# Estimating National Carbon Savings Potential from Electricity Demand Reduction in Buildings

*Dean Gamble and William Grayson, ICF International*


## ABSTRACT

Because residential and commercial buildings contribute 39% of all $CO_2$ emissions, reducing their carbon intensity will be an important component in reducing overall greenhouse gas levels. As a means to help evaluate the impact of national carbon policies on electricity demand, elasticity values were developed in two geographic regions for both the residential and commercial building sectors.

In contrast to previous studies, which utilized an econometric approach, this study attempted to derive elasticity values using a bottom-up approach. Using hourly energy simulations, residential and commercial baseline buildings were modeled and calibrated to approximately match national estimates of electricity consumption. A series of electricity-reducing upgrades were then characterized by their incremental cost and savings potential. Potential long-term market adoption was then estimated for each package based upon payback periods under multiple scenarios with varying electricity rates. The results from this process were then condensed into elasticity values, derived from comparing the rate of change for electricity prices to the rate of change in energy savings associated with these prices.

This paper discusses the methodology for defining the elasticity functions and how these estimates compare to previous research. The results illustrate that this approach produces values comparable to previous studies and also reproduces variations by sector and geographic region as has been seen by others. With refinement, this approach can be exploited in analyses attempting to gauge the impact of national carbon policies on US electricity demand.


## Introduction

Elasticity is an economic measure of the relationship between changes in the demand of a resource and changes in its price. It is represented by the following equation:

$$E = \frac{\%\_Change\_in\_Quantity\_Demanded}{\%\_Change\_in\_\mathrm{Pr}\,ice}$$

Therefore, knowing the elasticity of a resource allows one to evaluate the impact that changing prices will have on total demand. In the context of this paper, the elasticity of electricity is considered and is an important metric for determining the impact of environmental initiatives such a national carbon policy for the United States. In evaluating these policies, if the impact that the policy will have on electricity prices can be assessed, then the elasticity value can be subsequently used to estimate changes in national electricity demand.

For many types of resources including electricity, the resource demand decreases as price increases. This results in a negative elasticity. The extent to which electricity demand falls is dependent on the time period considered. Consider a residential consumer who is burdened with increased prices. In the short-term, the consumer may have limited options to reduce demand.

For example, the consumer could reduce thermostat set-points during the summer to reduce cooling consumption, but in contrast it would likely be cost-prohibitive to replace a fully functioning air conditioner with a higher efficiency model. Over longer time periods, however, the consumer may have the option of cost-effectively replacing their air conditioner upon its failure.

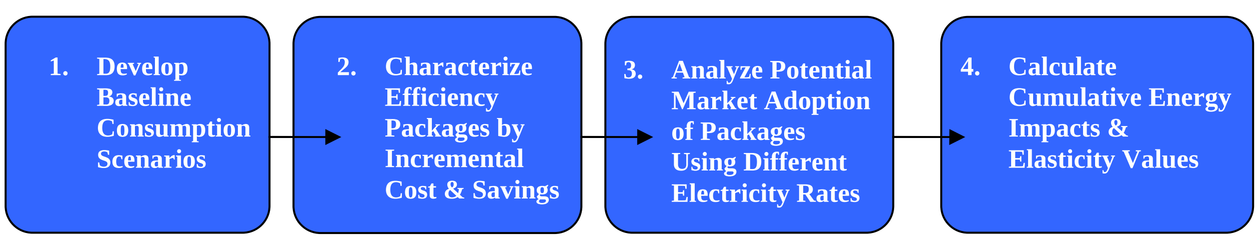
For this reason, the elasticity of electricity can be evaluated from a short-term or long-term perspective. Previous studies have estimated the short-term and long-term elasticity of electricity using an econometric approach – reviewing historical consumption data relative to changes in electricity prices.

One comprehensive survey of literature by Bohi & Zimmerman determined that consensus estimates of short and long term elasticity for residential electricity were -0.20 and -0.70. The range of estimates for commercial elasticity was too great to determine consensus values. Another study by Maddala estimated price elasticities for each US state except Hawaii. Short-term values ranged from a minimum of -0.28 to a maximum of -0.06, with a mean of -0.16, while long-term values ranged from a minimum of min of -0.87 to a maximum of 0.24, with a mean of -0.24. A third study by Houthakker, Verleger, and Sheehan, also found evidence of regionally different elasticities for residential electricity. A more recent paper (Bernstein & Griffin 2005) summarizes these studies and produces an additional assessment of regional and national electricity elasticity values. Their estimation of national short-term and long-term elasticity values in the residential sector are -0.20 and -0.32 respectively. In the commercial sector, their short-term and long-term estimations are -0.21 and -0.97.

In effect, these studies are capturing changes in energy-consuming behavior, but without knowing what these behaviors are. The approach used in this paper estimates elasticity by considering what long-term energy-consuming behaviors might occur in response to changes in electricity prices and then estimating the likelihood of their adoption in the marketplace. In the following sections, the methodology used to develop these elasticity values under various scenarios is presented, the resulting elasticity values are compared to the studies noted above, and the benefits and limitations of this approach are discussed.

## Methodology

For this study, a four-step process was used to develop the long-term elasticity functions: develop base-case building consumption scenarios, characterize energy efficiency packages according to incremental cost and savings, analyze the short and long term market potential of these energy efficiency packages under various electricity cost scenarios, and finally calculate the energy impact from these installations and their associated elasticity values.



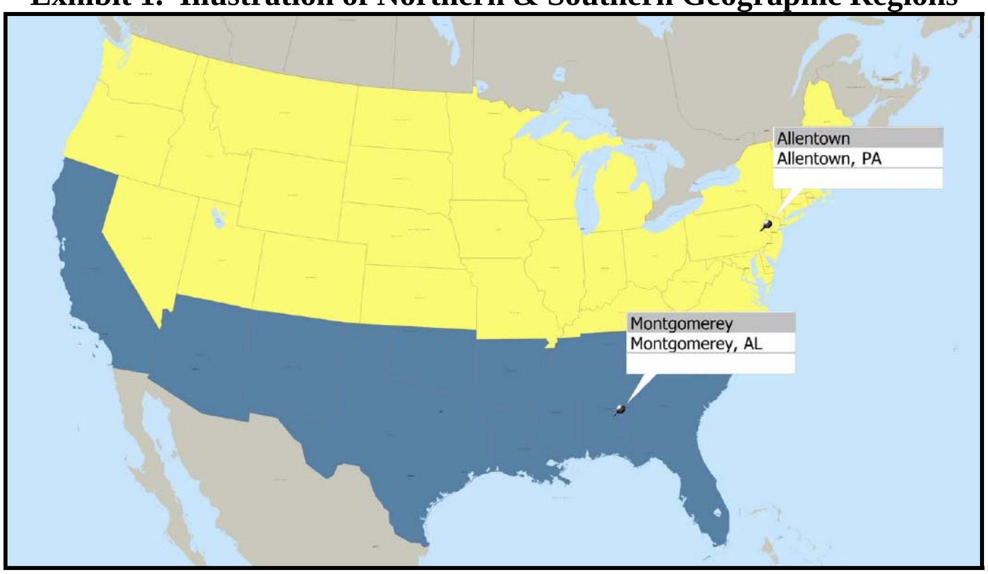
**Step 1: Develop Base-Case Building Consumption Scenarios**

In order to estimate energy savings potential, a base-case model of building energy consumption was first developed. The intent of this step was to create representative building configurations such that when estimated building-level consumption for each configuration was multiplied by the quantity of buildings in existence, the total consumption across all configurations would be on par with national estimates of electricity consumption.

The configurations developed were representative of new and existing structures; commercial and residential buildings; and two broad geographic locations. Each configuration was defined by its geographic location, architectural characteristics (e.g., number of stories, conditioned floor area, window area), energy efficiency features (e.g., insulation values, equipment efficiency, lighting density), and operating characteristics (e.g., hours of use, occupancy rates, hot water use per day).

Geographic location and associated climate clearly have an impact on consumption. Two geographic regions, the northern and southern continental United States, were used for this analysis so that differences in elasticity due to these variations could be illustrated. Using a greater quantity of regions in future analyses would further refine the results. To select representative locations for the two geographic regions analyzed, the population weighted average Heating Degree Days (HDD) and Cooling Degree Days (CDD) were calculated. The mapping process used was developed by the Pacific Northwest National Laboratory for the purpose of states or local jurisdictions to define specific weather files for energy code compliance calculations. The resulting locations were Montgomery, AL for the southern region and Allentown, PA for the northern region.

**Exhibit 1. Illustration of Northern & Southern Geographic Regions**




With the geographic locations selected, the baseline architectural characteristics and energy efficiency features were next defined. While no single study was referenced in defining these parameters, the values were informed by the 2006 International Energy Conservation Code, the Energy Information Administration's Residential Energy Consumption Survey (EIA RECS 2001) and Commercial Building Energy Consumption Survey (EIA CBECS 2003), and the

American Housing Survey (US Census Bureau 2006). The key parameters of each building type are summarized in the following two exhibits.

**Exhibit 2. Summary of Key Baseline Residential Housing Characteristics**

| Region | | Northern | | Southern | |
|---|---|---|---|---|---|
| **Housing Characteristics** | | **Existing** | **New** | **Existing** | **New** |
| Sub Sector | | Single-Family Attached<br>Single-Family Detached | | Single-Family Attached<br>Single-Family Detached | |
| Stories Above Grade | | Attached: 1<br>Detached: 2 | Attached: 1<br>Detached: 2 | Attached: 1<br>Detached: 1 | Attached: 1<br>Detached: 2 |
| Foundation Type | | Attached: Slab<br>Detached: Basement | | Attached: Slab<br>Detached: Slab | |
| Square Feet Per Floor | | Attached: 900<br>Detached: 1,000 | Attached: 1,000<br>Detached: 1,100 | Attached: 900<br>Detached: 1,850 | Attached: 1,000<br>Detached: 1,000 |
| Window Area to Floor Area Ratio | | Attached: 10%<br>Detached: 16% | Attached: 10%<br>Detached: 18% | Attached: 10%<br>Detached: 16% | Attached: 10%<br>Detached: 18% |
| % Ducts Outside Cond Space [1] | | Attached: 0 or 100%<br>Detached: 75% | Attached: 0 or 100%<br>Detached: 75% | Attached: 0 or 100%<br>Detached: 100% | Attached: 0 or 100%<br>Detached: 75% |
| Aspect Ratio | (Front to Side) | 2:1 | | 2:1 | |
| **Envelope Information** | | **Existing** | **New** | **Existing** | **New** |
| Attic Insulation | R-Value | Attached: 19<br>Detached: 30 | Attached: 38<br>Detached: 30 | Attached: 19<br>Detached: 30 | Attached: 30<br>Detached: 30 |
| Ceiling Insulation Grade | | 3 | | 3 | |
| Wall Construction | | 2x4 | 2x6 | 2x4 | 2x4 |
| Wall Insulation | R-Value | 13 | 19 | 9 | 13 |
| Wall Sheathing | | OSB | | OSB | |
| Wall Insulation Grade | | 3 | | 3 | |
| Number of Panes | | 2 | | 2 | |
| Window U-Value | | Attached: 0.65<br>Detached: 0.55 | Attached: 0.35<br>Detached: 0.35 | Attached: 0.75<br>Detached: 0.75 | Attached: 0.65<br>Detached: 0.65 |
| Window SHGC | | Attached: 0.55<br>Detached: 0.55 | Attached: 0.45<br>Detached: 0.40 | Attached: 0.55<br>Detached: 0.55 | Attached: 0.40<br>Detached: 0.40 |
| Frame Type | | Metal | Vinyl | Metal | Metal |
| Infiltration Value | Natural ACH | Attached: 0.75<br>Detached: 0.75 | Attached: 0.38<br>Detached: 0.47 | Attached: 0.75<br>Detached: 0.75 | Attached: 0.33<br>Detached: 0.41 |
| Slab Insulation | R-Value | Attached: 0<br>Detached: 0 | Attached: 10<br>Detached: 10 | Attached: 0<br>Detached: 0 | Attached: 0<br>Detached: 0 |
| Basement Space Type | | Unconditioned with Floor Insulation | | Unconditioned with Floor Insulation | |
| Basement Wall Insulation | R-Value | None | | None | |
| Basement Wall Sheathing | | None | | None | |
| Floor Insulation Over Bsmt | R-Value | Attached: N/A<br>Detached: 11 | Attached: N/A<br>Detached: 19 | Attached: N/A<br>Detached: 0 | Attached: N/A<br>Detached: 0 |
| **Systems Information** | | **Existing** | **New** | **Existing** | **New** |
| System Type | | Gas Furnace / Central AC | | Gas Furnace / Central AC | |
| Cooling Efficiency | SEER | 11 | 13 | 13 | 13 |
| Heating Eff. (AFUE) | AFUE | Attached: 80<br>Detached: 80 | Attached: 80<br>Detached: 83 | Attached: 80<br>Detached: 80 | Attached: 80<br>Detached: 80 |
| Duct Insulation | R-Value | Attached: 4<br>Detached: 4 | Attached: 4<br>Detached: 6 | Attached: 2<br>Detached: 2 | Attached: 4<br>Detached: 6 |
| Duct Leakage Value | CFM/100 sq ft | 15 | 10 | 15 | 10 |
| Thermostat | | Manual | | Manual | |
| **Domestic Hot Water** | | **Existing** | **New** | **Existing** | **New** |
| DHW Fuel Type & Energy Factor | EF | Gas; 0.59 | | Gas; 0.59 | |
| DHW Capacity | Gallons | 40 | | 40 | |
| **Lighting and Appliances** | | **Existing** | **New** | **Existing** | **New** |
| Dishwasher Efficiency | | Standard Efficiency | | Standard Efficiency | |
| Refrigerator Efficiency | | Standard Efficiency | | Standard Efficiency | |
| Quantity of Flourescent Fixtures (beyond 10%) | | 0 | | 0 | |
| **Location** | | **Existing** | **New** | **Existing** | **New** |
| City, State | | Allentown, PA | | Montgomery, AL | |

1. For top-level attached units, 100% ducts in unconditioned space; for other units, all ducts in conditioned space.

**Exhibit 3. Summary of Key Baseline Commercial Building Characteristics**

| Vintage | | Existing | | | | | |
|---|---|---|---|---|---|---|---|
| **Building Characteristics** | | **Assembly** | **Education** | **Healthcare** | **Lodging** | **Office** | **Retail** |
| Stories Above Grade | | 1 | 2 | 4 | 10 | 8 | 1 |
| Square Feet Per Building | | 50,000 | 150,000 | 250,000 | 180,000 | 250,000 | 70,000 |
| Window Area to Wall Area Ratio | | N 12.9%; S 12.9%; E 12.9%; W 12.9% | N 57.8%; S 57.8%; E 57.8%; W 57.8% | N 39.2%; S 39.2%; E 39.2%; W 39.2% | N 45.4%; S 45.4%; E 45.4%; W 45.4% | N 57.8%; S 57.8%; E 57.8%; W 57.8% | N 5.2%; S 5.2%; E 5.2%; W 5.2% |
| **Envelope Information** | | | | | | | |
| Roof Insulation | R-Value (Ext. + Add'l) | 18+0 | 18+0 | 0+30 | 14+0 | 14+0 | 18+0 |
| Wall Construction | | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. |
| Wall Insulation | R-Value | 19 | 19 | 19 | 11 | 11 | 19 |
| Wall Sheathing | R-Value | 2 | 2 | 2 | 2 | 2 | 2 |
| Number of Panes | | 1 | 1 | 1 | 2 | 2 | 1 |
| Glass Type | | Clear, 1/8" | Clear, 1/8" | Clear, 1/8" | Clear, 1/8", 1/4" air (N)<br>Clear, 1/4", 1/4" air (SEW) | Clear, 1/8", 1/4" air (N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/8" |
| Frame Type | | Aluminum w/o Break, Fixed | Aluminum w/o Break, Operable | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed |
| **Systems Information** | | | | | | | |
| Cooling Source | | Packaged Single Zone DX | Packaged Single Zone DX | Constant Speed Electric Centrifugal Chiller | Constant Speed Electric Centrifugal Chiller | Electric Reciprocating Chiller | Packaged Single Zone DX |
| Cooling Efficiency | | 8 EER | 8 EER | 0.75 kW/ton | 0.676 kW/ton | 0.80 kW/ton | 8 EER |
| Heating Source | | Furnace | Furnace | Hot Water Boiler (Natural Draft) | Hot Water Boiler (Natural Draft) | Hot Water Boiler (Natural Draft) | Furnace |
| Heating Efficiency | AFUE | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 |
| Economizer? | | Yes | Yes | Yes | No | Yes | Yes |
| **Location** | | | | | | | |
| Northern | | Allentown, PA | | | | | |
| Southern | | Montgomery, AL | | | | | |

| Vintage | | New | | | | | |
|---|---|---|---|---|---|---|---|
| **Building Characteristics** | | **Assembly** | **Education** | **Healthcare** | **Lodging** | **Office** | **Retail** |
| Stories Above Grade | | 1 | 2 | 4 | 10 | 8 | 1 |
| Square Feet Per Building | | 50,000 | 150,000 | 250,000 | 180,000 | 250,000 | 70,000 |
| Window Area to Wall Area Ratio | | N 12.9%; S 12.9%; E 12.9%; W 12.9% | N 57.8%; S 57.8%; E 57.8%; W 57.8% | N 39.2%; S 39.2%; E 39.2%; W 39.2% | N 45.4%; S 45.4%; E 45.4%; W 45.4% | N 57.2%; S 57.2%; E 57.2%; W 57.2% | N 5.2%; S 5.2%; E 5.2%; W 5.2% |
| **Envelope Information** | | | | | | | |
| Roof Insulation | R-Value (Ext. + Add'l) | 18+0 | 18+0 | 0+30 | 18+0 | 18+0 | 18+0 |
| Wall Construction | | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. | Metal Frame, 2x6, 24" o.c. |
| Wall Insulation | R-Value | 19 | 19 | 19 | 19 | 19 | 19 |
| Wall Sheathing | R-Value | 2 | 2 | 2 | 2 | 2 | 2 |
| Number of Panes | | 2 | 2 | 2 | 2 | 2 | 2 |
| Glass Type | | Clear, 1/4", 1/2" air(N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/4", 1/2" air(N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/4", 1/2" air(N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/4", 1/2" air(N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/4", 1/2" air(N)<br>Bronze, 1/4", 1/4" air (SEW) | Clear, 1/4", 1/2" air(N)<br>Clear, 1/4", 1/4" air (SEW) |
| Frame Type | | Aluminum w/o Break, Fixed | Aluminum w/o Break, Operable | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed | Aluminum w/o Break, Fixed |
| **Systems Information** | | | | | | | |
| Cooling Source | | Packaged Single Zone DX | Packaged Single Zone DX | Constant Speed Electric Centrifugal Chiller | Constant Speed Electric Centrifugal Chiller | Constant Speed Electric Centrifugal Chiller | Packaged Single Zone DX |
| Cooling Efficiency | | 8.5 | 8.5 | 0.676 | 0.676 kW/ton | 0.676 kW/ton | 8.5 EER |
| Heating Source | | Furnace | Furnace | Hot Water Boiler (Natural Draft) | Hot Water Boiler (Natural Draft) | Hot Water Boiler (Natural Draft) | Furnace |
| Heating Efficiency | AFUE | 0.78 | 0.78 | 0.8 | 0.8 | 0.8 | 0.78 |
| Economizer? | | Yes | Yes | Yes | No | Yes | Yes |
| **Location** | | | | | | | |
| Northern | | Allentown, PA | | | | | |
| Southern | | Montgomery, AL | | | | | |

Operating characteristics were defined using the Residential Energy Services Network's Home Energy Rating System (RESNET 2006) for the residential sector and ASHRAE 90.1-2004, the prevailing energy code for the commercial sector.

DOE-2 hourly simulations were next completed to estimate annual electricity consumption for each configuration. These data were then benchmarked relative to historical electricity consumption within the building sector using EIA RECS and EIA CBECS. A summary of the electricity consumption for each configuration, the national estimate of electricity consumption, and the comparison to EIA data are shown in Exhibit 4.

**Exhibit 4. Summary of Base-Case Scenario Electricity Consumption**

| Commercial | Annual Consumption Per Unit | Residential | Annual Consumption Per Unit |
|---|---|---|---|
| Southern Region | kWh | Southern Region | kWh |
| Existing Construction - Assembly | 473,400 | Existing Construction - Single Family | 10,677 |
| Existing Construction - Education | 1,313,700 | Existing Construction - Attached Family | 7,544 |
| Existing Construction - Hospital (Inpatient) | 5,999,000 | | |
| Existing Construction - Lodging | 3,639,700 | | |
| Existing Construction - Retail | 2,590,900 | | |
| Existing Construction - Office | 5,207,300 | | |
| Northern Region | kWh | Northern Region | kWh |
| Existing Construction - Assembly | 399,240 | Existing Construction - Single Family | 8,353 |
| Existing Construction - Education | 1,042,800 | Existing Construction - Attached Family | 6,605 |
| Existing Construction - Hospital (Inpatient) | 5,250,000 | | |
| Existing Construction - Lodging | 3,119,400 | | |
| Existing Construction - Retail | 2,354,000 | | |
| Existing Construction - Office | 4,486,300 | | |
| National | Total GWh | National | Total GWh |
| Existing Construction - Assembly | 167,253 | Existing Construction - Single Family | 735,385 |
| Existing Construction - Education | 138,564 | Existing Construction - Attached Family | 194,594 |
| Existing Construction - Hospital (Inpatient) | 51,968 | | |
| Existing Construction - Lodging | 93,200 | | |
| Existing Construction - Retail | 267,430 | | |
| Existing Construction - Office | 260,724 | | |
| All Commercial Buildings | 979,139 | All Residential Buildings | 929,980 |
| EIA - 2001 CBECS for Selected Sectors | 890,000 | EIA - 2001 RECS | 1,140,000 |
| % Difference | -10% | % Difference | 18% |

## Step 2: Analyze Energy Savings Packages

The next step in estimating elasticity values was to identify and analyze two potential energy efficiency upgrade "packages", which represent bundles of currently available efficiency technologies. The goal of defining these packages was to reasonably bound the levels of efficiency that could be broadly supported in today's marketplace. Therefore, these bounds did not consider the potential of emerging or niche technologies.

To estimate the lower bound of efficiency, the first package was loosely based upon ENERGY STAR guidelines for new and existing buildings. Because the ENERGY STAR program is designed as a voluntary market transformation program, it promotes efficiency upgrades that are both readily available and have been evaluated for cost-effectiveness.

To estimate the upper bound of efficiency, the second package was loosely based upon the standards set forth in the 2005 Energy Policy Act for federal efficiency tax credits, and include best available technologies. This more aggressive package of efficiency upgrades generally had a higher incremental cost and larger savings than the first package. The key upgrade measures considered are summarized by sector in Exhibit 5. Due to space constraints, the specific measures included in each package have not been included.

**Exhibit 5. Upgrade Measures Considered by Sector**

| Commercial Upgrade Measures | Residential Upgrade Measures |
|---|---|
| High Efficiency HVAC Systems; Use of Economizer | High Efficiency HVAC Systems |
| Variable Speed Fans & Pumps | ECM Motor |
| Ventilation Balancing | Increased Duct Insulation |
| Optimized Temperature Set-points | Decreased Duct Leakage |
| Optimized Fan Schedule & Chiller Setback for Shoulder Seasons | Ducts in Conditioned Space |
| Occupancy-based HVAC & Device Power Management | High Efficiency Storage Domestic Hot Water Heaters |
| High Efficiency Lighting / Occupancy Sensors / Day Lighting | Instantaneous Hot Water Heaters |
| Towel & Linen Reuse Program | Programamble Thermostats |
| High Efficiency Office Equipment - Vending & Copying | Increased Ceiling & Wall Insulation; Increased Window Efficiency |
| Power Management of Registers | High Quality Insulation Installation |
| ENERGY STAR Lighting & Appliances | Reduced Infiltration with and without Mechanical Ventilation |
| Increased Roof & Wall Insulation; Increased Window Efficiency | ENERGY STAR Lighting & Appliances |

DOE-2 hourly simulations were then used to estimate the savings potential for each package. The following exhibits display the incremental cost, annual savings, and payback period of each efficiency package applied to each building sub-sector.

**Exhibit 6. Characteristics of Efficiency Upgrade Packages – Commercial Buildings**

| | Southern Region | | | | | Northern Region | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Annual Savings Per Unit | | Annual Savings | Incremental Cost | Payback | Annual Savings Per Unit | | Annual Savings | Incremental Cost | Payback |
| | kWh | Therms | $ | $ | Period | kWh | Therms | $ | $ | Period |
| **Lower-Bound Packages** | | | | | | | | | | |
| New Construction - Assembly | 137,470 | 1,926 | 22,136 | 127,684 | 6 | 112,600 | 4,881 | 21,956 | 127,684 | 6 |
| New Construction - Education | 364,800 | 3,072 | 56,380 | 305,629 | 5 | 253,950 | 12,344 | 51,066 | 305,629 | 6 |
| New Construction - Hospital (Inpatient) | 1,347,200 | -19,600 | 172,378 | 219,199 | 1 | 1,110,900 | -22,900 | 134,340 | 219,199 | 2 |
| New Construction - Lodging | 1,336,800 | 6,920 | 201,582 | 156,438 | 1 | 1,097,900 | 11,900 | 172,756 | 156,438 | 1 |
| New Construction - Retail | 496,600 | 6,053 | 78,917 | 211,485 | 3 | 403,200 | 21,503 | 83,284 | 211,485 | 3 |
| New Construction - Office | 1,878,500 | 1,800 | 274,091 | 371,740 | 1 | 1,501,100 | 5,400 | 223,612 | 371,740 | 2 |
| Existing Construction - Assembly | 171,950 | 1,901 | 27,099 | 66,464 | 2 | 137,450 | 5,998 | 26,848 | 66,464 | 2 |
| Existing Construction - Education | 437,060 | 2,967 | 66,721 | 240,682 | 4 | 309,700 | 12,405 | 59,210 | 240,682 | 4 |
| Existing Construction - Hospital (Inpatient) | 1,810,500 | -23,000 | 235,526 | 242,053 | 1 | 1,537,500 | -25,700 | 192,869 | 242,053 | 1 |
| Existing Construction - Lodging | 1,715,400 | 5,766 | 255,067 | 156,438 | 1 | 1,432,500 | 14,800 | 224,564 | 156,438 | 1 |
| Existing Construction - Retail | 568,000 | 5,335 | 88,425 | 125,664 | 1 | 446,900 | 26,902 | 95,863 | 125,664 | 1 |
| Existing Construction - Office | 2,388,100 | -8,900 | 335,491 | 371,740 | 1 | 2,054,800 | -2,000 | 295,219 | 371,740 | 1 |
| **Upper-Bound Packages** | | | | | | | | | | |
| New Construction - Assembly | 196,520 | 1,358 | 30,029 | 404,868 | 13 | 177,880 | 3,487 | 29,794 | 404,868 | 14 |
| New Construction - Education | 575,210 | 2,879 | 86,625 | 827,549 | 10 | 445,870 | 10,678 | 76,927 | 827,549 | 11 |
| New Construction - Hospital (Inpatient) | 1,717,800 | -26,500 | 218,050 | 838,678 | 4 | 1,441,700 | -30,200 | 173,787 | 838,678 | 5 |
| New Construction - Lodging | 1,347,700 | 8,665 | 205,181 | 335,276 | 2 | 1,083,600 | 16,700 | 176,244 | 335,276 | 2 |
| New Construction - Retail | 787,800 | 5,502 | 120,444 | 760,086 | 6 | 663,000 | 16,524 | 115,137 | 760,086 | 7 |
| New Construction - Office | 2,032,800 | -6,800 | 286,475 | 751,233 | 3 | 1,661,500 | -3,300 | 236,764 | 751,233 | 3 |
| Existing Construction - Assembly | 174,530 | 1,985 | 27,571 | 72,378 | 3 | 138,240 | 6,799 | 27,891 | 72,378 | 3 |
| Existing Construction - Education | 434,270 | 3,017 | 66,375 | 258,343 | 4 | 304,380 | 12,661 | 58,736 | 258,343 | 4 |
| Existing Construction - Hospital (Inpatient) | 1,889,400 | -21,400 | 248,804 | 374,848 | 2 | 1,579,400 | -23,000 | 202,063 | 374,848 | 2 |
| Existing Construction - Lodging | 1,813,300 | 7,878 | 271,689 | 209,881 | 1 | 1,511,000 | 13,500 | 234,426 | 209,881 | 1 |
| Existing Construction - Retail | 583,800 | 5,348 | 90,728 | 134,107 | 1 | 457,700 | 22,801 | 92,679 | 134,107 | 1 |
| Existing Construction - Office | 2,533,800 | 7,200 | 375,232 | 482,058 | 1 | 2,088,700 | -1,000 | 301,286 | 482,058 | 2 |

**Exhibit 7. Characteristics of Efficiency Upgrade Packages – Residential Buildings**

| | Southern Region | | | | | Northern Region | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Annual Savings Per Unit | | Annual Savings | Incremental Cost | Payback | Annual Savings Per Unit | | Annual Savings | Incremental Cost | Payback |
| | kWh | Therms | $ | $ | Period | kWh | Therms | $ | $ | Period |
| **Lower-Bound Packages** | | | | | | | | | | |
| New Construction - Single Family | 1,200 | 90 | 320 | 3,299 | 10 | 459 | 254 | 444 | 2,398 | 5 |
| New Construction - Attached Family | 641 | 24 | 136 | 1,147 | 8 | 466 | 32 | 120 | 626 | 5 |
| Existing Construction - Single Family | 1,396 | 180 | 483 | 4,634 | 10 | 324 | 328 | 529 | 2,971 | 6 |
| Existing Construction - Attached Family | 512 | 83 | 201 | 715 | 4 | 301 | 141 | 253 | 918 | 4 |
| **Upper-Bound Packages** | | | | | | | | | | |
| New Construction - Single Family | 2,768 | 146 | 650 | 7,492 | 12 | 1,095 | 416 | 780 | 10,261 | 13 |
| New Construction - Attached Family | 1,341 | 80 | 329 | 2,138 | 7 | 868 | 141 | 342 | 4,265 | 12 |
| Existing Construction - Single Family | 2,816 | 198 | 732 | 11,255 | 15 | 981 | 384 | 715 | 9,000 | 13 |
| Existing Construction - Attached Family | 1,098 | 98 | 316 | 1,948 | 6 | 732 | 173 | 368 | 1,830 | 5 |

## Step 3: Analyze Market Adoption Potential

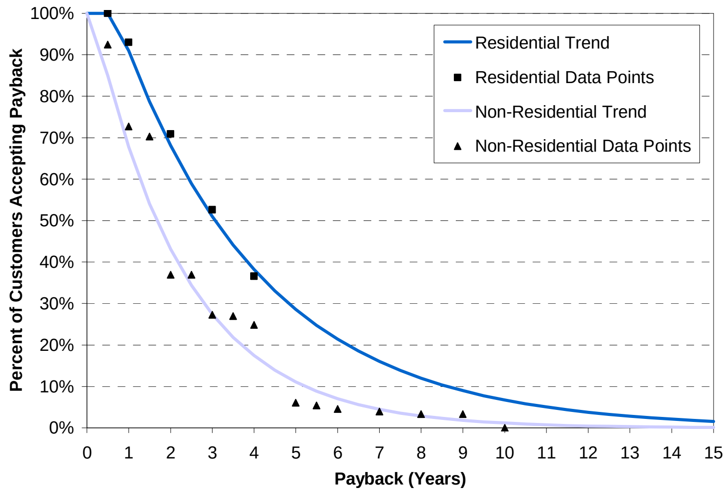
After characterizing both the baseline scenario and the lower and upper bound efficiency packages, the market adoption potential for each package was estimated. The intent of this step was to estimate the number of installations of each package that is likely to occur over short and long term time horizons. The adoption potential for each package is assumed to be dependent upon the technical feasibility of installing each package, the market acceptance of the package (which is estimated to be a function of payback period), and the percentage of the market that has not yet adopted such upgrades. These factors are described in greater detail below.

**Technical applicability**. The percentage of all buildings for which it would be technically feasible to upgrade the baseline technology. For many measures, the applicability would be

100%.  However, for certain measures, such as the addition of wall insulation to existing homes, variations in wall construction and accessibility would reduce the applicability below 100%.

**Market applicability**. The maximum percentage of the marketplace that would be willing to adopt the technology, based solely upon the payback period.  This factor estimates payback acceptance rates based on consumers' stated willingness to pay for energy efficiency projects with different paybacks.  Separate payback acceptance curves were developed for the residential and non-residential sectors.  The non-residential payback acceptance curves are based on the responses of commercial and industrial customers to surveys conducted as part of an energy efficiency baseline study (ICF 2006).  The residential surveys completed as a part of that study did not include a payback acceptance question.  Therefore, proxy data was used from a statistically representative survey of 407 residential customers from across the United States (Shelton Group 2005). The following exhibit shows the percentage of consumers willing to pursue an energy-saving project at a given payback period.

**Exhibit 8. Acceptance Payback Curves**




The implication of the curve is that willingness to pursue a project drops off very quickly as the payback period rises. Though the vast majority of consumers would be willing to pursue a project with a payback of 1 year, only half are willing to accept a project with a 3-year payback. While consumers' hypothetical self-reported payback threshold generally differs considerably from their actual behavior, these data are useful in that they're grounded in actual consumer statements.

**Percent not yet adopted**. The percentage of buildings that have not already been upgraded to the efficient technology.  Because each of the measures considered is commercially available, it is reasonable to expect that some percentage of the market has already adopted the measure.

The above factors were combined to produce an overall applicability factor, defined as:

Overall Applicability = Technical Applicability x Market Applicability x % Not Yet Adopted

It is worth noting that the Market Applicability factor changed with each electricity price scenario considered, because the Applicability Factor is dependent on payback period.  As prices rise, payback period is shortened and market acceptance increases. The other two factors used in the analysis remained static.

The electricity price scenarios considered ranged from $0.10 to $0.15 per kWh for residential buildings and from $0.09 to $0.14/kWh for commercial buildings. The low ends of these ranges are reflective of national average retail rates in 2006 (EIA 2007). The high ends of these ranges were selected to illustrate the possible impacts on elasticity that may result from a national carbon policy. While these values do not reference a specific study, long-term increases exceeding 45% have been suggested (Douglas 2007). The following exhibits displays the applicability factors estimated for each package, including the variation in market applicability for each electricity rate considered.

## Exhibit 9. Applicability Factors – Commercial Buildings

| | Southern Region | | | | | | | | Northern Region | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Technical Applicability (%) | Market Applicability (%) | | | | | | Not Yet Adopted (%) | Technical Applicability (%) | Market Applicability (%) | | | | | | Not Yet Adopted (%) |
| | | kWh Rate | | | | | | | | kWh Rate | | | | | | |
| **Lower-Bound Packages** | | $0.09 | $0.10 | $0.11 | $0.12 | $0.13 | $0.14 | | | $0.09 | $0.10 | $0.11 | $0.12 | $0.13 | $0.14 | |
| New Construction - Assembly | 90% | 2% | 3% | 4% | 5% | 7% | 8% | 85% | 90% | 3% | 4% | 5% | 6% | 7% | 8% | 85% |
| New Construction - Education | 90% | 3% | 4% | 5% | 6% | 8% | 9% | 85% | 90% | 3% | 4% | 4% | 5% | 6% | 7% | 85% |
| New Construction - Hospital (Inpatient) | 90% | 41% | 46% | 50% | 54% | 57% | 60% | 85% | 90% | 30% | 35% | 40% | 44% | 47% | 51% | 85% |
| New Construction - Lodging | 90% | 63% | 66% | 69% | 71% | 73% | 75% | 85% | 90% | 58% | 61% | 64% | 66% | 69% | 71% | 85% |
| New Construction - Retail | 90% | 18% | 21% | 24% | 26% | 29% | 32% | 85% | 90% | 23% | 25% | 28% | 30% | 32% | 34% | 85% |
| New Construction - Office | 90% | 42% | 46% | 49% | 52% | 55% | 58% | 85% | 90% | 34% | 38% | 41% | 44% | 47% | 50% | 85% |
| Existing Construction - Assembly | 90% | 21% | 24% | 27% | 30% | 32% | 35% | 95% | 90% | 23% | 26% | 28% | 30% | 33% | 35% | 95% |
| Existing Construction - Education | 90% | 9% | 12% | 14% | 16% | 18% | 21% | 95% | 90% | 9% | 10% | 12% | 14% | 15% | 17% | 95% |
| Existing Construction - Hospital (Inpatient) | 90% | 50% | 54% | 58% | 61% | 64% | 67% | 95% | 90% | 41% | 46% | 50% | 54% | 57% | 60% | 95% |
| Existing Construction - Lodging | 90% | 70% | 73% | 75% | 77% | 79% | 81% | 95% | 90% | 67% | 70% | 72% | 74% | 76% | 78% | 95% |
| Existing Construction - Retail | 90% | 41% | 45% | 48% | 51% | 53% | 56% | 95% | 90% | 49% | 51% | 53% | 55% | 57% | 59% | 95% |
| Existing Construction - Office | 90% | 49% | 53% | 56% | 59% | 62% | 64% | 95% | 90% | 44% | 48% | 52% | 55% | 58% | 60% | 95% |
| **Upper-Bound Packages** | | | | | | | | | | | | | | | | |
| New Construction - Assembly | 90% | 0% | 0% | 0% | 0% | 0% | 0% | 85% | 90% | 0% | 0% | 0% | 0% | 0% | 0% | 85% |
| New Construction - Education | 90% | 0% | 0% | 0% | 1% | 1% | 1% | 85% | 90% | 0% | 0% | 0% | 0% | 1% | 1% | 85% |
| New Construction - Hospital (Inpatient) | 90% | 6% | 8% | 11% | 13% | 16% | 19% | 85% | 90% | 2% | 4% | 6% | 8% | 10% | 12% | 85% |
| New Construction - Lodging | 90% | 35% | 39% | 42% | 45% | 48% | 51% | 85% | 90% | 31% | 34% | 37% | 40% | 42% | 45% | 85% |
| New Construction - Retail | 90% | 1% | 2% | 3% | 4% | 5% | 6% | 85% | 90% | 2% | 2% | 3% | 4% | 4% | 5% | 85% |
| New Construction - Office | 90% | 17% | 20% | 23% | 27% | 30% | 32% | 85% | 90% | 11% | 14% | 17% | 20% | 23% | 25% | 85% |
| Existing Construction - Assembly | 90% | 19% | 22% | 24% | 27% | 30% | 32% | 95% | 90% | 22% | 24% | 27% | 29% | 31% | 33% | 95% |
| Existing Construction - Education | 90% | 8% | 10% | 12% | 14% | 16% | 18% | 95% | 90% | 7% | 9% | 10% | 11% | 13% | 14% | 95% |
| Existing Construction - Hospital (Inpatient) | 90% | 35% | 40% | 44% | 47% | 51% | 54% | 95% | 90% | 27% | 31% | 35% | 39% | 43% | 46% | 95% |
| Existing Construction - Lodging | 90% | 63% | 66% | 69% | 71% | 73% | 75% | 95% | 90% | 58% | 62% | 64% | 67% | 69% | 71% | 95% |
| Existing Construction - Retail | 90% | 40% | 43% | 46% | 49% | 52% | 54% | 95% | 90% | 45% | 47% | 49% | 51% | 53% | 55% | 95% |
| Existing Construction - Office | 90% | 44% | 48% | 51% | 54% | 57% | 59% | 95% | 90% | 35% | 39% | 42% | 46% | 49% | 51% | 95% |

## Exhibit 10. Applicability Factors – Residential Buildings

| | Southern Region | | | | | | | | Northern Region | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Technical Applicability (%) | Market Applicability (%) | | | | | | Not Yet Adopted (%) | Technical Applicability (%) | Market Applicability (%) | | | | | | Not Yet Adopted (%) |
| | | kWh Rate | | | | | | | | kWh Rate | | | | | | |
| **Lower-Bound Packages** | | $0.10 | $0.11 | $0.12 | $0.13 | $0.14 | $0.15 | | | $0.10 | $0.11 | $0.12 | $0.13 | $0.14 | $0.15 | |
| New Construction - Single Family | 90% | 3% | 3% | 4% | 5% | 5% | 6% | 85% | 90% | 23% | 24% | 24% | 24% | 25% | 25% | 85% |
| New Construction - Attached Family | 90% | 5% | 5% | 7% | 8% | 9% | 10% | 85% | 90% | 18% | 20% | 21% | 23% | 25% | 26% | 85% |
| Existing Construction - Single Family | 90% | 4% | 5% | 6% | 6% | 7% | 7% | 95% | 90% | 23% | 23% | 23% | 23% | 24% | 24% | 95% |
| Existing Construction - Attached Family | 90% | 37% | 38% | 39% | 41% | 42% | 43% | 95% | 90% | 40% | 40% | 41% | 41% | 42% | 42% | 95% |
| **Upper-Bound Packages** | | | | | | | | | | | | | | | | |
| New Construction - Single Family | 90% | 2% | 2% | 2% | 3% | 3% | 4% | 95% | 90% | 2% | 2% | 2% | 2% | 2% | 3% | 95% |
| New Construction - Attached Family | 90% | 11% | 12% | 14% | 15% | 16% | 18% | 95% | 90% | 2% | 2% | 2% | 3% | 3% | 3% | 95% |
| Existing Construction - Single Family | 90% | 0% | 1% | 1% | 1% | 1% | 1% | 98% | 90% | 2% | 3% | 3% | 3% | 3% | 3% | 98% |
| Existing Construction - Attached Family | 90% | 13% | 15% | 16% | 17% | 19% | 20% | 98% | 90% | 24% | 25% | 26% | 27% | 28% | 29% | 98% |

Because the upgrades for each package were selected by the authors for mass-market adoption, the Technical Applicability factors were assumed to be relatively high. The % Not Yet Adopted factors were also based upon the authors' best judgment, due to the scarcity of published data related to these values. However, they were informed by available statistics, such as the current national penetration of ENERGY STAR New Homes, which roughly corresponds with the factor for the lower-bound package for residential new construction.

The analysis next estimated the adoption of each package within the marketplace from 2013 to 2030. Upgrades were assumed to occur at the time when new buildings were constructed or, for existing buildings, on a "replace on fail" scenario. Therefore, 100% of new buildings were considered eligible for receiving the upgrades in each year and it was assumed that 5% of existing buildings would be eligible in each year. Overall adoption was then estimated by multiplying the overall applicability factor by the total number of buildings associated with each baseline scenario and by the annual eligibility factor (i.e., 100% for new buildings and 5% for existing buildings). To account for new construction that would occur between 2013 and 2003, a constant growth rate of 1.35% was assumed for both residential and commercial construction.

### Step 4: Estimate National Impacts & Elasticities Using Multiple Electric Price Scenarios

Having configured the base-case buildings, estimating the cost and savings of the energy efficiency bundles, as well as the short and long term market adoption potential, the national electricity savings potential could be calculated for each electricity price scenario. Then, by dividing the percent change in savings by the percent change in electricity price, the elasticity of each scenario could be calculated. These impacts are presented over the time horizon for each geographic region and each price point considered in Exhibits 11 & 12.

**Exhibit 11. Consumption Savings & Elasticities – Commercial Buildings**

| | Electric Price ($/kWh) | Consumption Savings (GWh) | | | | Δ Price | 2015 | | 2020 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | 2030 | | Δ Cons. | Elasticity | Δ Cons. | Elasticity | Δ Cons. | Elasticity | Δ Cons. | Elasticity |
| North | $0.09 | 5,575 | 20,086 | 36,582 | 55,269 | - | - | - | - | - | - | - | - | - |
| | $0.10 | 5,983 | 21,534 | 39,212 | 59,240 | 11% | -7% | -0.69 | -7% | -0.68 | -7% | -0.68 | -7% | -0.68 |
| | $0.11 | 6,351 | 22,838 | 41,583 | 62,816 | 10% | -6% | -0.64 | -6% | -0.64 | -6% | -0.63 | -6% | -0.63 |
| | $0.12 | 6,684 | 24,020 | 43,727 | 66,053 | 9% | -5% | -0.60 | -5% | -0.59 | -5% | -0.59 | -5% | -0.59 |
| | $0.13 | 6,988 | 25,094 | 45,677 | 68,995 | 8% | -5% | -0.57 | -4% | -0.56 | -4% | -0.56 | -4% | -0.56 |
| | $0.14 | 7,266 | 26,075 | 47,457 | 71,680 | 7% | -4% | -0.54 | -4% | -0.53 | -4% | -0.53 | -4% | -0.52 |
| South | $0.09 | 9,514 | 34,315 | 62,509 | 94,449 | - | - | - | - | - | - | - | - | - |
| | $0.10 | 10,375 | 37,394 | 68,111 | 102,908 | 11% | -9% | -0.86 | -9% | -0.85 | -9% | -0.85 | -9% | -0.85 |
| | $0.11 | 11,161 | 40,205 | 73,223 | 110,627 | 10% | -8% | -0.79 | -8% | -0.79 | -8% | -0.79 | -8% | -0.79 |
| | $0.12 | 11,883 | 42,779 | 77,902 | 117,691 | 9% | -6% | -0.74 | -6% | -0.73 | -6% | -0.73 | -6% | -0.73 |
| | $0.13 | 12,547 | 45,143 | 82,199 | 124,178 | 8% | -6% | -0.70 | -6% | -0.69 | -6% | -0.69 | -6% | -0.69 |
| | $0.14 | 13,160 | 47,321 | 86,157 | 130,151 | 7% | -5% | -0.66 | -5% | -0.65 | -5% | -0.65 | -5% | -0.65 |

**Exhibit 12. Consumption Savings & Elasticities – Residential Buildings**

| | Electric Price ($/kWh) | Consumption Savings (GWh) | | | | Δ Price | 2015 | | 2020 | | 2025 | | 2030 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2020 | 2025 | 2030 | | Δ Cons. | Elasticity | Δ Cons. | Elasticity | Δ Cons. | Elasticity | Δ Cons. | Elasticity |
| North | $0.10 | 886 | 3,134 | 5,689 | 8,583 | - | - | - | - | - | - | - | - | - |
| | $0.11 | 907 | 3,204 | 5,816 | 8,774 | 10% | -2% | -0.24 | -2% | -0.23 | -2% | -0.23 | -2% | -0.23 |
| | $0.12 | 928 | 3,274 | 5,942 | 8,964 | 9% | -2% | -0.26 | -2% | -0.25 | -2% | -0.25 | -2% | -0.25 |
| | $0.13 | 949 | 3,345 | 6,069 | 9,155 | 8% | -2% | -0.28 | -2% | -0.26 | -2% | -0.26 | -2% | -0.26 |
| | $0.14 | 969 | 3,415 | 6,196 | 9,346 | 8% | -2% | -0.29 | -2% | -0.28 | -2% | -0.28 | -2% | -0.28 |
| | $0.15 | 990 | 3,486 | 6,323 | 9,536 | 7% | -2% | -0.31 | -2% | -0.30 | -2% | -0.29 | -2% | -0.29 |
| South | $0.10 | 593 | 2,092 | 3,795 | 5,724 | - | - | - | - | - | - | - | - | - |
| | $0.11 | 651 | 2,283 | 4,138 | 6,239 | 9% | -10% | -1.05 | -9% | -0.98 | -9% | -0.97 | -9% | -0.97 |
| | $0.12 | 712 | 2,483 | 4,496 | 6,777 | 9% | -9% | -1.09 | -9% | -1.03 | -9% | -1.02 | -9% | -1.01 |
| | $0.13 | 775 | 2,691 | 4,868 | 7,335 | 8% | -9% | -1.13 | -8% | -1.07 | -8% | -1.06 | -8% | -1.05 |
| | $0.14 | 841 | 2,906 | 5,255 | 7,914 | 7% | -8% | -1.17 | -8% | -1.10 | -8% | -1.09 | -8% | -1.09 |
| | $0.15 | 909 | 3,129 | 5,654 | 8,513 | 7% | -8% | -1.20 | -8% | -1.13 | -8% | -1.12 | -8% | -1.12 |

National weighted elasticity values were then calculated for the residential and commercial building sector by multiplying the elasticity value from each region by its proportion of national electric retail sales for that sector, as determined by EIA (EIA 2006). This resulted in the national elasticity values reported in Exhibit 13.

**Exhibit 13. National Elasticity Values**

| Electric Price | Residential | | | | Commercial | | | |
|---|---|---|---|---|---|---|---|---|
| ($/kWh) | 2015 | 2020 | 2025 | 2030 | 2015 | 2020 | 2025 | 2030 |
| Lowest Rate | -0.63 | -0.60 | -0.59 | -0.59 | -0.77 | -0.76 | -0.76 | -0.76 |
| ↓ | -0.66 | -0.63 | -0.62 | -0.62 | -0.71 | -0.70 | -0.70 | -0.70 |
| | -0.69 | -0.65 | -0.65 | -0.65 | -0.67 | -0.66 | -0.66 | -0.66 |
| | -0.72 | -0.68 | -0.67 | -0.67 | -0.63 | -0.62 | -0.62 | -0.62 |
| Highest Rate | -0.74 | -0.70 | -0.70 | -0.69 | -0.59 | -0.58 | -0.58 | -0.58 |

## Discussion

The methodology described above allowed for the estimation of long-term elasticity values for residential and commercial building sectors in two geographic regions. This bottom-up approach contrasts with traditional econometric approaches used by others.

Interestingly, the resulting national values for the residential sector, ranging from -0.59 to -0.74, are comparable with the long-term consensus value of -0.70 identified by Bohi and Zimmerman, but are higher than the value of -0.32 identified by Bernstein and Griffin. The resulting national values for the commercial sector, ranging from -0.58 to -0.77 are lower than the long-term value of -0.97 identified by Bernstein and Griffin. Other research had difficulty identifying consensus values for the commercial sector. Using this methodology, variations in values were also identified between geographic regions in both residential and commercial sectors, which reinforces trends identified in other studies. As expected, variations in the commercial sector are smaller than within the residential sector.

While the approach described in this paper produced elasticity values comparable with previous studies, there are a number of potential refinements that could further enhance this methodology. For example, the methodology could benefit from an expansion of the geographic regions considered, the quantity of packages evaluated, and a more refined approach to estimating the applicability factor of each upgrade package. Regarding this last point, future work should consider the impact of varying policy models on market adoption, such as voluntary vs. regulatory structures. The methodology described in this paper assumes that adoption of the efficiency packages is purely voluntary and not influenced by utility sponsored efficiency programs. Such programs would likely reduce market barriers and provide incentives, further reducing payback periods and increasing adoption rates. The model also does not consider secondary effects, including the possibility that elasticities can change over time based upon marketplace perceptions of energy efficiency, or the economies of scale that might achieved by widespread deployment of energy efficiency technologies.

## Conclusion

This paper presents a rudimentary process for estimating regional elasticity values for the residential and commercial sectors based upon a new bottom-up approach. Such an analysis contrasts with the traditional econometric approach used in previous studies. This new approach produces long-term elasticity values generally in line with prior research, including a demonstration of differences in values for different sectors and geographic regions. With further refinement, this approach could be used to produce estimates of elasticity values for a greater number of scenarios with increased resolution and confidence. Such a methodology would be of use to efforts to analyze the long-term impact of national carbon policy on the demand of electricity within the United States.

## References


Bernstein, Mark, and J. Griffin. 2005. *Regional Differences in the Price-Elasticity of Demand For Energy*. Santa Monica, Calif.: RAND Corporation.

Douglas, John. 2007. "Modeling the Technology Mix." *EPRI Journal* (spring): 16-19.

[EIA] Energy Information Administration. 2006. *Annual Electric Power Industry Report.* http://www.eia.doe.gov/cneaf/electricity/page/eia861.html. Washington, DC: Energy Information Administration.

[EIA] Energy Information Administration. 2007. *Average Retail Price of Electricity to Ultimate Customers by End-Use Sector.* http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html. Washington, DC: Energy Information Administration.

[EIA CBECS] Energy Information Administration. 2003. *Commercial Buildings Energy Consumption Survey: Building Characteristics.* http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html. Washington, DC.: Energy Information Administration.

[EIA RECS] Energy Information Administration. 2001. *Residential Energy Consumption Survey: Housing Characteristics.* http://www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html. Washington, DC.: Energy Information Administration.

ICF International. 2006. *Arizona Public Service Energy Efficiency Baseline & Market Potential Study*. Plano, Tex.: ICF International.

[RESNET] Residential Energy Services Network, Inc.. 2006. *2006 Mortgage Industry National Home Energy Rating Systems Standards.* Oceanside, Calif.: Residential Energy Services Network, Inc..

Shelton Group. 2005. *Energy Pulse 2005: What American Consumers Want in Home Energy Efficiency*. Knoxville, Tenn.: Shelton Group.

U.S. Census Bureau. 2006. *American Housing Survey for the United States: 2005.* Current Housing Reports, Series H150/05. Washington, DC: U.S. Government Printing Office.