains constant; and
- The stud size remains constant.

- Sheathing measures are applied only to walls with insulated cavities.

Costs

Wood Stud Wall costs were developed by Navigant Consulting as detailed in Appendix B. CMU costs were developed by NREL from home performance industry partners, estimation services, and web-based retailers. Data from industry sources for Wood Stud Wall insulation distinguishes between siding and brick because the exterior finish drives the cost. The cost figures for wall sheathing do not include the cost of siding replacement. All wall-type measures are normalized to the exterior wall net surface area insulated.

14 Water Heating Component Types - Properties and Costs

14.1 Distribution

Properties

The major energy-related property associated with Water Heating Distribution is the insulation R-value. Performance standards for Hot Water Piping are provided in Appendix A.

Measure Rules and Definitions

For Hot Water Piping, there are two components: R-2 and R-5. The basecase is assumed to be "Uninsulated". NREL rules allow measures that increase the insulation to R-2 or R-5.

Costs

Hot Water Piping component and action costs were developed by Navigant Consulting as detailed in Appendix B. Measure costs are normalized per linear foot of pipe length.

14.2 Showers, Sinks

Properties

Shower and Sink properties include a Fixture Type, a qualitative Flow Type (high/medium/low) and listed in Gallons per Minute (GPM).

Measure Rules and Definitions

NREL rules allow the replacement of High-Flow or Typical-Flow fixtures with Low Flow fixtures. The after-component's Fixture Flow Rate must meet or exceed the Federal Standard Flow Rate. The baseline replacement of a fixture with the same Fixture Flow Rate is included, except for the high-flow fixtures that no longer meet Federal Standards.

Costs

Plumbing Fixture component and action costs are gathered from web-based retailers, major home improvement retail outlets, and estimation services.

14.3 Water Heater

Properties

Water heater properties are collected from the Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Directory of Certified Product Performance (9). The major energy-related properties are Energy Factor (EF), First Hour Rating (FHR), Input, and Recovery Efficiency (RE). Only natural gas-fired tankless water heaters are included in the database. The major energy-related properties for tankless water heaters are Energy Factor, Input, Recovery Efficiency, and Maximum GPM over a 77 Degree Fahrenheit rise.

EF is defined as the ratio of useful energy output from the water heater to the total amount of energy delivered to the water heater. The higher the EF is, the more efficient the water heater. FHR is the amount of hot water in gallons a storage water heater can supply per hour (starting with a tank full of hot water). RE is the percentage of heat from the energy source that is transferred to the water.

Performance standards for Heat Pump Water Heaters are included in Appendix A (Table A-14). Performance standards for Tank Water Heaters are included in Appendix A (Table A-22). Performance standards for Tankless Water Heaters are included in Appendix A (Table A-24).

Measure Rules and Definitions

NREL rules allow three types of measures: Install, Replace, and Remove. In remove-type measures the before-component is any Tank Water Heater component and the after-component is "None". In install-type measures the before-component is "None" and the after-component is any Tank Water Heater component, provided it meets the minimum federal standard, as defined in Appendix A. In replace-type measures NREL rules allow measures where:

- The Fuel Type does not change;
- The Volume does not change;
- The Energy Factor increases; and
- The tank meets minimum federal standards.

Additionally, the NREL rules create a baseline measure, where the energy factor remains constant. Currently, a Tankless Water Heater replacement is not included.

Costs

Water Heater measure costs were developed by Navigant Consulting as detailed in Appendix B. Costs are normalized per gallon of Water Heater size.

15 Windows & Doors Component Types - Properties and Costs

15.1 Doors (Entry)

Properties

Door (Entry) measures address the replacement of an existing entry door. The energy-related properties are the overall door U-factor and the solar heat gain coefficient (SHGC). U-factor is the inverse of R-value and SHGC is the ratio of solar heat gain through a glazing system compared to that of an unobstructed opening. Doors are classified by the operation and glazing level. A door's operation is determined by the manner in which a door opens: "swinging" doors are hinged and "sliding" doors move on a track. A door's glazing level determines classification into the following categories: "Opaque" doors have 0% glazing, "<= ½-Lite" have less than 29.8% glazing, and ">½-Lite" have more than 29.8% glazing.

Performance levels for Doors are included in Appendix A (Table A-8 and Table A-9).

Measure Rules and Definitions

NREL rules require the after-component to have a lower U-factor than the before-component and for the door operation to be the same.

Costs

Door (Entry) component costs are assembled from web-based sources and the action costs are formed from estimation services.

15.2 Skylights and Windows

Properties

Skylight and Window components are created based on ASHRAE thermophysical material properties (10). The energy-related properties include frame material (e.g., vinyl, wood, etc.), number of panes, gas fill between panes (e.g., argon), surface treatments (e.g., super low-e), U-factor, and Solar Heat Gain Coefficient (SHGC). Additionally, the Storm Sash property defines the presence of a Low-E storm sash on the exterior of a window. The Film property defines the presence of clear, gray, or reflective metallic window film added to the interior surface of a window, changing the U-factor and SHGC properties for the component.

Performance standards for Skylights and Windows are included in Appendix A (Table A-18 and Table A-19).

Measure Rules and Definitions

NREL rules require the skylight or window replacement to result in a lower U-factor. Additionally, installing an exterior storm sash is an allowable measure for all single-pane windows. NREL rules allow the application of a clear, gray, or reflective metallic window film to an existing single pane or double pane window.

Costs

Storm window costs were developed by Navigant Consulting as detailed in Appendix B. Other measure costs for Skylights and Windows were developed by NREL using data obtained from HES, home performance industry partners, publications, and estimation services. Action costs include the removal of existing Skylights and Windows and the installation of Skylights and Windows. Costs for Skylights and Windows are normalized to Skylight area and Window area, respectively. Measure costs for Window Films are obtained from web-based retailers and estimation services. Action costs for the installation of Window Films are gathered from estimation services.

16 References

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Appendix A: Performance Standards

A.1 Attics and Ceilings

The IECC-requirements for Attics and Ceilings are provided in Table A-1 (11).

Table A-1: Summary of IECC Criteria for Ceilings (Minimum Insulation R-Value [h-ft2-R/Btu])

Climate Zone	2009	2012
1	R-30	R-30
2-3	R-30	R-38
4-5	R-38	R-49
6-8	R-49	R-49

A.2 Basement Walls

The IECC-2009 requirements for Basement Walls are provided in Table A-2 (11).

Table A-2: Summary of IECC Criteria for Basement Walls (Basement Wall Required Insulation [h-ft2-R/Btu] (Continuous/Cavity) [6])

Climate Zone	2009	2012
1-2	None	None
3	R-5 / R-13	R-5 / R-13
4-5	R-10 / R-13	R-10 / R-13
6-8	R-15 / R-19 (R-5 & R-13)[7]	R-15 / R-19 (R-5 & R-13)

A.3 Ceiling Fans

The ENERGY STAR specifications for Ceiling Fans are defined on a performance basis: CFM of airflow per watt of power consumed by the motor and controls. Efficiency is measured on each of 3 speeds:

- At low speed, fans must have a minimum airflow of 1,250 CFM and an efficiency of 155 CFM/Watt;
- Qualifying ceiling fan models must come with a minimum 30-year motor warranty; one-year component(s) warranty; and 2-year light kits warranty; and
- At high speed, fans must have a minimum airflow of 5,000 CFM and an efficiency of 75 CFM/Watt.

Additionally, there are certain requirements for integral or attachable lighting (5).

[6] To satisfy the R-value requirement, either continuous or cavity insulation may be used.
[7] IECC-2009 determines that a combination of R-5 continuous insulation with R-13 cavity insulation satisfies the basement wall insulation requirement for climate zones 6-8.

A.4 Clothes Washers

Clothes Washer energy efficiency is evaluated with the Modified Energy Factor (MEF). The MEF was adopted in 2004 to replace the Energy Factor (EF) as the official energy-efficiency metric for Clothes Washers and is expressed as:

$$\mathrm{MEF} = \frac{\mathrm{C}}{\mathrm{M+E+D}},$$

where:

- C = capacity of the clothes container [ft^3]
- M = total clothes washer energy consumption per cycle, with such energy consumption expressed as the sum of the machine electrical energy consumption [kWh/cycle]
- E = hot water energy consumption [kWh/cycle]
- D = energy required for removal of the remaining moisture in the wash load [kWh/cycle].

Water factor (WF) is "the present water performance metric that allows the comparison of clothes washer water consumption independent of Clothes Washer capacity" (5) and is expressed as:

$$\mathrm{WF} = \frac{\mathrm{Q}}{\mathrm{C}},$$

where:

- Q = total weighted per-cycle water consumption [gal]
- C = capacity of the clothes container [ft^3].

The federal standards for MEF and WF are defined in a technical amendment to the Energy Independence and Security Act of 2007 (12). The federal standard and the current ENERGY STAR criteria for clothes washers are provided in Table A-3. The future update to the ENERGY STAR criteria is also provided; it takes effect January 1, 2011 (5).

Table A-3: Summary of Federal Standards and ENERGY STAR Criteria (Clothes Washers)

Criteria	Current Criteria (effective July 1, 2009)	Future Criteria (effective January 1, 2011)
ENERGY STAR (top and front loading models)	MEF≥1.8 WF≤7.5	MEF≥2.0 WF≤6.0
Federal Standards (top and front loading models)	MEF≥1.26	MEF≥1.26 WF≤9.5

A.5 Cooling Equipment

Cooling Equipment component types in the database are Central Air Conditioning (CAC) systems, Room AC (RAC) systems, and Air-Source Central Heat Pump (CHP) systems. The federal standard and ENERGY STAR requirements for Cooling Equipment are provided in Table A-4 and Table A-5 (13) (13).

Table A-4: Summary of Federal Standard and ENERGY STAR Criteria (Central Air Conditioners and Central Heat Pumps)

Cooling Equipment	Federal Standard		ENERGY STAR	
	Minimum SEER	Minimum HSPF	Minimum SEER	Minimum HSPF[8]
Central Air Conditioner	13.0	N/A	14.0	N/A
Central Heat Pump	13.0	7.7	14.0	8.0

Table A-5: Summary of Federal Standard and ENERGY STAR Criteria (Room Air Conditioners)

Cooling Equipment	Cooling Capacity [Btu/h]	Federal Standard	ENERGY STAR
		Minimum EER	Minimum EER
Room Air Conditioner	<8,000	9.7	10.7
	8,000-13,999	9.8	10.8
	14,000-19,999	9.7	10.7
	≥20,000	8.5	9.4

A.6 Crawlspaces

Crawlspace measures address two specific retrofit options: closing and conditioning a crawlspace, and insulating the interior crawlspace wall. IECC addresses insulation requirements for crawlspace walls, as provided in Table A-6 (11).

Table A-6: Summary of IECC Criteria for Crawlspace Wall Insulation R-Value [h-ft2-R/Btu] (Continuous/Cavity) [3]

Climate Zone	2009	2012
1-2	None	None
3	R-5 / R-13	R-5 / R-13
4A,B	R-10 / R-13	R-10 / R-13
4C-8	R-10 / R-13	R-15 / R-19

[8] While Heating Seasonal Performance Factor (HSPF) is not addressed in the cooling category, this criterion must also be satisfied by the CHP unit to qualify for ENERGY STAR status.

A.7 Dishwashers

Federal standards and ENERGY STAR classify dishwasher capacity as "compact" and "standard" and these are the classifications in the database (5). Current federal standards for Maximum Annual Energy and Maximum WF are reported in the Federal Register and are summarized in Table A-7 (12).

Table A-7: Summary of Federal Standards (Dishwashers)

Capacity Type	Maximum Annual Energy [kWh]	Maximum Water Factor [gal/cycle]
Standard (≥8 place settings + six serving pieces)	355	6.5
Compact (<8 place settings + six serving pieces)	260	4.5

Current ENERGY STAR criteria for energy and water use are effective through July 11, 2011 and use absolute performance standards in the form of annual energy use (UEC) in lieu of EF, which is a normalized metric (5).

A.8 Doors (Entry)

Door measures within the database address the U-factors and SHGC values associated with several door types. The IECC-2009 U-factor requirements for entry doors are provided in Table A-8 (11).

Table A-8: Summary of IECC-2009 Criteria (Entry Doors)

Climate Zone	Maximum Entry Door U-factor [Btu/ h-ft^2-R][9]
1	1.20
2	0.65
3	0.50
4-8	0.35

The ENERGY STAR qualifications for doors, provided in Table A-9, are not climate-dependent (5).

Table A-9: Summary of ENERGY STAR Criteria (Entry Doors)

Glazing Level	Required U-factor [Btu/h-ft^2-R]	SHGC
Opaque	≤ 0.21	No Rating
≤ ½ Lite	≤ 0.27	≤ 0.30
> ½-Lite	≤ 0.32	≤ 0.30

[9] IECC-2009 provides an exemption for a hinged, opaque door up to 24 square feet.

A.9 Duct Insulation

The IECC-2009 and 2012 requirements for duct insulation are dependent on the duct location and are independent of climate zone. As shown in Table A-10, the requirements depend on whether ducts are located in an attic. For the Duct Insulation measures in the database, all ducts are assumed to be located outside of the attic.

Table A-10: Summary of IECC-2009/2012 Criteria (Ducts)

Duct Location	Required R-Value [Btu/h-ft^2-R]
Attic	R-8
Elsewhere	R-6

A.10 Flood Lights, Light Bulbs, and Torchieres

All Compact Fluorescent Lights (CFL) and Light Emitting Diodes (LED) bulbs in the Measures Database qualify for the ENERGY STAR rating.

A.11 Crawlspace Ceiling

The IECC requirements for crawlspace ceilings, i.e., a floor over a crawlspace, are provided in Table A-11 (11).

Table A-11: Summary of IECC Criteria for Crawlspace Ceiling Insulation [h-ft2-R/Btu]

Climate Zone	2009	2012
1 - 2	R-13	R-13
3 - 4B	R-19	R-19
4C - 6	R-30 [10]	R-30
7 - 8	R-38 [6]	R-38

[10] Or insulation sufficient to fill the framing cavity, R-19 minimum.

A.12 Freezers and Refrigerators

The Energy Independence and Security Act of 2007 requires that DOE publish a final rule no later than December 31, 2010, to determine whether to amend the standards in effect for refrigerators, refrigerator-freezers, and freezers manufactured on or after January 1, 2014. On September 28, 2010, DOE submitted a Notice of Proposed Rulemaking for public comment (14). The proposed federal standards for energy use and ENERGY STAR criteria are provided in Table A-13 and are calculated using the appropriate AV in Table A-12 (5).

The main energy-related property for Freezers and Refrigerators is the Rated Annual Energy Consumption (UEC). The UEC is calculated using the Adjusted Volume (AV) property, which is shown in Table A-12. UEC is calculated based on configuration and AV according to the equations listed in Table A-13.

Table A-12: Equation for Adjusted Volume Based on Type

Type	Equation for Adjusted Volume
Refrigerator-Freezer	Fresh Volume + (1.63 x Freezer Volume)
Refrigerator	Fresh Volume
Freezer	1.73 x Freezer Volume

Table A-13: Federal Standards and ENERGY STAR Criteria (Refrigerator, Freezer, and Refrigerator-Freezers)

Product Category	NAECA as of July 1, 2001 Maximum Energy Usage in kWh/year	Current ENERGY STAR level Maximum Energy Usage in kWh/year (as of April 28,2008)	Configuration(s)	Ice	Defrost	Volume (cubic feet)
1. Refrigerators and Refrigerator-freezers with manual defrost	8.82 x AV+248.4	7.056 x AV+198.72	SR; SD; TF; SS; BF	Y ; N	M	7.75 or greater
2. Refrigerator-Freezer--partial automatic defrost	8.82 x AV+248.4	7.056 x AV+198.72	SR; TF; SS; BF	Y ; N	P	7.75 or greater
3. Refrigerator-Freezers--automatic defrost with top-mounted freezer without through-the-door ice service and all-refrigerators--automatic defrost	9.80 x AV+276	7.84 x AV+220.8	TF; SD; SR	N	A	7.75 or greater
4. Refrigerator-Freezers--automatic defrost with side-mounted freezer without through-the-door ice service	4.91 x AV+507.5	3.928 x AV+406	SS	N	A	7.75 or greater
5. Refrigerator-Freezers--automatic defrost with bottom-mounted freezer without through-the-door ice service	4.60 x AV+459	3.68 x AV+367.2	BF	N	A	7.75 or greater
6. Refrigerator-Freezers--automatic defrost with top-mounted freezer with through-the-door ice service	10.20 x AV+356	8.16 x AV+284.8	TF	Y	A	7.75 or greater
7. Refrigerator-Freezers--automatic defrost with side-mounted freezer with through-the-door ice service	10.10 x AV+406	8.08 x AV+324.8	SS	Y	A	7.75 or greater
8. Upright Freezers with Manual Defrost	7.55 x AV+258.3	6.795 x AV+232.47	UF		M	7.75 or greater
9. Upright Freezers with Automatic Defrost	12.43 x AV+326.1	11.187 x AV+293.49	UF		A	7.75 or greater
10. Chest Freezers and all other Freezers except Compact Freezers	9.88 x AV+143.7	8.892 x AV+129.33	CF		M; A	7.75 or greater
11. Compact Refrigerators and Refrigerator-Freezers with Manual Defrost	10.70 x AV+299	8.56 x AV+239.2	SR; SD; TF; SS; BF	Y ; N	M	Less than 7.75 and 36 inches or less in height
12. Compact Refrigerator-Freezer--partial automatic defrost	7.00 x AV+398	5.6 x AV+318.4	SR; TF; SS; BF	Y ; N	P	Less than 7.75 and 36 inches or less in height

13. Compact Refrigerator-Freezers--automatic defrost with top-mounted freezer and compact all-refrigerators--automatic defrost	12.70 x AV+355	10.16 x AV+284	TF; SD; SR	Y ; N	A	Less than 7.75 and 36 inches or less in height
14. Compact Refrigerator-Freezers--automatic defrost with side-mounted freezer	7.60 x AV+501	6.08 x AV+400.8	SS	Y ; N	A	Less than 7.75 and 36 inches or less in height
15. Compact Refrigerator-Freezers--automatic defrost with bottom-mounted freezer	13.10 x AV+367	10.48 x AV+293.6	BF	Y ; N	A	Less than 7.75 and 36 inches or less in height
16. Compact Upright Freezers with Manual Defrost	9.78 x AV+250.8	7.824 x AV+200.64	UF		M	Less than 7.75 and 36 inches or less in height
17. Compact Upright Freezers with Automatic Defrost	11.40 x AV+391	9.12 x AV+312.8	UF		A	Less than 7.75 and 36 inches or less in height
18. Compact Chest Freezers	10.45 x AV+152	8.36 x AV+121.6	CF		M; A	Less than 7.75 and 36 inches or less in height

(Table Source: http://www.energystar.gov/ia/products/appliances/refrig/NAECA_calculation.xls)

Key: TF= Top Freezer, BF= Bottom Freezer, SS=Side-by-side, SD=Refrigerator only-single door, SR=Refrigerator/Freezer-single door, UF=Upright Freezer, CF=Chest Freezer, A=Automatic Defrost, M=Manual Defrost, P=Partial Automatic Defrost.

A.13 Heat Pump Water Heaters

DOE has concluded that "heat pump water heaters can replace traditional electric resistance storage water heaters in most residences, although the installation requirements may be quite costly" and has decided not to establish a separate product class for HPWHs (8). Two types of HPWHs are included in the database: add-on and integrated (or drop-in). For Add-on HPWHs, DOE did not propose in the December 2009 Notice of Proposed Rulemaking (NOPR) to adopt standards for this product. As of September 2010, add-on HPWHs are not covered by federal rulemaking since the unit cannot heat water as a stand-alone product (8).

Regarding Integrated (or drop-in) HPWHs, DOE has treated this product as a design option for an electric tank water heater. Therefore, the database uses the federal standard for electric tank water heaters to calculate energy factors (EF):

$$\mathrm{EF} = 0.97 - (0.00132 \times \text{rated volume}).$$

The criteria for ENERGY STAR HPWHs are provided in Table A-14 (5).

Table A-14: Summary of ENERGY STAR Criteria (Heat Pump Water Heaters)

ENERGY STAR Criteria	Energy Factor	First-Hour Rating	Warranty	Safety
Heat Pump Water Heaters	EF >= 2.0	FHR >= 50 gallons per hour	Warranty >= 6 years on sealed systems	UL 174 & UL 1995

In addition to the criteria listed above, the integrated (or drop-in) units must satisfy:

- Maximum current rating of 24 amperes,
- Voltage no greater than 250 volts,
- Transfer of thermal energy from one temperature to a higher temperature level for the purpose of heating water.

A.14 Heating Equipment

Heating Equipment measures within the database include central Boilers, Direct Heaters, Electric Baseboards, Central Furnaces, and Central Heat Pumps. Central Boilers must meet the current federal standard of 80% AFUE (for hot water boilers) and 75% (for steam boilers), effective January 1, 1992. The federal standard for natural gas-fired central boiler efficiency increases on September 1, 2012 to 80% and 82% for steam and hot water, respectively (15). The federal standard for oil-fired central boiler efficiency increases on September 1, 2012 to 82% and 84% for steam and hot water, respectively (15). Central Furnaces must meet the current federal standard of 78% AFUE, effective January 1, 1992. The federal standard for Central Heat Pumps is a 7.7 Heating Seasonal Performance Factor (HSPF)[11].

[11] While Seasonal Energy Efficiency Ratio (SEER) is not addressed in the heating category, the central heat pump unit must have a minimum 13 SEER.

Direct heaters are defined as "vented home heating equipment and unvented home heating equipment" (8). Measures allow the replacement of an existing direct heater unit with a higher AFUE unit of identical design, provided the replacement unit meets the federal standard listed in Table A-15.

Table A-15: Summary of Federal Standards (Direct Heaters)

Product Class	Heating Capacity	Minimum AFUE (as of Jan. 1, 1990)
Gas, wall, fan type	≤ 42 kBtu/h	73
Gas, wall, fan type	> 42 kBtu/h	74
Gas, wall, gravity type	27 kBtu/h to 46 kBtu/h	64
Gas, floor, gravity type	> 37 kBtu/h	57
Gas, room, gravity type	> 46 kBtu/h	65
Gas, hearth, gravity type	27 kBtu/h to 46 kBtu/h	67 [12]

The ENERGY STAR requirements for heating equipment are provided in Table A-16 (5).

Table A-16: Summary of ENERGY STAR Criteria (Heating Equipment)

Heating Equipment	ENERGY STAR Minimum Heating Efficiency
Central Boiler	85% AFUE
Central Furnace (Oil)	85% AFUE
Central Furnace (Gas)	90% AFUE
Central Heat Pump	8.0 HSPF

A.15 Hot Water Piping

The IECC-2009 requires that all hot water piping be insulated to at least R-2. The IECC-2012 requires R-3 pipe insulation.

A.16 Plumbing Fixtures

As of January 1, 1994, the Federal Standard for maximum fixture flow rate is 2.5 GPM for shower heads and 2.2 GPM for kitchen and bathroom faucets (16). The WaterSense maximum fixture flow rate for kitchen and bathroom faucets is 1.5 GPM and for shower heads is 2.0 GPM.

A.17 Roofs

Effective December 2007, roofing products that meet the criteria in Table A-17 are ENERGY STAR qualified.

[12] The January 1, 1990 final rule for direct heaters does not prescribe a federal standard for gas hearth gravity type direct heaters. Currently, the database uses the proposed rule, effective April 16, 2013 for gas hearth gravity type direct heaters.

Table A-17: Summary of ENERGY STAR Criteria (Roofing Material)

Category	ENERGY STAR Initial Solar Reflectance	ENERGY STAR Maintenance of Solar Reflectance
Roofing Shingles	≥0.25	≥0.15

As referenced in Table A-17, Initial Solar Reflectance is the initial fraction of solar flux reflected by the roofing material expressed as a percent or within the range of 0.00 and 1.00. Maintenance of Solar Reflectance is the degraded solar reflectance of the roofing material three years after installation.

As of Version 2.1, radiant barriers earn the ENERGY STAR label. The EPA was scheduled to reinstate product review as of May 1, 2011, which may affect the eligibility of radiant barriers to earn the ENERGY STAR label.

A.18 Skylights and Windows

The IECC requirements for skylights and windows are provided in Table A-18 (11).

Table A-18: Summary of IECC Criteria (Skylights and Windows)

Climate Zone	Maximum Window U-factor [Btu/ h-ft^2-R]		Maximum Skylight U-factor [Btu/ h-ft^2-R]		Maximum SHCG [13]	
	2009	2012	2009	2012	2009	2012
1	1.20	1.20	0.75	0.75	0.30	0.25
2	0.65 [14]	0.40	0.75	0.65	0.30	0.25
3	0.50 [7]	0.35	0.65	0.55	0.30	0.25
4A,B	0.35	0.35	0.60	0.55	Not Rated	Not Rated
4C-8	0.35	0.32	0.60	0.55	Not Rated	Not Rated

As provided in Table A-19, the ENERGY STAR qualifications for skylights and windows are climate-dependent. The climate zones referenced by ENERGY STAR are different than the climate-zone definitions used in IECC-2009, summarized in Table A-20 (5).

[13] SHGC values apply to both skylights and windows.

[14] For impact rated fenestration complying with Section R301.2.1.2 of the International Residential Code or Section 1608.1.2 of the International Building Code, the maximum U-factor shall be 0.75 in Zone 2 and 0.65 in Zone 3.

Table A-19: Summary of ENERGY STAR Criteria (Windows)

Windows			
Climate Zone	**Maximum U-factor [Btu/ h-ft^2-R]**	**SHGC Requirements**	
Northern	0.30	None	Prescriptive
	0.31	≥0.35	Equivalent Energy Performance
	0.32	≥0.40	
North-Central	0.32	≤0.40	
South-Central	0.35	≤0.30	
Southern	0.60	≤0.27	

Table A-20: Summary of ENERGY STAR Criteria (Skylights)

Skylights		
Climate Zone	**Maximum Window U-factor [Btu/ h-ft^2-R]**	**SHCG Requirement**
Northern	≤0.55	Any
North-Central	≤0.55	≤0.40
South-Central	≤0.57	≤0.30
Southern	≤0.70	≤0.30

A.19 Slab Edges

The IECC-2009 and IECC-2012 requirements for slab floors are identical, and provided in Table A-21 (11).

Table A-21: Summary of IECC-2009/2012 Criteria (Slab Edges)

Climate Zone	Required R-Value and Insulation Depth [h-ft^2-R/Btu, ft]
1-3	0
4-5	R-10, 2ft
6-8	R-10, 4ft

A.20 Tank Water Heaters

Federal standards establish a minimum energy factor (EF) for each fuel type with an adjustment based on rated tank volume in gallons. The current regulated minimum energy factors are reported in the Federal Register for all Tank Water Heaters (8). The database uses the current ENERGY STAR rating,

which increased minimum energy factors effective September 1, 2010 (5). The standards for each fuel type are provided in Table A-22 (8)[15].

Table A-22: Summary of Federal Standards (Tank Water Heaters)

$\mathbf{EF_{fuel\ type}}$	Minimum Energy Factor
$\mathrm{EF_{electric}}$	$0.97 - (0.00132 \times \text{rated volume})$
$\mathrm{EF_{gas-fired}}$	$0.67 - (0.0019 \times \text{rated volume})$
$\mathrm{EF_{oil-fired}}$	$0.59 - (0.0019 \times \text{rated volume})$

The criteria for ENERGY STAR gas tank water heaters are provided in Table A-23 (5).

Table A-23: Summary of ENERGY STAR Criteria (Tank Water Heaters)

ENERGY STAR Criteria	Energy Factor	First-Hour Rating	Warranty	Safety
Gas Storage	EF >=0.67	FHR >= 67 gallons per hour	Warranty >= 6 years on sealed systems	ANSI Z21.10.1/CSA4.1

In addition to the criteria listed above, the tank water heating units must satisfy:

- Nominal input of 75,000 Btu/h or less and
- Rated storage volume from 20 to 100 gallons.

A.21 Tankless Water Heaters

Current federal standards establish a minimum energy factor (EF) with an adjustment based on rated storage volume in gallons (8):

$$\mathrm{EF_{tankless}} = 0.62 - (0.0019 \times \text{rated volume}).$$

The criteria for ENERGY STAR whole-home gas tankless water heaters are provided in Table A-24 (5).

Table A-24: Summary of ENERGY STAR Criteria (Gas Tankless Water Heaters)

ENERGY STAR Criteria	Energy Factor	Gallons-Per-Minute	Warranty	Safety
Whole-Home Gas Tankless	EF >= 0.82	GPM >= 2.5 over a 77°F rise	Warranty >= 10 years on heat exchanger and 5 years on parts	ANSI Z21.10.3/CSA4.3

In addition to the criteria listed above, the tankless water heating units must satisfy:

- Nominal input of over 50,000 Btu/h up to 200,000 Btu/h and
- Rated storage volume from 2 gallons or less.

[15] Propane-Gas and Natural-Gas type water heaters use the same equation to calculate federal energy factor standards.

A.22 Walls

The IECC-2009 and IECC-2012 requirements for exterior walls are provided in Table A-25 (11). For CMU Walls, the first R-value is used to evaluate performance levels.

Table A-25: Summary of IEC Criteria (Wood Frame Wall and CMU Wall Insulation)

Climate Zone	Required Wood Frame Wall R-Value [h-ft^2-R/Btu]		Required CMU Wall R-Value [h-ft^2-R/Btu][16]	
	2009	2012	2009	2012
1	13	13	3/4	3/4
2	13	13	4/6	4/6
3	13	20 or 13+5	5/8	8/13
4A-B	13	20 or 13+5	5/10	8/13
4C-5	20 or 13+5[17]	20 or 13+5	13/17	13/17
6	20 or 13+5	20+5 or 13+5	15/19	15/20
7-8	21	20+5 or 13+10	19/21	19/21

A.23 Water Coolers

Table A-26 summarizes the ENERGY STAR criterion for water coolers, assuming a hot and cold bottled unit (5).

Table A-26: The ENERGY STAR Criterion (Water Coolers)

Equipment	Water Service	ENERGY STAR Maximum Standby Energy Consumption
Water Cooler	Cold Only	1.20 kWh/day
Water Cooler	Hot and Cold	0.16 kWh/day

[16] The second R-value applies when more than half the insulation is on the interior of the mass wall.

[17] 13+5 signifies R-13 cavity insulation with R-5 insulating sheathing. If structural sheathing covers 25% or less of the exterior, structural sheathing may replace insulating sheathing. If structural sheathing covers more than 25% of the exterior, additional R-2 insulating sheathing is required.

Appendix B: Navigant Consulting Cost Report

NAVIGANT

DEVELOPMENT OF RESIDENTIAL ENERGY EFFICIENCY RETROFIT MEASURE COSTS

Final Report

Prepared for:
National Renewable Energy Laboratory

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Table of Contents

NAVIGANT

1 Introduction

Historically, the Department of Energy (DOE) and its associated national laboratories maintained several different sources of residential energy efficiency measure cost and lifetime data, including:

- Home Energy Saver, a tool used in the DOE's Home Energy Score Pilot Program, maintained by Lawrence Berkeley National Laboratory (LBNL)
- BEopt, an optimization tool used in building energy efficiency research such as the Building America Program, maintained by National Renewable Energy Laboratory (NREL)

Each of these databases contains valuable information and is used by different stakeholders (e.g., researchers, contractors, or homeowners), but the data may, in some cases, be inconsistent, outdated, or presented in different formats or developed using different assumptions. DOE desired to enhance consistency and accuracy by providing a singular source to all stakeholders, both internal and external to DOE. Therefore, the goal of the NREL team was to create a single resource, leveraging data available from these other sources, that is user friendly, accurate, and regularly updated, which would dramatically enhance the value of the information and lead to broader usage throughout the building energy efficiency stakeholder community. In support of this goal, NREL began development of a National Residential Efficiency Measures Database (NREMDB) and has completed version 2.0 of this database. The objective of NCI's effort was to support NREL's goal by expanding upon the existing data, improving its accuracy and enhancing its value to a broad spectrum of stakeholders.

NCI has expanded upon the existing data in the database by adding measures, collecting data from more than ten cost sources, and applying more rigorous analytical techniques, such as regression analysis. NCI's detailed approach to improving the database and updating costs for 31 measures is described in the following pages. The report includes a description of the prioritization process and prioritized measures, the approach taken to collecting and analyzing the cost data, and a description of the results of the analysis.

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2 Prioritization of Measures

NCI and NREL prioritized the potential list of measures to be updated or added to the measure cost database. The potential list of measures included those already contained in the database, new BEopt measures, and new construction measures. The potential list of measures was then prioritized based on the four criteria in Table 1.

Table 1. Measure Prioritization Criteria

Criteria	Description	Score
1. Measure Cost Quality	Quality of the measure cost data in the current version of the database	1 = Low; 0 = High
2. National Energy Savings Potential	Potential for national energy savings in the residential building sector of the measure	1 = High; 0 = Low
3. New BEopt Measure	Planned addition to BEopt modeling tool	1 = Yes; 0 = No
4. Labor Cost Quality	Quality of the labor cost component of the measure cost data in the current version of the database	1 = Low; 0 = High

The first criterion describes the quality of the measure cost data in the most recent version of the database. If the measure cost quality was considered low, the measure received a score of 1. If the measure cost quality was considered high, the measure received a score of 0. The second ranking criterion described the potential for national energy savings in the residential building sector. The measures with a high potential for energy savings received a score of 1 and those with low potential a score of 0. For the third criterion, measures that the BEopt team planned to add to the modeling software received a score of 1; otherwise the measure received a score of 0. The final criterion describes the quality of the labor cost component in the current version of the database. Some of the technology and envelope measures required better labor cost data. These measures received a score of 1; otherwise the measure received a score of 0.

The criteria described above were used to rank the potential list of measures into four tiers:

- Tier 1 included measures that have low measure cost quality with high national energy savings potential
- Tier 2 included measures that are either new BEopt measures or have low labor cost quality
- Tier 3 included measures that have low measure cost quality in current version of NREMDB and low national energy savings potential
- Tier 4 included measures that have high measure cost quality in current version of NREMDB

NCI addressed tiers 1 and 2 based on the availability of project resources. The prioritized list of measures by tier can be found in Appendix A.

3 Measure Cost Calculation

The components of a "Fully Installed Measure Cost" are provided for each of the prioritized measures for both retrofit and new construction applications. The fully installed measure cost includes both material cost and contractor labor cost components. The labor cost can be scaled to account for regional and complexity factors, as described in the sections that follow.

3.1 Measure Cost Equations

The general equations used to develop fully installed measure costs are:

Fully Installed Retrofit Measure Cost = Material + Labor
$(M_v*NU + M_f) + [((F_{c1}*F_{c2}\ldots*F_{cn})*LH_v*NU + LH_f)*HLR]*F_r$

Fully Installed New Measure Cost = Material + Labor
$(M_v*NU + M_f) + [(LH_v*NU + LH_f)*HLR]*F_r$

Where:

NU = measure normalizing units (e.g., square feet)
M_f = fixed material cost ($)
M_v = variable material cost ($)
LH_f = fixed labor hours (hr)
LH_v = variable labor hours (hr)
HLR = hourly labor rate ($/hr)
F_c = complexity factor (unitless)
F_r = regional labor rate factor (unitless)

3.1.1 Complexity Drivers

Many measures can have drivers that add complexity to the installation. For example, the cost to seal ducts can be affected by the drive time, attic height and access, presence of hazardous materials, the condition of existing duct systems, etc. NCI attempted to develop complexity factor cost adders that affect the material or labor cost. The complexity factors are provided in a table format that allows the data user to choose to apply the individual cost adders as appropriate. Complexity drivers are discussed in greater detail in section 4.3.2 of this report.

3.1.2 Regional Drivers

Labor wage rates vary by region. NCI used a regional labor factor to adjust labor costs by region. Therefore, labor costs provided in the results of the analysis are considered "non-regionalized" labor costs that have been adjusted to a nationally indexed value. NCI has provided the labor index factors as multipliers to adjust labor costs to a specific state, if necessary, in section 4.1.4 of this report.

3.1.3 New Construction Costs

For most measures, new construction costs differ from retrofits because the labor hours required for installation differ. Therefore, NCI developed labor installation costs for both new construction and retrofit applications separately.

For envelope measures specifically, the current version of the database only includes installing insulation in existing homes. However, BEopt uses full assembly costs for envelope components. Therefore, NCI also provided framing and associated costs for new construction applications, to be applied as appropriate.

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4 Approach

NCI worked with NREL to refine the approach to updating and developing new cost data for the measures in the database. The data collection and analysis approach taken provided fully installed measure retail costs, including both material and labor costs, for both new and existing construction. For all measures, "installed" was defined as installed by a contractor, not do-it-yourself (DIY) costs.

4.1 Data Collection

To support NREL's goal of creating a database that serves as a national source for component and labor cost information, NCI collected data from secondary sources and then supplemented the secondary data with primary data collected as necessary to address gaps and uncertainties.

4.1.1 Measure Definitions

NCI began by defining the measure specifications for new measures and updating the existing measures where needed. Where there were many relevant efficiency levels, cost data was collected around four efficiency levels:

- Typical/Installed Base
- Federal Standard or International Energy Conservation Code (IECC)
- ENERGY STAR
- Best Available

Typical represents the average, or most common product being sold in the market; *Installed Base* represents the currently installed and "in use" equipment (not sales); and *Standard* represents the minimum efficiency required by current standards or building codes. The typical parameter was determined based on sales and industry data. The installed base was an NCI estimate based on historical shipments and Energy Information Administration (EIA) data from the Residential Energy Consumption Survey. The standard was simply based on the energy efficiency minimum standard or building code.

NCI also defined the labor costs into three categories: new construction installation, existing construction installation, and removal. Replacement cost can be calculated by adding the existing construction installation cost and the removal cost. The purpose of capturing multiple labor activity costs was to allow for aggregating across multiple components in the future, e.g., removing a furnace and installing a heat pump.

4.1.2 Secondary Data Collection

NCI began by collecting cost data from more than ten secondary sources, including existing energy efficiency cost databases, online retailers, and product specific sources. The existing cost databases included the existing version of NREMDB; government and organization databases, such as Federal Appliance Standards, EIA, and ASHRAE; and private industry databases, such as RS Means and the NCI

Cost Database, which included cost information from several utility programs that evaluated comparable efficiency measures. NCI also collected cost data from online web retailers, such as Grainger, Lowes, Home Depot, and Sears.

Table 2. Secondary Sources Summary

Category	Source(s)
NREL Existing Database	• National Residential Efficiency Measures Database, Version 2.0, 2011
Government / Organization Databases	• Federal Appliance Standards Final Rule Technical Support Documents • *Energy Information Administration – Technology Forecast Updates – Residential and Commercial Building Technologies Reference Case*, NCI and SAIC, September 2011 • *Economic Database in Support of ASHRAE 90.2 (Energy-Efficient Design of Low-Rise Residential Buildings), 1481 RP*, NAHB Research Center, May 2009
Private Industry Databases	• NCI Cost Database, 2011 • RS Means CostWorks Online Construction Cost Data, 2011
Online Web Retailers	• Grainger • Home Depot • Lowes • Sears
Product Specific Sources	• Technology studies

Data was also collected from product specific sources, retailers, and studies, depending on the measure. The secondary cost data sources that were used for each of the prioritized measures can be found in Appendix B.

4.1.3 Primary Data Collection

For measures where there was insufficient data after the secondary data collection, NCI collected primary data from contractor interviews. The measures that NCI prioritized for primary data collection after the secondary data collection were solar water heating and geothermal heat pumps.

NCI developed a standard template for each of these measures to ensure that appropriate information about baseline and efficient measures was captured in the interview. NCI also elicited responses from installers across the Building America climate regions to ensure that regional variations in measures, labor costs, and other factors were captured. NCI completed 12 contractor interviews for geothermal heat pumps and 10 contractor interviews for solar water heating.

NCI also solicited data from contractors on specific measures to supplement or confirm data from secondary sources. These measures included air sealing, duct sealing, and windows.

4.1.4 Data Formatting

The data was adjusted to represent 2011$ and non-regionalized (national) costs. The data collected was from various vintages and NCI updated all costs to 2011$, using the R.S. Means Historical Cost Indexes. R.S. Means (http://rsmeans.reedconstructiondata.com) is a private cost information source for the construction and equipment industries produced by Reed Construction Data that compiles up-to-date estimates for equipment and labor costs.

Primary data was collected from contractors across several states and utility data from the NCI Cost Database represented various regions across the country. Due to the variations in the labor costs from one area to the other, NCI adjusted all labor costs to represent national labor costs using state adjustment factors from the Residential Central Air Conditioner and Heat Pumps Final Rule Technical Support Document, which are based on the population weighted aggregation of the R.S. Means City Cost Indices.

Table 3. Installation Cost Indices (National Average Value = 100.0)[1]

State	Index	State	Index	State	Index
Alabama	59.2	Kentucky	82.6	North Dakota	59.4
Alaska	111	Louisiana	61.5	Ohio	98.8
Arizona	77.9	Maine	71.2	Oklahoma	59.3
Arkansas	57.4	Maryland	95.7	Oregon	105.3
California	129.7	Massachusetts	129.5	Pennsylvania	131.2
Colorado	82.6	Michigan	113.2	Rhode Island	121.7
Connecticut	123.1	Minnesota	127.3	South Carolina	41.8
Delaware	126.3	Mississippi	63.6	South Dakota	48.2
District of Columbia	101.6	Missouri	106.4	Tennessee	77.3
Florida	68.6	Montana	75.1	Texas	65
Georgia	75	Nebraska	82.2	Utah	74.5
Hawaii	116.8	Nevada	111	Vermont	71.5
Idaho	71	New Hampshire	93.9	Virginia	75.2
Illinois	142.5	New Jersey	139.6	Washington	107.7
Indiana	89.5	New Mexico	77.2	West Virginia	93.6
Iowa	75.2	New York	170	Wisconsin	104.2
Kansas	69.8	North Carolina	42	Wyoming	61.5

4.2 *Data Analysis*

After collecting the raw cost information, NCI reviewed the cost data for each measure and applied the most appropriate analysis to the data to develop representative costs. The analysis methods selected for each measure depended on the cost sources, the nature of the measure, and the amount of available data. The analysis methods selected included regression modeling, simple average, or custom cost estimating.

[1] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/hvac_ch_08_lcc_2011-06-24.pdf

Regression modeling was used when there was a significant data volume in order to use as much data as possible to determine representative costs. Simple average was used when data was more limited, especially around certain efficiency levels. Custom cost estimates were used when there was limited data and costs varied significantly, mostly in labor intensive measures. For all approaches, NCI discarded outliers where a particular observation appeared to be inconsistent with the other values.

4.2.1 Regression Model

NCI used regression modeling when appropriate to utilize as much data as possible to determine costs. Regression modeling is a form of analysis that attempts to quantify the behavior of uncertain parameters relative to other observable, and potentially influential, variables. Relevant performance factors were incorporated as independent variables in the cost models for measures analyzed using this approach. Most measures were regressed for performance (e.g., SEER, R-value) and/or size variables. For measures that used regression modeling, NCI has provided the resulting regression equations, including slope and intercepts, in the spreadsheet.

4.2.2 Simple Average

NCI used a simple average when there was limited data to perform a regression. The arithmetic mean averages all cost observations into a single point estimate and represents the middle or expected value of a data set. The simple average method took all cost observations for a particular measure at each performance level and averaged them.

4.2.3 Custom Cost Estimates

NCI employed a custom cost estimate where a unique equipment or system configuration needed to be defined by the project team and a cost estimate "built up" for the specific technical details of the measure. This approach was typical of "engineered" and/or technically complex types of measures. The process was fairly subjective and relied on best engineering judgment. The process usually included multiple sources of data, but often limited installation data. For example, installing ground source heat pumps is labor intensive and quotes from contractors usually contain different labor actions, leading to a less than equal comparison. Costs then become "representative" of the specific procedure instead of the typical measure installation.

The analytical approaches that were used for each of the prioritized measures can be found in Appendix B.

4.3 Additional Factors

4.3.1 Lifetimes

NCI also collected the lifetimes for the measures in the database. NCI collected the data from various data sources. Most of the data for the equipment measures came from the Federal Appliance Standards, Appliance Magazine, and technology studies. Most of the lifetime data for the envelope measures came from National Association of Home Builders and Bank of America Home Equity Study of Life

Expectancy of Home Components.[2] NCI calculated the average lifetime from the data collected, as well as the range (when available).

4.3.2 Complexity Drivers

Many of the residential energy efficiency measures covered in this project have additional complexities that impact the cost of installation. Beyond a basic installation, these complexities add additional cost to the installation in terms of effort, materials, or labor hours.

Measures for which Federal standards exist were analyzed in great detail at the time the rulemakings were conducted. These measures include water heaters, central air conditioners, air source heat pumps, furnaces, boilers, ranges/cooktops, stoves/ovens, and dehumidifiers. At the time of these analyses, DOE evaluated cost complexities that can impact the cost of installation of these measures. NCI used this information to include complexity installation adders for these measures.

For the energy efficiency measures for which Federal standards do not exist, NCI sought to evaluate installation complexities and develop associated cost estimates for those complexities through alternative research channels. Most of these efforts to develop installation complexities for non-standards energy efficiency measures were unfruitful for one of two reasons: Additional labor cost data associated with specific installation elements was not readily available, and/or the costs of the specific installation elements were confounded by the "average" installation cost data that was available.

The first inhibiting factor is that the cost of specific installation elements for most of the residential energy efficiency measures covered in this study is not readily available. Many estimates for installation costs do not break out the component parts of the installation, nor do they include adders for additional installation complexities. Therefore, determining the cost of additional labor elements (such as long drive times for contractors, confined installation space conditions, presence of hazardous materials, etc.) cannot easily be completed with readily available data.

The second factor inhibiting the accurate collection of installation complexities is that the cost of specific installation elements is confounded by the "average" installation costs presented in sources. Installation costs are often the weighted average cost of all installation types, meaning they take into account both typical and less typical (higher and lower cost) installations. The distinction in sources is often not made clear. Therefore, once the cost of an installation complexity is determined, adding it to the average installation cost is not representative of the total installation cost of that particular complex installation. If there was sufficient data with a complexity identified as being present or not, one could derive average cost and up-charge. This paucity of fully characterized data is the primary barrier to accurately presenting installation complexities.

An example to illustrate: The additional cost to install a water heater in an attic is $64. However, the total cost to install a water heater in an attic is not accurately represented by adding $64 to the average installation cost for a water heater because the average installation cost might already be inflated by the

[2] *Study of Life Expectancy of Home Components*, National Association of Home Builders and Bank of America Home Equity, February 2007.

fact that some water heater installations require an attic installation. In effect, you would be double counting (or partially double counting) the additional cost of installing the water heater in the attic. Therefore, to accurately represent the total installation cost of the complex installation, you would need to know the most basic installation cost for a given energy efficiency measure and proceed to build up the installation cost using all known installation cost elements applicable to the particular installation. This detailed installation element data is not readily available from known sources.

Measures for which cost complexity data was available have been included in the analysis.

4.4 Results

NCI analyzed the 31 measures in Tiers 1 and 2 and the results of the data collection and the analysis have been provided to NREL in a Microsoft Excel spreadsheet. The spray foam insulation measure was included in the appropriate areas, such as wall insulation.

4.4.1 Spreadsheet

In the Excel spreadsheet, each of the 31 measures has an "Analysis" page that shows the data collected, outliers removed, and analysis performed. Each measure also has a "Results" page that summarizes the material and installation cost results and the lifetime data. There is a lifetime page that houses all the raw lifetime data, source information, and analysis.

4.4.2 Data Quality and Scoring

NCI developed a composite score for each of the measures' data quality. NCI reviewed the data from the various secondary and primary sources and, using ten criteria, calculated a quality value ranging from 0 to 10 for each source. Each source was evaluated against each of the ten criteria. If the criterion was satisfied, the source received a score of 1 for that criterion; otherwise it received a score of 0. The scores (1 or 0) for each of the 10 criteria were then summed to create an aggregate score from 0 to 10 for each source. NCI adapted this approach of using a combination of descriptive and analytical techniques from a recent Northeast Energy Efficiency Partnership (NEEP) study[3]. The ten criteria are described in Table 4 below.

Table 4. Quality Criteria

Criteria	Action	Score	
Clarity of Cost Definition	Review technical specification (what was priced for efficient components and activities)	1 = Capacity and Efficiency Listed; Cost is clearly defined	0 = Either missing or vague definition
Clarity of Base Definition	Review technical specification (what was priced for baseline components and activities)	1 = Capacity and Efficiency Listed; Base is clearly defined	0 = Either missing or vague definition

[3] Incremental Cost Study for Gas and Electric Technologies, Prepared for NEEP, NCI, 2011.

Vintage of Research	Review source dates (when it was priced)	1 = 2009 or newer	0 = Before 2009
Number of Sources	Review number of sources	1 = At least 5 sources	0 = Less than 5 sources, or if sources are unknown
Number of Observations	Review number of observations used in analysis	1 = At least 20 observations made	0 = Less than 20 observations made
Quality of Sources	Review the quality of sources used in analysis	1 = Reliable sources used: contractor, distributor interviews, etc	0 = Unknown sources, Internet data
Transparency	Review transparency of analysis (how was data analyzed)	1 = Transparency of sources, types, and analysis	0 = Non transparent
Updateability	Review of data for updateability	1 = Can be reasonably updated	0 = Cannot be updated
Approach of Analysis	Review approach of analyses that was used and any descriptive statistics provided	1 = More robust analysis approach	0 = Simple approach to analysis
Reasonableness of Results	Review reliability or 'reasonableness' of the results	1 = Reasonable	0 = Unreasonable

Using the above criteria, NCI scored the data sources for each of the measures and then averaged them to develop a composite score for each measure. The measures that received a composite score of above 6 received a "high" quality rating. Scores equal to or between 4 and 6 received a "medium" quality rating. And, scores of less than 4 received a "low" quality rating. The composite score for each measure and corresponding quality rating can be found in Appendix B.

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5 Summary and Recommendations

5.1.1 Project Summary

NCI expanded upon the existing NREMDB by developing material and installation costs for 31 energy efficiency measures for a variety of sizes and efficiencies appropriate to each measure. NCI collected data from more than 10 energy efficiency cost databases and sources and supplemented with primary data collection where needed. NCI also applied rigorous analytical techniques to the data, including regression analysis, simple averaging, and custom cost estimates. NCI developed lifetime data for the 31 measures and provided complexity costs where available. The results of the data collection and analysis were provided to NREL in an Excel spreadsheet.

5.1.2 Updating

NCI recommends that NREL update rapidly changing cost measures, such as Photovoltaics (PV) and Light Emitting Diodes (LEDs), preferably every six months or at least annually because prices are rapidly decreasingly. NCI does not recommend Heat Pump Water Heaters (HPWHs) to be updated every six months because the prices are not changing as rapidly as PV and LEDs. However, NCI does expect the price of HPWHs to come down and they should be updated at least annually or biannually.

5.1.3 Future Efforts

Future efforts with regard to the database may include periodically updating the cost data so that it remains relevant and adding additional measures to the database. Energy efficiency measure candidates that could be added to the database include the Tier 3 and Tier 4 measures, listed in Appendix A. NCI also recommends that the database be coordinated in the future with the Pacific Northwest National Laboratory (PNNL) Building Component Cost Community database, which was still in development at the time of this report.

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Appendix A: Prioritized List of Measures

Priority Tier	ID	Measure Description	1. Measure Cost Quality 1 = Low 0 = High	2. National Energy Savings Potential 1 = High 0 = Low	3. New BEopt Measure 1 = Yes 0 = No	4. Labor Cost Quality 1 = Low 0 = High	Total Score
1	1	Light Emitting Diodes	1	1	1	0	3
	2	Air-to-Air Heat Pump	1	1	0	0	2
	3	Central Air Conditioner	1	1	0	0	2
	4	Natural Gas Boiler	1	1	0	0	2
	5	Natural Gas Furnace	1	1	0	0	2
	6	Insulate Wall Cavity	1	1	0	0	2
	7	Replace Window	1	1	0	0	2
	8	Replace Water Heater	1	1	0	0	2
	9	Insulate Hot Water Piping	1	1	0	0	2
	10	Spray Foam Insulation	1	1	0	0	2
	11	Air Sealing	1	1	0	0	2
	12	Install Duct Insulation	1	1	0	0	2
	13	Insulate Ceiling	1	1	0	0	2
	14	Insulate Crawlspace	1	1	0	0	2
	15	Storm Windows	1	1	0	0	2
	16	Duct Sealing	1	1	0	0	2
	17	Insulate Slab Edge	1	1	0	0	2
2	18	Ranges/Cooktops	1	0	1	0	2
	19	Stoves/Oven	1	0	1	0	2

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Priority Tier	ID	Measure Description	1. Measure Cost Quality	2. National Energy Savings Potential	3. New BEopt Measure	4. Labor Cost Quality	Total Score
	20	Ground Source Heat Pump	1	0	1	0	2
	21	Dehumidifier	1	0	1	0	2
	22	Mini-Split HP/AC	1	0	1	0	2
	23	Solar Hot Water	1	0	1	0	2
	24	PV	1	0	1	0	2
	25	Mechanical Ventilation	1	0	1	0	2
	26	Ceiling Fan	1	0	0	1	2
	27	Lighting Control	1	0	0	1	2
	28	Install Wall Sheathing	1	0	0	1	2
	29	Insulate Basement Wall	1	0	0	1	2
	30	Radiant Barriers	1	0	0	1	2
	31	Install Roof Sheathing	1	0	0	1	2
3	32	Clothes Dryer	1	0	0	0	1
	33	Replace Doors	1	0	0	0	1
	34	Replace Skylight	1	0	0	0	1
	35	Room Air Conditioner	1	0	0	0	1
	36	Concrete Masonry Unit Walls	1	0	0	0	1
	37	Whole House Fans	1	0	0	0	1
	38	Replace Roof Material	1	0	0	0	1
	39	Replace Siding	1	0	0	0	1
	40	Structural Insulated Panels	1	0	0	0	1
4	41	Clothes Washer	0	1	0	0	1
	42	Compact Fluorescent Lamps	0	1	0	0	1
	43	Plumbing Fixtures	0	1	0	0	1

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Priority Tier	ID	Measure Description	1. Measure Cost Quality	2. National Energy Savings Potential	3. New BEopt Measure	4. Labor Cost Quality	Total Score
	44	Dishwasher	0	0	0	0	0
	45	Freezer	0	0	0	0	0
	46	Refrigerator	0	0	0	0	0
	47	Thermostat	0	0	0	0	0
	48	Add Hot Water Tank Insulation Wrap	0	0	0	0	0
	49	Well Pump	0	0	0	0	0
	50	Window Films	0	0	0	0	0
	51	Water Cooler	0	0	0	0	0
	52	Home Energy Management	0	0	0	0	0

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Appendix B: Data Sources, Analytical Approaches, and Data Quality Scoring

Priority Tier	ID	Measure Description	Data Sources									Analytical Approach			Data Quality	
			Existing NREL Database	Federal Appliance Standards	EIA	NAHB ASHRAE Cost Data	NCI Cost Database	RSMeans	Online Retailers	Product Specific Sources	Primary Research	Regression Modeling	Simple Average	Custom Cost Estimate	Average Score	Measure Data Quality Rating
1	1	Light Emitting Diodes	X				X	X	X	X			X		4.4	MEDIUM
1	2	Air-to-Air Heat Pump	X	X	X		X	X				X			6.3	HIGH
1	3	Central Air Conditioner	X	X	X	X	X	X	X			X			5.6	MEDIUM
1	4	Natural Gas Boiler	X	X	X		X	X	X			X			6.1	HIGH
1	5	Natural Gas Furnace	X	X	X	X	X	X	X			X			6.1	HIGH
1	6	Insulate Wall Cavity	X			X	X	X	X			X			5.3	MEDIUM
1	7	Replace Window				X	X	X	X			X			5.6	MEDIUM
1	8	Replace Water Heater	X	X	X		X	X	X			X			6.6	HIGH
1	9	Insulate Hot Water Piping	X				X	X	X			X			4.8	MEDIUM
1	10	Spray Foam Insulation				X	X	X				X			5.0	MEDIUM
1	11	Air Sealing	X			X	X	X	X	X	X	X			4.3	MEDIUM
1	12	Install Duct Insulation	X				X	X	X				X		5.2	MEDIUM
1	13	Insulate Ceiling	X			X	X	X	X	X		X			5.0	MEDIUM
1	14	Insulate Crawlspace	X			X	X	X	X				X		4.0	MEDIUM
1	15	Storm Windows						X	X	X			X		4.0	MEDIUM

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Priority Tier	ID	Measure Description	Data Sources									Analytical Approach			Data Quality	
			Existing NREL Database	Federal Appliance Standards	EIA	NAHB ASHRAE Cost Data	NCI Cost Database	RSMeans	Online Retailers	Product Specific Sources	Primary Research	Regression Modeling	Simple Average	Custom Cost Estimate	Average Score	Measure Data Quality Rating
1	16	Duct Sealing	X				X			X			X		4.8	MEDIUM
1	17	Insulate Slab Edge	X			X		X	X			X			3.8	LOW
2	18	Ranges/Cooktops		X	X			X	X			X			4.8	MEDIUM
2	19	Stoves/Oven		X			X	X	X				X		5.8	MEDIUM
2	20	Ground Source Heat Pump			X				X	X	X			X	6.0	MEDIUM
2	21	Dehumidifier		X				X	X			X			5.3	MEDIUM
2	22	Mini-Split HP/AC						X	X			X			4.5	MEDIUM
2	23	Solar Hot Water			X			X		X	X			X	6.3	HIGH
2	24	PV						X	X	X				X	4.7	MEDIUM
2	25	Mechanical Ventilation							X	X		X			4.0	MEDIUM
2	26	Ceiling Fan	X				X	X	X	X		X			4.8	MEDIUM
2	27	Lighting Control	X				X	X	X	X			X		5.7	MEDIUM
2	28	Install Wall Sheathing	X			X		X	X	X		X			4.0	MEDIUM
2	29	Insulate Basement Wall	X			X	X	X	X			X			4.2	MEDIUM
2	30	Radiant Barriers	X					X	X				X		3.7	LOW
2	31	Install Roof Sheathing	X			X		X	X	X		X			3.6	LOW

Appendix C: Data Schemas

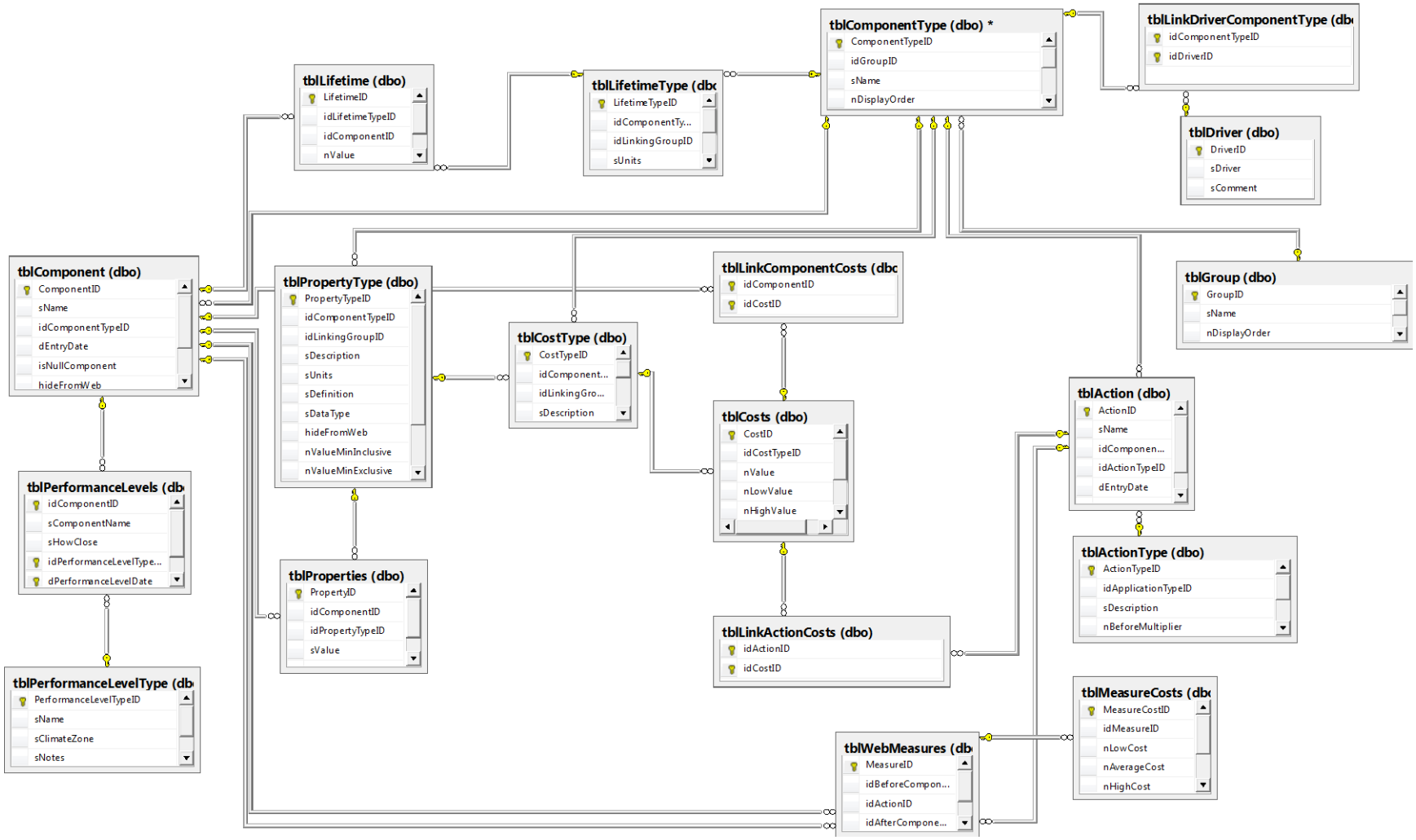

Figure C-1: Database Schema

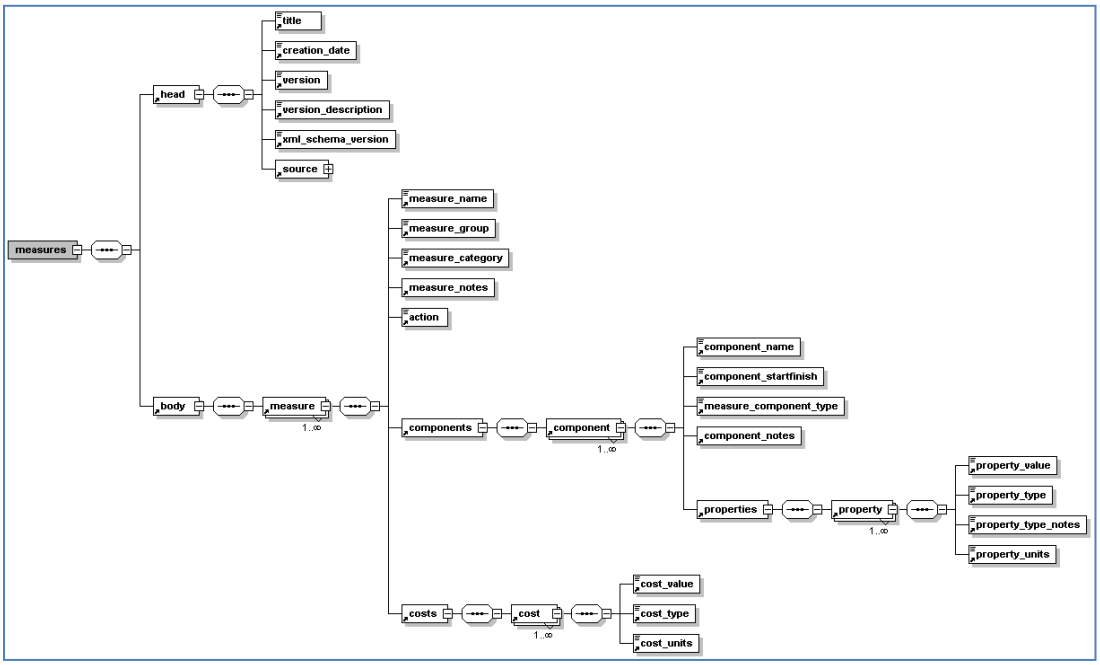

Figure C-2: Measure-centric XML Feed Schema Overview

```
<?xml version="1.0" encoding="utf-8"?>
<measures xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="http://nreldevy.nrel.gov/ap/retrofits/api/api.xsd">
  <head>
    <title>National Residential Efficiency Measures Database</title>
    <creation_date>9/1/10</creation_date>
    <version>v2.0.0</version>
    <version_description>Public Release</version_description>
    <xml_schema_version>v2.0</xml_schema_version>
    <source>
      <moreinformation>http://www.nrel.gov/ap/retrofits/</moreinformation>
      <disclaimer>http://www.nrel.gov/ap/retrofits/disclaimer.cfm</disclaimer>
      <credit>National Renewable Energy Laboratory</credit>
      <feedback>http://www.nrel.gov/ap/retrofits/comments.cfm</feedback>
    </source>
  </head>
  <body>
    <measure>
      <measure_name><![CDATA[Original Leakage -> 75% Leakage Reduction]]></measure_name>
      <measure_group>Enclosure</measure_group>
      <measure_category>Air Sealing</measure_category>
      <measure_notes/>
      <action>Seal to 75% Leakage Reduction</action>
      <components>
        <component>
          <component_name><![CDATA[Original Leakage]]></component_name>
          <component_startfinish>Before</component_startfinish>
          <measure_component_type>Air Sealing</measure_component_type>
          <component_notes/>
          <properties>
            <property>
              <property_value><![CDATA[30]]></property_value>
              <property_type><![CDATA[Lifetime>]]></property_type>
              <property_type_notes><![CDATA[]]></property_type_notes>
              <property_units><![CDATA[Years]]></property_units>
            </property>
            <property>
              <property_value><![CDATA[100]]></property_value>
              <property_type><![CDATA[Percent of Original Leakage>]]></property_type>
              <property_type_notes><![CDATA[This represents the leakage area of the house as a percentage of the pre-retrofit leakage area.]]></property_type_notes>
              <property_units><![CDATA[%]]></property_units>
            </property>
          </properties>
        </component>
```

Figure C-3: Measure-centric XML Sample