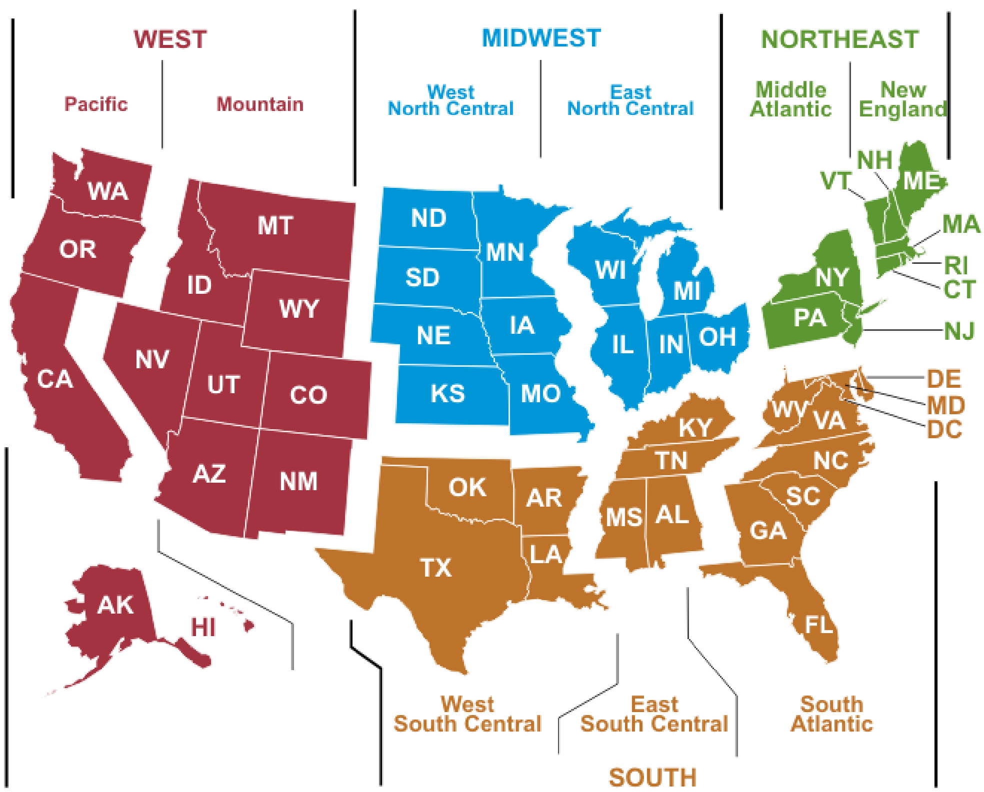
Chapter 4. Residential Demand Module

The NEMS Residential Demand Module (RDM) projects future residential sector energy requirements based on projections of the number of households and the stock, efficiency, and intensity of energy-consuming equipment. The RDM projections begin with a base-year estimate of the housing stock, the types and numbers of energy-consuming appliances servicing the stock, and the unit energy consumption (UEC) by appliance (in million Btu per household per year). The projection process adds new housing units to the stock, determines the equipment installed in new units, retires existing housing units, and retires and replaces appliances. The primary exogenous drivers for the module are housing starts by type (single-family, multifamily, and mobile homes) and by Census division, and prices for each energy source for each of the nine U.S. Census divisions (see Figure 4.1).

The RDM also requires projections of available equipment and their installed costs over the projection horizon. Over time, equipment efficiency tends to increase because of general technological advances and also because of federal and/or state efficiency standards. As energy prices and available equipment change over the projection horizon, the module includes projected changes to the type and efficiency of equipment purchased as well as projected changes in the usage intensity of the equipment stock.

Figure 4.1. United States Census Divisions



Source: U.S. Energy Information Administration, Office of Energy Analysis.

Major end-use equipment for which stocks are modeled—many of which often span several fuels—include space conditioning (heating and cooling) equipment, furnace fans and boiler pumps, water heaters, refrigerators, freezers, dishwashers, clothes washers, cook stoves, clothes dryers, and lighting. The RDM's output includes number of households, equipment stock, average equipment efficiencies, and energy consumed by service, fuel, and geographic location. Modeled in lesser detail based on changes in device penetration/ saturation and estimated annual energy consumption are several miscellaneous electric loads (MELs): televisions and related equipment (set-top boxes, home theater systems, DVD players, and video game consoles), computers and related equipment (desktops, laptops, monitors, networking equipment), rechargeable electronics, ceiling fans, coffee makers, dehumidifiers, microwaves, pool heaters and pumps, home security systems, wine coolers, and portable electric spas. In addition to the modeled end uses previously listed, the average energy consumption per household is projected for other electric and non-electric uses. The fuels represented are distillate fuel oil, liquefied petroleum gas, natural gas, kerosene, electricity, wood, geothermal, and solar energy. The RDM's output includes number of households; energy consumed by service, fuel, and geographic location; and equipment stock and average equipment efficiencies for major end uses.

One of the implicit assumptions embodied in the residential sector Reference case projections is that, through 2050, there will be no radical changes in technology or consumer behavior. No new regulations of efficiency beyond those currently embodied in law or new government programs fostering efficiency improvements are assumed. Technologies that have not gained widespread acceptance today will generally not achieve significant penetration by the end of the projection horizon. Currently available technologies will evolve in both efficiency and cost. In general, future technologies at the same efficiency level will be less expensive, in real dollar terms, than those available today. When choosing new or replacement technologies, consumers will behave similarly to the way they now behave, and the intensity of end uses will change moderately in response to price changes. [4.1]

Key assumptions

Housing Stock Submodule

An important determinant of future energy consumption is the projected number of households. Base-year estimates for 2009 are derived from the U.S. Energy Information Administration's Residential Energy Consumption Survey (RECS) (Table 4.1). The number of occupied households is projected separately for each Census division and comprises the previous year's surviving stock as well as housing starts provided by the NEMS Macroeconomic Activity Module. The Housing Stock Submodule assumes a constant survival rate (the percentage of households that are present in the current projection year, which were also present in the preceding year) for each type of housing unit: 99.7% for single-family units, 99.5% for multifamily units, and 96.6% for mobile home units.

Table 4.1. 2009 Households

Census	Single-Family Units	Multifamily Units	Mobile Homes	Total Units
New England	3,374,597	2,052,063	84,437	5,511,097
Middle Atlantic	9,287,267	5,536,739	435,344	15,259,350
East North Central	13,077,414	4,217,199	558,802	17,853,414
West North Central	6,153,386	1,406,903	503,817	8,064,106
South Atlantic	15,162,865	4,656,262	2,405,757	22,224,884
East South Central	5,480,023	945,846	658,471	7,084,340
West South Central	9,095,440	2,822,348	853,143	12,770,931
Mountain	5,983,945	1,258,517	662,813	7,905,276
Pacific	10,937,616	5,226,838	778,377	16,942,832
United States	78,552,553	28,122,715	6,940,961	113,616,230

Source: U.S. Energy Information Administration, 2009 Residential Energy Consumption Survey.

Projected fuel consumption is dependent not only on the projected number of housing units, but also on the type and geographic distribution of the households. The intensity of space heating energy use varies greatly across the various climate zones in the United States. Also, fuel prevalence varies across the country; oil (distillate) is more frequently used as a heating fuel in the New England and Middle Atlantic Census divisions than in the rest of the country, while natural gas dominates in the Midwest. An example of differences by housing type is the more prevalent use of liquefied petroleum gas in mobile homes relative to other housing types.

Technology Choice Submodule

The key inputs for the Technology Choice Submodule are fuel prices by Census division and characteristics (installed cost, annual maintenance cost, efficiency, and equipment life) of available equipment. The Integrating Module of NEMS estimates fuel prices through an equilibrium simulation that balances supply and demand and passes the prices to the Residential module.

Prices combined with equipment UEC (a function of efficiency) determine the operating costs of equipment. Equipment characteristics are exogenous to the model and are modified to reflect federal standards, equipment subsidies or tax credits, and anticipated changes in the market place. Table 4.2 lists capital costs and efficiency for selected residential appliances for the years 2013 and 2020.

Table 4.2. Installed cost and efficiency ratings of selected equipment

Equipment Type	Relative Performance[1]	2013 Installed Cost (2013$)	2013 Efficiency[2]	2020 Efficiency[2]	Approximate Hurdle Rate
Electric Heat Pump (heating component)	Minimum	$3,150	7.7	8.2	
	Best	$4,500	9.8	11.7	25%
Natural Gas Furnace	Minimum	$1,900	0.80	0.80	
	Best	$2,950	0.98	0.98	15%
Room Air Conditioner	Minimum	$385	9.8	10.8	
	Best	$565	11.5	11.9	42%
Central Air Conditioner[3]	Minimum	$2,100	13.0	13.0	
	Best	$5,100	24.0	24.0	25%
Refrigerator[4]	Minimum	$580	541	406	
	Best	$930	349	349	10%
Electric Water Heater	Minimum	$615	0.90	0.95	
	Best	$2,170	2.45	2.75	50%
Solar Water Heater	N/A	$7,520	N/A	N/A	30%

[1]Minimum performance refers to the lowest-efficiency equipment available. Best refers to the highest-efficiency equipment available.
[2]Efficiency measurements vary by equipment type. Electric heat pumps are based on Heating Seasonal Performance Factor (HSPF); natural gas furnaces are based on Annual Fuel Utilization Efficiency (AFUE); central air conditioners are based on Seasonal Energy Efficiency Ratio (SEER); room air conditioners are based on Energy Efficiency Ratio (EER); refrigerators are based on kilowatt-hours per year; and water heaters are based on Energy Factor (delivered Btu divided by input Btu).
[3]Values are for northern regions of United States.
[4]Reflects a refrigerator with a top-mounted freezer with 20.6 cubic feet nominal volume.
Source: EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case, prepared for U.S. Energy Information Administration, Navigant Consulting, Inc., March 2014.

Table 4.3 provides the cost and performance parameters for representative distributed generation technologies. Residential solar photovoltaic system penetration is based on a ZIP code-level hurdle model, while fuel cell and distributed wind system penetration is calculated using a 30-year cash flow analysis.

The RDM also incorporates endogenous *learning* for the residential distributed generation technologies, allowing for declining technology costs as shipments increase. For fuel cell and photovoltaic systems, learning parameter assumptions for the Reference case result in a 13% reduction in capital costs each time the installed capacity in buildings doubles (in the case of photovoltaics, utility-scale capacity is also included for learning). Capital costs for small wind, a relatively mature technology, decline only 3% with each doubling of shipments.

Table 4.3. Capital cost and performance parameters of selected residential distributed generation technologies

Technology Type	Year of Introduction	Average Generating Capacity (kW_{DC})	Electrical Efficiency	Combined Efficiency (Elec. + Thermal)	Installed Capital Cost (2015$ per kW_{DC})	Service Life (Years)
Solar Photovoltaic	2015	5	0.170	N/A	$4,053	30
	2020	5	0.201	N/A	$2,950	30
	2025	5	0.232	N/A	$2,272	30
	2030	5	0.260	N/A	$1,947	30
	2035	5	0.279	N/A	$1,801	30
	2040	5	0.281	N/A	$1,654	30
Fuel Cell	2015	5	0.400	0.859	$11,989	30
	2020	5	0.400	0.851	$10,320	30
	2025	5	0.410	0.842	$8,867	30
	2030	5	0.410	0.834	$8,030	30
	2035	5	0.420	0.828	$7,407	30
	2040	5	0.420	0.828	$6,846	30
Wind	2015	5	0.130	N/A	$8,400	30
	2020	5	0.130	N/A	$8,376	30
	2025	5	0.130	N/A	$8,028	30
	2030	5	0.130	N/A	$7,858	30
	2035	5	0.130	N/A	$7,617	30
	2040	5	0.130	N/A	$7,397	30

Source: EIA analysis, as well as technology-specific report: Review of Distributed Generation and Combined Heat and Power Technology Performance and Cost Estimates and Analytic Assumptions for the National Energy Modeling System (Leidos, Inc., 2016).

The Residential Demand Module projects equipment purchases based on a nested choice methodology. The first stage of the choice methodology determines the fuel and technology to be used. The equipment choices for cooling and water heating are linked to the space heating choice for new construction. Technology and fuel choice for replacement equipment uses a nested methodology similar to that for new construction, but includes (in addition to the capital and installation costs of the equipment) explicit costs for fuel or technology switching (e.g., costs for installing gas lines if switching from electricity or distillate fuel oil to natural gas, or costs for adding ductwork if switching from electric resistance heat to central heating types). Also, for replacements, there is no linking of fuel choice for water heating and cooking as is done for new construction. Technology switching across fuels upon replacement is allowed for space heating, air conditioning, water heating, cooking, and clothes drying.

Once the fuel and technology choice for a particular end use is determined, the second stage of the choice methodology determines efficiency. In any given year, there are several available equipment options of varying efficiency (minimum standard, some intermediate or ENERGY STAR levels, and highest efficiency). Efficiency choice is based on a functional form and coefficients which give greater or lesser importance to the installed capital cost (first cost) versus the operating cost. Generally, within a technology class, the higher the first cost, the lower the operating cost. For new construction, efficiency choices are made based on the costs of both the heating and cooling equipment and the building shell characteristics.

Once equipment efficiencies for a technology and fuel are determined, the installed efficiency for its entire stock is calculated.

Appliance Stock Submodule

The Appliance Stock Submodule is an accounting framework that tracks the quantity and average efficiency of equipment by end use, technology, and fuel. It separately tracks equipment requirements for new construction and existing housing units. For existing units, this submodule calculates the number of units that survive from previous years, allows certain end uses to further penetrate into the existing housing stock, and calculates the total number of units required for replacement and further penetration. Air conditioning, dishwashing, and clothes drying are three major end uses not considered to be *fully penetrated*.

Once a piece of equipment enters into the stock, an accounting of its remaining life begins. The decay function is based on Weibull distribution shape parameters that approximate linear decay functions. The estimated maximum and minimum equipment lifetimes used to inform the Weibull shape parameters are shown in Table 4.4. Weibull shapes allow some retirement before the listed minimum lifetime, as well as allow some equipment to survive beyond its listed maximum lifetime. It is assumed that, when a house is retired from the stock, all of the equipment contained in that house retires as well; i.e., there is no second-hand market for this equipment.

Table 4.4. Minimum and maximum life expectancies of equipment

Equipment	Minimum Life	Maximum Life
Heat Pumps	7	21
Central Forced-Air Furnaces	10	25
Hydronic Space Heaters	20	30
Room Air Conditioners	8	16
Central Air Conditioners	7	21
Gas Water Heaters	4	14
Electric Water Heaters	10	22
Cooking Stoves	16	21
Clothes Dryers	11	20
Refrigerators	7	26
Freezers	11	31

Source: Lawrence Berkeley National Laboratory, Baseline Data for the Residential Sector and Development of a Residential Forecasting Database, May 1994, and analysis of RECS 2001 data.

Fuel Consumption Submodule

Energy consumption is calculated by multiplying the vintage equipment stocks by their respective UECs. The UECs include adjustments for the average efficiency of the stock vintages, short-term price elasticity of demand and *rebound* effects on usage (see discussion below), the size of new construction relative to the existing stock, people per household, shell efficiency, and weather effects (space heating and cooling). The various levels of aggregated consumption (consumption by fuel, by service, etc.) are derived from these detailed equipment-specific calculations.

Equipment efficiency

Average energy consumption for most technology types is initially based on estimates derived primarily from RECS 2009. As the stock efficiency changes over the projection period, energy consumption decreases in inverse proportion to efficiency. Also, as efficiency increases, the efficiency rebound effect (discussed below) will offset some of the reductions in energy consumption by increased demand for the end-use service. For example, if the stock average for electric heat pumps is now 10% more efficient than in 2005, then all else (weather, real energy prices, shell efficiency, etc.) constant, energy consumption per heat pump would average about 9% less.

Miscellaneous electric loads (MELs)

Unlike the technology choice submodule’s accounting framework, the energy consumption projection of several miscellaneous electric loads (MELs) is characterized by assumed changes in per-unit consumption multiplied by assumed changes in the number of units. In this way, stock and UEC concepts are projected, but without the decision-making parameters or investment calculations of the Technology Choice Submodule. The UECs of certain MELs may be further modified beyond their input assumption by factors such as income, square footage, and/or degree days, where relevant.

Adjusting for the size of housing units

Estimates for the size of each new home built in the projection period vary by type and region, and are determined by a projection based on historical data from the U.S. Census Bureau [4.2]. For existing structures, it is assumed that about 1% of households that existed in 2009 add about 600 square feet to the heated floor space in each year of the projection period [4.3]. The energy consumption for space heating, air conditioning, and lighting is assumed to increase with the square footage of the structure. This results in an increase in the average size of a housing unit from 1,644 to 1,933 square feet from 2009 through 2050.

Adjusting for weather and climate

Weather in any given year always includes short-term deviations from the expected longer-term average (or climate). Recognition of the effect of weather on space heating and air conditioning is necessary to avoid inadvertently projecting abnormal weather conditions into the future. The residential module adjusts space heating and cooling UECs by Census division using data on heating and cooling degree days (HDD and CDD). Short-term projections are informed by the National Oceanic and Atmospheric Administration’s (NOAA) 15-month outlook from their Climate Prediction Center [4.4], which often encompasses the first forecast year. State-level projections of degree days beyond that are informed by a linear trend using the most recent 30 years of complete annual historical degree day data, which are then population-weighted to the Census division level. In this way, the projection accounts for projected population migrations across the nation and continues any realized historical changes in degree days at the state level.

Short-term price effect and efficiency rebound

It is assumed that energy consumption for a given end-use service is affected by the marginal cost of providing that service. That is, all else equal, a change in the price of a fuel will have an opposite, but less than proportional, effect on fuel consumption. The current value for the short-term elasticity parameter for non-electric fuels is -0.15 [4.5]. This value implies that, for a 1% increase in the price of a fuel, there will be a corresponding decrease in energy consumption of -0.15%. Changes in equipment efficiency affect the marginal cost of providing a service. For example, a 10% increase in efficiency will reduce the cost of providing the end-use service by 10%. Based on the short-term elasticity, the demand for the service will rise by 1.5% (-10% multiplied by -0.15). Only space heating, cooling, and lighting are assumed to be affected by both elasticities and the efficiency rebound effect. For electricity, the short-term elasticity parameter is set to -0.30 to account for successful deployment of smart grid projects funded under the American Recovery and Reinvestment Act of 2009.

Shell efficiency

Shell integrity of the building envelope is an important determinant of the heating and cooling load for each type of household. In the NEMS Residential Demand Module, the shell integrity is represented by an index, which changes over time to reflect improvements in the building shell. The shell integrity index is dimensioned by vintage of house, type of house, fuel type, service (heating and cooling), and Census division. The age, type, location, and type of heating fuel are important factors in determining the level of shell integrity. Homes are classified by age as new (post-2009) or existing. Existing homes are represented by the most recent RECS survey and are assigned a shell index value based on the mix of homes that exist in the base year. The improvement over time in the shell integrity of these homes is a function of two factors: an assumed annual efficiency improvement and improvements made when real fuel prices increase. No price-related adjustment is made when fuel prices fall. For new construction, building shell efficiency is determined by the relative costs and energy bill savings for several levels of heating and cooling equipment, in conjunction with the building shell attributes. The packages represented in NEMS include homes that meet the International Energy Conservation Code (IECC) [4.6] and homes that are built with the most efficient shell components, as well as non-compliant homes that fail to meet the IECC. Shell efficiency in new homes increases over time when energy prices rise, or the cost of more-efficient equipment falls, all else equal.

Legislation and regulations

The Clean Power Plan

The Clean Power Plan (CPP) rule, issued under Section 111(d) of the Clean Air Act, allows states to comply with emissions targets by incentivizing energy efficiency in their buildings. In the NEMS residential module, the effects of incentivizing energy efficiency are modeled using subsidies for energy efficient heating, cooling, water heating, lighting, and refrigeration technologies starting as early as 2020. For residential building shells, a subsidy for energy efficient building shell packages that exceed code is assumed in either 2020 or 2025, depending on the Census division’s assumed level of energy efficiency activity. These subsidies are accumulated with an assumed 50% added for program administration costs and sent to the power sector along with the accumulated energy savings for emission credits.

Consolidated Appropriations Act of 2016 (H.R. 2029)

The H.R.2029 legislation—passed in December 2015—extended the investment tax credit (ITC) provisions of the Energy Policy Act of 2005 for renewable energy technologies. The five-year ITC extension for solar energy systems allows for a 30% tax credit through 2019, then decreasing to 26% in 2020, 22% in 2021, and expiring after 2021.

American Recovery and Reinvestment Act of 2009 (ARRA2009)

The ARRA2009 legislation passed in February 2009 provided energy efficiency funding for federal agencies, State Energy Programs, and block grants, as well as a sizable increase in funding for weatherization. To account for the impact of this funding, it is assumed that the total funding was aimed at increasing the efficiency of the existing housing stock. The assumptions regarding the energy savings for heating and cooling are based on evaluations of the impact of weatherization programs over time. Further, it is assumed each house requires a $2,600 investment to achieve the heating and cooling energy savings estimated by Oak Ridge National Laboratory [4.7] and that the efficiency measures last approximately 20 years. Assumptions for funding amounts and timing were revised downward and further into the future based on analysis of the weatherization program by the Inspector General of the U.S. Department of Energy [4.8].

The ARRA2009 provisions remove the cap on the 30% tax credit for ground-source heat pumps, solar PV, solar thermal water heaters, and small wind turbines through 2016. Additionally, the cap for the tax credits for other energy efficiency improvements, such as windows and efficient furnaces, was increased to $1,500 through the end of 2010. Several tax credits were extended at reduced credit levels through the end of 2011 as part of the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010. These tax credits were further extended through the end of 2013 as part of the American Taxpayer Relief Act of 2012, but since those tax credits were not in existence during 2012 and thus were not part of consumers' decision-making process, these tax credits were modeled only for 2013, not for 2012.

Successful deployment of smart grid projects based on ARRA2009 funding could stimulate more rapid investment in smart grid technologies, especially smart meters on buildings and homes, which would make consumers more responsive to electricity price changes. To represent this, the price elasticity of demand for residential electricity was increased for the services that have the ability to alter energy intensity (e.g., lighting).

Energy Improvement and Extension Act of 2008 (EIEA2008)

EIEA2008 extended and amended many of the tax credits that were made available to residential consumers in EPACT2005. The tax credits for energy-efficient equipment could be claimed through 2016, while the $2,000 cap for solar technologies was removed. Additionally, the tax credit for ground-source (geothermal) heat pumps was increased to $2,000. The production tax credits for dishwashers, clothes washers, and refrigerators were extended by one to two years, depending on the efficiency level and product. See the EPACT2005 section below for more details about product coverage.

Energy Independence and Security Act of 2007 (EISA2007)

EISA2007 contained several provisions that impact projections of residential energy use. Standards for general service incandescent light bulbs were phased in over 2012-2014, with a more restrictive standard specified in 2020. It is estimated that these standards required 29% fewer Watts per bulb in the first phase-in, increasing to 67% in 2020. General service incandescent bulbs become substandard in the 2012-2014 period and, during this time, halogen bulbs serve as the incandescent option in the RDM. These halogen

Energy Policy Act of 2005 (EPACT2005)

The passage of EPACT2005 in August 2005 provides additional minimum efficiency standards for residential equipment and provides tax credits to producers and purchasers of energy-efficient equipment and builders bulbs then become substandard in the 2020 specification, reducing general service lighting options to compact fluorescent lamp (CFL) and light-emitting diode (LED) technologies.

Energy Policy Act of 2005 (EPACT2005)

The passage of EPACT2005 in August 2005 provides additional minimum efficiency standards for residential equipment and provides tax credits to producers and purchasers of energy-efficient equipment and builders of energy-efficient homes. The standards contained in EPACT2005 include a 190-Watt maximum for torchiere lamps in 2006, dehumidifier standards for 2007 and 2012, and ceiling fan light kit standards in 2007. For manufactured homes that were 30% more energy efficient than the latest code, a $1,000 tax credit could be claimed in 2006 and 2007. Likewise, builders of homes that were 50% more energy efficient than code could claim a $2,000 credit over the same period. The builder tax credits and production tax credits were assumed to be passed through to the consumer in the form of lower purchase cost. EPACT2005 includes production tax credits for energy-efficient refrigerators, dishwashers, and clothes washers in 2006 and 2007, with dollar amounts varying by type of appliance and level of efficiency met, subject to annual caps. Consumers could claim a 10% tax credit in 2006 and 2007 for several types of appliances specified by EPACT2005, including energy-efficient gas, propane, or oil furnaces or boilers; energy-efficient central air conditioners; air- and ground-source heat pumps; water heaters; and windows. Lastly, consumers could claim a 30% tax credit in 2006 and 2007 for purchases of solar PV, solar water heaters, and fuel cells, subject to a cap.

Notes and sources

[4.1] The Model Documentation Report contains additional details concerning model structure and operation. Refer to U.S. Energy Information Administration, Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System, DOE/EIA-M067(2017) (March 2017). http://www.eia.gov/outlooks/aeo/nems/documentation/.

[4.2] U.S. Bureau of Census, Survey of Construction data from various years of publications.

[4.3] U.S. Bureau of Census, Annual Housing Survey 2001 and Professional Remodeler, 2002 Home Remodeling Study.

[4.4] National Oceanic and Atmospheric Administration, National Weather Service, Experimental Monthly Degree Day Forecast, http://www.cpc.ncep.noaa.gov/pacdir/DDdir/ddforecast.txt. Explanation of forecast available at http://www.cpc.ncep.noaa.gov/pacdir/DDdir/N1.html.

[4.5] See Dahl, Carol, A Survey of Energy Demand Elasticities in Support of the Development of the NEMS, October 1993.

[4.6] The IECC established guidelines for builders to meet specific targets concerning energy efficiency with respect to heating and cooling load.

[4.7] Oak Ridge National Laboratory, Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005, September 2005.

[4.8] U.S. Department of Energy, Office of Inspector General, Office of Audit Services, Special Report: Progress in Implementing the Department of Energy's Weatherization Assistance Program under the American Recovery and Reinvestment Act, February 2010.