U.S. DEPARTMENT OF ENERGY

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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Cost-Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions – Technical Support Document

V Mendon
R Lucas
S Goel

April 2013

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

This analysis was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy's (DOE) Building Energy Codes Program (BECP). DOE supports the development and adoption of energy efficient and cost-effective residential and commercial building energy codes. These codes set the minimum requirements for energy efficient building design and construction and ensure energy savings on a national level. This analysis focuses on one and two family dwellings, townhomes, and low-rise multifamily residential buildings. For these buildings, the basis of the energy codes is the International Energy Conservation Code (IECC). This report does not address commercial and high-rise residential buildings (four or more stories).

The IECC is developed and published on a three-year cycle, with a new version published at the end of each cycle. This analysis examines the 2006, 2009, and 2012 versions of the IECC as applied to individual states. Each version of the IECC includes provisions that increase energy-efficiency levels over its predecessor.

This report documents the analysis PNNL conducted to assess the cost effectiveness of the 2009 and 2012 IECC over the 2006 IECC at the state level. For each state, PNNL's analysis compares the newer version (or versions) of the IECC against an older version currently in use in the state. For states that have adopted the 2006 IECC or equivalent, the analysis evaluates the cost effectiveness of updating the state code to either the 2009 or 2012 IECC. For a state with a code already equivalent to the 2009 IECC, the analysis evaluates moving up to the 2012 IECC.

While some states adopt the IECC as published, other states amend the code. Still other states develop entirely unique state energy codes. Finally, some states have either no code at all or have a code based on a pre-2006 version of the IECC. PNNL conducted customized analyses for those states with amended IECC versions; assumed states with no code or an old code as using the 2006 IECC, and did not analyze state with custom codes.

DOE has established a methodology for determining energy savings and cost effectiveness of various building energy codes (Taylor et al. 2012). The methodology defines an analysis procedure including:

- Definitions of two building prototypes (single-family and multifamily)
- Identification of preferred calculation tools
- Climate locations
- Construction cost data sources
- Cost-effectiveness metrics and associated economic parameters
- Procedures for aggregating location-specific results to state, climate-zone, and national levels.

This technical support document provides additional detail and documents the specific assumptions used in applying the cost-effectiveness methodology.

The analysis is conducted using DOE's *EnergyPlus* simulation software. PNNL developed two prototype building models to represent the single-family and the multifamily buildings defined in the methodology. These two prototypes were then expanded to a suite of 32 energy models to represent four commonly used heating systems in homes (i.e., gas furnace, oil furnace, heat pump, and electric furnace) and four commonly used foundations (i.e., vented crawlspace, slab-on-grade, heated basement, and unheated basement). Different versions of the models are created to match the requirements of the 2006, 2009, and 2012 IECC for each location. The entire set is simulated across 119 locations to represent the different climate-zone and moisture regimes in each state across the country.

The annual energy consumption for space heating, cooling, domestic hot water heating, and lighting is extracted for each case. The energy use is converted to energy cost using fuel costs in the different states. Incremental first costs are calculated for each location for the energy provisions of the 2009 and 2012 IECC over the baseline code, as applicable, using the Building Component Cost Community (BC3) data repository.[1] These first costs are adjusted for variation in construction and material costs across the country using location multipliers developed by Faithful+Gould for PNNL.[2] The energy costs and first costs are aggregated based on new housing construction starts from the U.S. Census data[3], weights of the different foundation types from the Residential Energy Consumption Survey data[4], and heating system weights based on National Association of Home Builders data (NAHB 2009). Life cycle cost (LCC) analysis is then conducted for each case to assess cost effectiveness. DOE uses LCC as the primary measure of cost effectiveness.

Table ES.1 shows the final energy cost savings results of the analysis. Table ES.2 summarizes the LCC savings results for each state. These data show that construction based on the 2009 and 2012 IECC results in greater energy savings than construction based on the 2006 IECC and is cost effective for all states.

Table ES.1. National Weighted Energy Cost Savings

	2009 IECC	2012 IECC
National Energy Cost Savings over the 2006 IECC	10.8% ($ 168)	32.1% ($ 500)

Table ES.2. State Life Cycle Cost Savings over the 2006 IECC (2012 dollars)

State	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
Alabama	2,117	6,182
Alaska	5,861	20,745
Arizona	3,245	6,550

[1] http://bc3.pnnl.gov/wiki/index.php/Main_Page.
[2] http://bc3.pnnl.gov/wiki/images/7/7f/Location_Factors_Report.pdf.
[3] United States Census Bureau Building Permits; Accessed April 27, 2012 at http://censtats.census.gov/bldg/bldgprmt.shtml.
[4] 2009 RECS Survey Data 'Structural and Geographic Characteristics' http://www.eia.gov/consumption/residential/data/2009/#undefined.

Table ES.2. (contd)

State	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
Arkansas	1,948	6,679
California	1,192	2,136
Colorado	1,528	5,435
Connecticut	3,793	13,709
Delaware	4,316	14,778
District of Columbia	2,024	6,852
Florida	2,320	4,147
Georgia	2,210	6,415
Hawaii	5,150	14,238
Idaho	1,444	5,515
Illinois	1,784	6,506
Indiana	1,781	6,764
Iowa	2,823	10,416
Kansas	2,556	8,828
Kentucky	2,279	7,646
Louisiana	1,663	4,107
Maine	5,109	18,944
Maryland	3,473	11,688
Massachusetts	3,914	14,777
Michigan	3,363	12,346
Minnesota	3,196	11,817
Mississippi	2,022	5,400
Missouri	2,229	7,826
Montana	1,668	5,920
Nebraska	1,908	7,141
Nevada	2,543	7,352
New Hampshire	3,925	14,573
New Jersey	3,445	11,877
New Mexico	1,835	5,897
New York	3,870	13,677
North Carolina	1,844	5,911
North Dakota	2,353	8,719
Ohio	1,959	7,120
Oklahoma	2,526	8,621
Oregon	1,422	4,917
Pennsylvania	3,189	11,845
Rhode Island	4,043	15,074
South Carolina	2,215	6,650
South Dakota	2,583	9,514
Tennessee	1,809	6,102

Table ES.2. (contd)

State	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
Texas	2,433	5,942
Utah	1,385	4,879
Vermont	5,133	18,861
Virginia	2,186	7,487
Washington	1,498	5,299
West Virginia	1,996	7,301
Wisconsin	3,056	11,272
Wyoming	1,809	6,441

Acronyms and Abbreviations

ACH50	50-Pa pressure differential
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BC3	Building Component Cost Community
BECP	Building Energy Codes Program
CFL	compact fluorescent lamp
CFM	cubic feet per minute
DOE	U.S. Department of Energy
ECPA	Energy Conservation and Production Act
EF	Energy Factor
ELA	effective leakage area
HVAC	heating, ventilation, and air conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society of North America
IMC	International Mechanical Code
IRC	International Residential Code
LCC	life cycle cost
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient
TMY	Typical Meteorological Year
U-factor	effective thermal conductance
WFR	window-to-floor ratio
WHAM	Water Heater Analysis Model
WWR	window-to-wall ratio

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1.0 Introduction

The U.S. Department of Energy (DOE) supports the development and adoption of building codes that promote energy efficiency. Title III of the Energy Conservation and Production Act (ECPA), as amended, mandates that DOE participate in the development of model building energy codes and assist states in adopting and implementing these codes. The designated residential model energy code is the International Energy Conservation Code (IECC) published by the International Code Council (ICC).

This report documents the methodology and assumptions used in a state-by-state analysis of two recent versions of the IECC (2009 and 2012) conducted by the Pacific Northwest National Laboratory (PNNL) in support of the DOE's Building Energy Codes Program (BECP). The analysis and associated methodology cover single-family detached homes and low-rise multifamily buildings.

1.1 Purpose of Analysis

The IECC is developed and published on a three-year cycle, with a new version published at the end of each cycle. This analysis examines the 2006, 2009, and 2012 versions of the IECC as applied to individual states. These versions are referred to as the 2006 IECC, the 2009 IECC, and the 2012 IECC in this report. Each version of the IECC includes provisions that increase energy-efficiency levels over its predecessor. For each state, PNNL's analysis compares the newer version (or versions) of the IECC against an older version currently in use in the state. For states that have adopted the 2006 IECC or an equivalent code, the analysis evaluates the cost effectiveness of updating the state code to either the 2009 or 2012 IECC. For a state with a code already equivalent to the 2009 IECC, the analysis evaluates energy efficiency-improvements that would be realized by adopting the 2012 IECC.

Not all states adopt the IECC directly. Some states adopt amended versions, some develop custom state codes, and some have either no code or an older code based on a pre-2006 IECC. PNNL conducted customized analyses for those states with amended versions of the IECC and assumed homes in states with no code or an older code are built to a level of energy efficiency equivalent to the 2006 IECC. PNNL did not analyze custom state codes that are not based on the IECC.

DOE has established a methodology for determining energy savings and cost effectiveness of various building energy codes (Taylor et al. 2012). The methodology, hereafter referred to as the cost-effectiveness methodology, is available for download from DOE's energy codes website.[1] The cost-effectiveness methodology defines an energy analysis procedure, including definitions of two building prototypes (single-family and multifamily), identification of preferred calculation tools, and selection of climate locations to be analyzed; establishes preferred construction cost data sources; defines cost-effectiveness metrics and associated economic parameters; and defines a procedure for aggregating location-specific results to state, climate-zone, and national levels. This technical support document provides additional detail and documents the specific assumptions used in applying the cost-effectiveness methodology.

[1] http://www.energycodes.gov/development/residential/methodology.

1.2 Report Contents

This report documents the process of evaluating energy cost savings and cost effectiveness of newer versions of the IECC relative to an older version. Energy savings are computed using energy simulations of two base residential building prototypes—a single-family detached home and a low-rise multifamily building. These two prototypes are simulated using four different heating systems (i.e., gas furnace, heat pump, oil furnace, and electric furnace) and four different foundation types (i.e., vented crawlspace, slab-on-grade, heated basement, and unheated basement) to represent typical residential new-construction stock. These options result in an expanded set of 32 models that are simulated across 119 representative climate locations, yielding a set of 3808 building-energy models for each analyzed version of the IECC.

The energy savings results and the associated incremental costs for each case are aggregated to state, climate zones and national levels using U.S. Census data on new housing construction starts.[1] A cost-effectiveness analysis is carried out to determine three cost-effectiveness metrics—life-cycle cost (LCC), simple payback period, and consumer cash flow—for each analyzed version of the IECC.

This report is divided into three parts. Part one (Chapters 2 through 5) provides details on the energy modeling and assumptions. Part two (Chapters 6 and 7) details the incremental cost calculation for each location, economic calculations, and the aggregation scheme for generating state and national average energy cost savings and cost effectiveness results. Finally, part three (Chapter 8) summarizes state and national energy cost savings and cost effectiveness results. These final results also are published as a part of the individual state and national cost effectiveness reports.[2]

More details are provided in the appendices. Appendix A provides detailed modeling assumptions and prototype descriptions used in the energy simulations, including internal heat gains assumptions, and various schedules. Appendix B lays out the prescriptive code requirements of the 2006, 2009, and 2012 IECC. Finally, Appendix C describes prescriptive code requirements for states with amended versions of the IECC that are modeled in the customized state analyses.

[1] United States Census Bureau Building Permits; Accessed April 27, 2012 http://censtats.census.gov/bldg/bldgprmt.shtml.

[2] Residential IECC Cost Effectiveness Analysis and Results http://www.energycodes.gov/development/residential/iecc_analysis.

2.0 Process and Methodology

2.1 Analysis Overview

The 2009 and 2012 IECC include provisions that promote substantial improvements in energy efficiency compared to the 2006 IECC. The focus of this analysis is assessing the energy savings and cost effectiveness of the two newer versions of the IECC for typical single-family detached homes and low-rise multifamily buildings, and aggregating those results to appropriate state and/or national levels. The sequence of operations for a given state is described below:

1. Identify the relevant state code and any state-specific amendments. This establishes the baseline code for the state and determines whether both the 2009 and 2012 IECC will be analyzed (if the 2006 IECC is the baseline) or just the 2012 IECC (if the 2009 IECC is the baseline).
2. Assemble construction cost data for the building elements that have changed between the baseline code and the analyzed code(s). Apply regional adjustments to these national average costs so they represent the specific locations analyzed.
3. Simulate the energy differences (savings) between the baseline code and the newer code(s) for each of the climate locations.
4. Aggregate energy savings and incremental costs to state, climate-zone, and national levels and calculate cost-effectiveness metrics (e.g., LCC, payback period, consumer cash flow, etc.) for each new code.

Annual energy use for each case is simulated using DOE's EnergyPlus™ software, Version 5.0.[1] The cost-effectiveness methodology defines details of the single-family and multifamily prototype buildings such as typical constructions, mechanical systems, internal gains and operating assumptions. The building prototypes include four foundation types and four heating system types to appropriately account for location-specific construction practices and fuel usage. The energy results are aggregated across building types, foundation types, heating equipment types, and locations using weighting factors defined in the cost-effectiveness methodology to provide national, climate-zone-specific, and state-specific energy cost savings.

The cost effectiveness of code changes is determined using energy cost savings from the improvements in the code(s) and the associated incremental first cost of construction. Incremental first costs of energy efficient code changes are determined through several sources as detailed in subsequent chapters. Location-specific cost multipliers are used to account for regional variations in construction costs. Location-specific fuel prices are taken from the most recent state-specific residential fuel prices available from DOE's Energy Information Administration. .[2, 3, 4]

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[1] EnergyPlus at http://apps1.eere.energy.gov/buildings/energyplus.

[2] U.S. Department of Energy (DOE). 2012a. *Electric Power Monthly*. DOE/EIA-0226. Washington, D.C. http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

[3] U.S. Department of Energy (DOE). 2012b. *Natural Gas Monthly*. DOE/EIA-0130. Washington, D.C. http://www.eia.gov/oil_gas/natural_gas/data_publications/natural_gas_monthly/ngm.html

[4] U.S. Department of Energy (DOE). 2012c. *Petroleum Marketing Monthly*. DOE/EIA-0380. Washington, D.C. http://www.eia.gov/petroleum/marketing/monthly/

2.2 Climate Locations

The cost-effectiveness methodology details the selection of the climate locations used in this analysis. In each state, one representative climate location is chosen for each unique combination of climate zone - 1 through 8 and moisture regime - moist, dry, marine, and warm-humid. This results in 119 weather locations that are used in the analysis. Table 2.1 lists these locations.

To simulate energy use for each case, the latest Typical Meteorological Year weather files (TMY3)[1] are used with EnergyPlus. The TMY3 dataset contains 1020 locations nationwide, including Guam, Puerto Rico, and the U.S. Virgin Islands. However, a complete TMY3 file is not available for some state-climate zone combinations. In these cases, professional judgment is used to select a best representative TMY3 data location outside the state.

Table 2.1. Locations for Cost-Effectiveness Analysis

State	Climate Zone	Moisture Regime[(a)]	Location
Alabama	2	A, WH	Mobile
Alabama	3	A	Birmingham
Alabama	3	A, WH	Montgomery
Alaska	7		Anchorage
Alaska	8		Fairbanks
Arizona	2	B	Phoenix
Arizona	3	B	Kingman
Arizona	4	B	Prescott
Arizona	5	B	Winslow
Arkansas	3	A	Little Rock
Arkansas	3	A, WH	Shreveport (Louisiana)
Arkansas	4	A	Springfield (Missouri)
California	2	B	Tucson (Arizona)
California	3	B	Los Angeles
California	3	C	San Francisco
California	4	B	Sacramento
California	4	C	Arcata
California	5	B	Reno (NV)
California	6	B	Eagle
Colorado	4	B	Trinidad
Colorado	5	B	Colorado Springs
Colorado	6	B	Eagle County
Colorado	7		Gunnison County
Connecticut	5	A	Hartford-Bradley
Delaware	4	A	Wilmington

[1] National Solar Radiation Data Base. 1991-2005 Update: Typical Meteorological Year 3. Accessed April 27, 2012 at http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

Table 2.1. (contd)

State	Climate Zone	Moisture Regime[(a)]	Location
District of Columbia	4	A	Baltimore (Maryland)
Florida	1	A, WH	Miami
Florida	2	A, WH	Tampa
Georgia	2	A, WH	Savannah
Georgia	3	A	Atlanta
Georgia	3	A, WH	Macon
Georgia	4	A	Chattanooga (Tennessee)
Hawaii	1	A	Honolulu
Idaho	5	B	Boise
Idaho	6	B	Pocatello
Illinois	4	A	St. Louis (Missouri)
Illinois	5	A	Peoria
Indiana	4	A	Evansville
Indiana	5	A	Indianapolis
Iowa	5	A	Des Moines
Iowa	6	A	Mason City
Kansas	4	A	Topeka
Kansas	5	A	Goodland
Kentucky	4	A	Lexington
Louisiana	2	A, WH	Baton Rouge
Louisiana	3	A	Monroe
Louisiana	3	A, WH	Shreveport
Maine	6	A	Portland
Maine	7		Caribou
Maryland	4	A	Baltimore
Maryland	5	A	Harrisburg (Pennsylvania)
Massachusetts	5	A	Boston-Logan
Michigan	5	A	Lansing
Michigan	6	A	Alpena County
Michigan	7		Sault Ste. Marie
Minnesota	6	A	Minneapolis-St. Paul.
Minnesota	7		Duluth
Mississippi	2	A, WH	Mobile (Alabama)
Mississippi	3	A	Tupelo
Mississippi	3	A, WH	Jackson
Missouri	4	A	St. Louis
Missouri	5	A	Kirksville
Montana	6	B	Helena
Nebraska	5	A	Omaha
Nevada	3	B	Las Vegas

Table 2.1. (contd)

State	Climate Zone	Moisture Regime[(a)]	Location
Nevada	5	B	Reno
New Hampshire	5	A	Manchester
New Hampshire	6	A	Concord
New Jersey	4	A	Newark
New Jersey	5	A	Allentown (Pennsylvania)
New Mexico	3	B	Lubbock (Texas)
New Mexico	4	B	Albuquerque
New Mexico	5	B	Winslow (Arizona)
New York	4	A	New York
New York	5	A	Albany
New York	6	A	Binghamton
North Carolina	3	A	Charlotte
North Carolina	3	A, WH	Wilmington
North Carolina	4	A	Raleigh
North Carolina	5	A	Elkins (West Virginia)
North Dakota	6	A	Bismarck
North Dakota	7		Minot
Ohio	4	A	Cincinnati (Kentucky)
Ohio	5	A	Columbus
Oklahoma	3	A	Oklahoma
Oklahoma	4	B	Amarillo (Texas)
Oregon	4	C	Portland
Oregon	5	B	Redmond
Pennsylvania	4	A	Philadelphia
Pennsylvania	5	A	Harrisburg.
Pennsylvania	6	A	Bradford
Rhode Island	5	A	Providence-
South Carolina	3	A	Columbia
South Carolina	3	A, WH	Charleston
South Dakota	5	A	Sioux City (Iowa)
South Dakota	6	A	Pierre
Tennessee	3	A	Memphis
Tennessee	4	A	Nashville
Texas	2	A, WH	Houston
Texas	2	B, WH	San Antonio
Texas	3	A	Wichita Falls
Texas	3	A, WH	Fort Worth-Alliance.
Texas	3	B	El Paso
Texas	4	B	Amarillo
Utah	3	B	Saint George
Utah	5	B	Salt Lake City
Utah	6	B	Vernal

Table 2.1. (contd)

State	Climate Zone	Moisture Regime[(a)]	Location
Vermont	6	A	Burlington
Virginia	4	A	Richmond
Washington	4	C	Seattle
Washington	5	B	Spokane
Washington	6	B	Kalispell (Montana)
West Virginia	4	A	Charleston
West Virginia	5	A	Elkins
Wisconsin	6	A	Madison
Wisconsin	7		Duluth (Minnesota)
Wyoming	5	B	Scottsbluff (Nebraska)
Wyoming	6	B	Cheyenne
Wyoming	7		Jackson Hole

(a) Moisture zone designations are defined as follows:
A = Moist
B = Dry
C = Marine
WH = Warm-Humid.

Climate zones 7 and 8 have no moisture designations in the code.

3.0 Energy Simulation Infrastructure

Energy savings estimates are generated using DOE's EnergyPlus, version 5.0, simulation software. The two prototype building models (i.e., single-family detached home and low-rise multifamily apartment building) are simulated with four heating systems and four foundation types, resulting in 32 separate models for each of three IECC versions. These 96 models are simulated in each of the 119 locations for a total of 11,424 EnergyPlus simulations for the entire national analysis.

The numerous input files (EnergyPlus Input Data Files—IDF) are generated using a PNNL in-house utility that combines a generic input data file template with a large table of input parameters. The generated files are executed in batch style on a Linux computer cluster and managed with the *Make*[1] utility to minimize the need for manual intervention to synchronize output files with input files. Custom post-processing scripts written in the Perl[2] language are used to automate the process of retrieving key values from the simulation outputs and forwarding them to a statistical analysis software package for calculating the cost-effectiveness metrics and aggregating results to appropriate levels.

The simulation input and output files are available for download from DOE's Energy Codes website at http://www.energycodes.gov/development/residential/iecc_models.

[1] Make http://www.gnu.org/software/make/.
[2] Perl http://www.perl.org/.

4.0 Prototype Building Models

The single-family and multifamily prototype building models are intended to represent residential new-construction stock. The cost-effectiveness methodology defines the major elements that characterize these prototypes and the relevant code's primary prescriptive manifestation defines the prototypes' envelope efficiencies in each location of interest. Appendix A summarizes those characteristics along with numerous additional details required to assemble complete EnergyPlus input files for the various simulations. It also provides details on internal gains assumptions and calculations and includes schedules used in the energy simulations. Two electronic spreadsheets, known as scorecards[1] which contain key modeling assumptions and inputs for the two prototypes, are available on DOE's energy codes website.[2] All 11,424 EnergyPlus input files and associated output files from this analysis also are available for download on the same website.[2]

4.1 Building Geometry

The single-family prototype is configured as a 2400 ft^2, two-story detached home with one of four different foundation types. The house is divided into either two or three thermal zones based on the foundation type. All models contain a living space zone and an attic zone; an additional foundation zone is added for models with a crawlspace or basement foundation. Figure 4.1 shows a snapshot of the single-family model with a crawlspace extracted from OpenStudio[3], which is an EnergyPlus plug-in for the SketchUp[4] software.

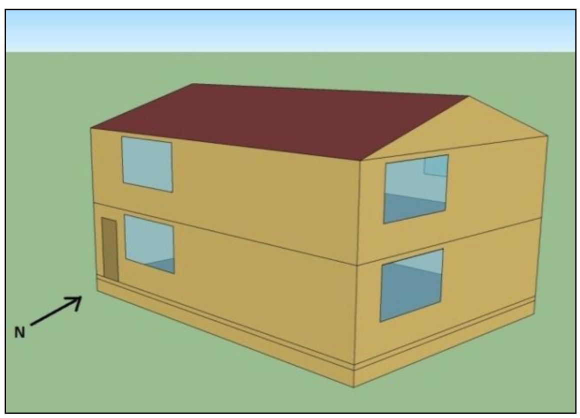

Figure 4.1. Image of the Single-Family Prototype

As depicted in Figure 4.2 and Figure 4.3, the multifamily prototype is configured as a three-story building with six dwelling units per floor, arranged in two rows with an open breezeway running through the middle. Each dwelling unit is modeled as a separate thermal zone. In addition to the resulting 18

[1] The term *scorecard* was coined by the ASHRAE project committee for Standard 90.1 for summaries of commercial building simulation inputs. These scorecards summarize only inputs, not outputs or scores or any kind.
[2] http://www.energycodes.gov/development/residential/iecc_models.
[3] http://apps1.eere.energy.gov/buildings/energyplus/openstudio_suite.cfm.
[4] http://www.sketchup.com/.

thermal zones (one for each dwelling unit), the model has an attic zone and, for models with a crawlspace or basement, a foundation zone.

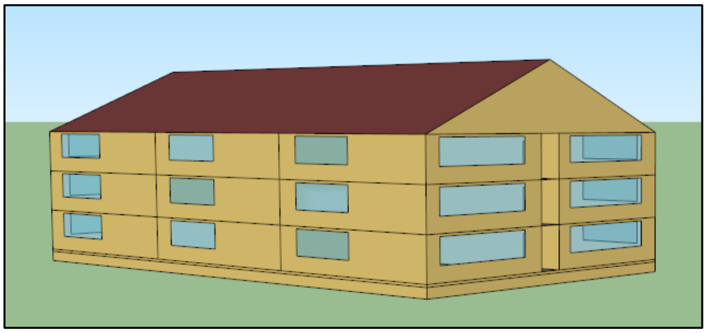

Figure 4.2. Image of the Multifamily Prototype

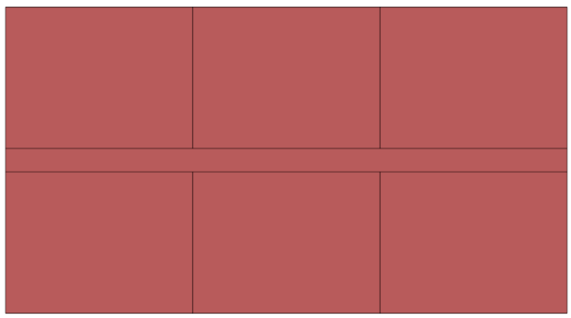

Figure 4.3. Plan View Showing Prototype Central Breezeway

4.2 Building Envelope

Both prototypes have gabled roofs with a 4:12 roof slope. Roof construction is assumed to be medium colored asphalt shingles with ceiling insulation placed entirely in the attic on the attic floor. For the multifamily prototype, ceiling insulation is assumed to be placed only on the ceilings at the top story exposed to unconditioned attic air. The attic is considered to be vented for both prototype buildings. The exterior walls are assumed to be wood-framed, with 2 × 4-in. studs spaced 16 in. on center or 2 × 6-in. studs spaced 24 in. on center depending on the thickness of wall insulation specified by the IECC. The floors are assumed to have wood joists spaced 24 in. on center. The ceiling, wall, and floor insulation levels are modeled according to the IECC code requirements for each code vintage.

Vertical fenestration for the single-family prototype is configured as a 15 percent window-to-floor ratio (WFR) distributed equally along all cardinal directions. The multifamily prototype is modeled with 23 percent window-to-wall ratio (WWR). However, the WWR calculation for the multi-family prototype does not include exterior walls facing the central breezeway. The WFR for the multifamily building prototype then is 10%.Vertical fenestration is modeled using the U-factor and solar heat gain coefficient (SHGC) requirements specified in each version of the IECC. The models do not account for external shading geometry. No skylights are assumed for either prototype.

Four foundation types are simulated in this analysis: 1) slab-on-grade, 2) crawlspace vented to the outdoors with insulation assumed to be placed entirely in the floor joists, 3) heated basement with the below grade walls insulated to the requirements of the IECC, and 4) unheated basement with the insulation placed entirely in the floor joists.

4.3 Internal Gains

The IECC provides limited guidance on specifying internal gains for the standard reference and proposed designs (Table 404.5.2(1) in the 2006 IECC). The table specifies equation 4.1 below for use in calculating total daily internal heat gains based on the conditioned floor area and the number of bedrooms of the home. Table 4.1 below summarizes the corresponding internal gains applicable to the single-family and multifamily prototypes.

$$\text{Internal Gains} = 17{,}900 + 23.8 \times \text{CFA} + 4104 \text{ x Nbr (Btu/day)} \qquad (4.1)$$

where CFA is the conditioned floor area (ft^2) and Nbr is the number of bedrooms.

Table 4.1. Internal Gains for Single-Family and Multifamily Prototypes as Specified by the 2006 IECC

	CFA[a]	Nbr[b]	Internal Gains (Btu/Day)	Internal Gains (kBtu/year)
Single-family	2,400	3	87,332	31,876
Multifamily	1,200	2	54,668	19,954

(a) CFA = Conditioned floor area.
(b) Nbr = Number of bedrooms.

To facilitate evaluation of lighting and appliance changes in EnergyPlus, these daily totals are split into various end uses. This breakdown of appliance loads and corresponding appliance-use schedules (Appendix A, Section A.4) is developed to match, as closely as possible, the Building America research benchmark (Hendron and Engebrecht 2009). The approximate difference between the internal gains specified by the IECC and the sum of lighting and appliances from Building America, an IECC adjustment factor, is added as an additional miscellaneous load component. A breakdown of annual energy consumption and associated internal loads for major appliances and other equipment for the single-family and multifamily prototypes are shown in Table 4.2 and Table 4.3, respectively.

Table 4.2. Breakdown of Internal Gains for the Single-Family Prototype

Appliance	Power	Total Electricity (kWh/yr)	Internal Heat Gain (Fractions)			Internal Heat Gains (kWh/yr)		
			Fraction Sensible	Fraction Latent	Fraction Lost	2006 IECC	2009 IECC	2012 IECC
Refrigerator	91.09W	668.90	1.00	0.00	0.00	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.20	87	87	87
Clothes Dryer	222.11W	868.15	0.15	0.05	0.80	174	174	174
Dishwasher	68.33W	214.16	0.60	0.15	0.25	161	161	161
Range (electric/gas)	248.97W	604.90	0.40	0.30	0.30	423	423	423
Miscellaneous Plug Loads	0.228 W/sq.ft	3238.13	0.69	0.06	0.25	2429	2429	2429
Miscellaneous Electric Loads	182.5 W	1598.00	0.69	0.06	0.25	1199	1199	1199
IECC Adjustment Factor	0.0275 W/ft^2	390.56	0.69	0.06	0.25	293	293	293
Lighting			1.00	0.00	0.00	1635	1345	1164
Occupants	3 Occupants					2123	2123	2123
Totals					**kWh/yr**	**9192**	**8902**	**8721**
					kBtu/yr	**31,362**	**30,373**	**29,755**
					Btu/day	**85,924**	**83,213**	**81,522**

Table 4.3. Breakdown of Internal Gains for the Multifamily Prototype (per dwelling unit)

Appliance	Power	Total Electricity (kWh/yr)	Fraction Sensible	Fraction Latent	Fraction lost	Internal Heat Gains (kWh/yr)		
						2006 IECC	2009 IECC	2012 IECC
Refrigerator	91.09 W	668.90	1.00	0.00	0	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.2	87	87	87
Clothes Dryer	222.11 W	868.15	0.15	0.05	0.8	174	174	174
Dishwasher	68.33 W	214.16	0.60	0.15	0.25	161	161	161
Range (electric)	248.97 W	604.00	0.40	0.30	0.3	423	423	423
Miscellaneous Plug Loads	0.228 W/ft^2	1619.00	0.69	0.06	0.25	1214	1214	1214
Miscellaneous Electric Loads	121.88 W	1067.00	0.69	0.06	0.25	800	800	800
IECC Adjustment Factor	0.0275 W/ft^2	195.28	0.69	0.06	0.25	146	146	146
Lighting			1.00	0.00	0	493	405	351
Occupants	2 Occupants					1416	1416	1416
Total					**kWh/yr**	**5583**	**5495**	**5440**
					kBtu/yr	**19,049**	**18,748**	**18,562**
					Btu/day	**52,189**	**51,364**	**50,855**

4.4 Lighting

Lighting is modeled as hardwired, plug-in, exterior, and garage lighting. The baseline 2006 IECC lighting characteristics and energy consumption are based on the Building America Simulation Protocols (Hendron and Engebrecht 2010). The corresponding lighting energy use for the 2006 IECC is calculated using Building America's equations shown in **Error! Reference source not found.** based on conditioned floor area (CFA).

Table 4.4. Baseline Lighting Energy Use for the 2006 IECC

Type		Energy Use
Interior Hardwired	=	0.8 × (CFA x 0.542 + 334) kWh/yr
Interior Plug-in Lighting	=	0.2 × (CFA x 0.542 + 334) kWh/yr
Garage Lighting	=	Garage Area × 0.08 + 8 kWh/yr
Exterior Lighting	=	CFA × 0.145 kWh/yr

Building America assumes that 66 percent of all lamps are incandescent, 21 percent are compact fluorescent, and the remaining 13 percent are T-8 linear fluorescent in the baseline. The 2009 IECC and the 2012 IECC require 50 percent and 75 percent, respectively, of all lighting in permanently installed fixtures to be high efficacy. The lighting energy consumption for the 2009 and 2012 IECC is calculated using Building America's smart lamp replacement approach using fractions specified in Table 4.5 and equations 4.2, 4.3 and 4.4.

Interior Hardwired lighting energy = *Lhw x {[(Finc, HW + 0.34) + (FCFL, HW-0.21) x 0.27 + FLED, HW x 0.30 + (FLF, HW - 0.13) x 0.17] x SAF x 0.9 + 0.1 (kWh/yr)* (4.2)

Garage lighting energy = *LGAR x {[(Finc, GAR + 0.34) + (FCFL, GAR-0.21) x 0.27 + FLED, GAR x 0.30 + (FLF, GAR - 0.13) x 0.17] x 0.9 + 0.1 (kWh/yr)* (4.3)

Exterior lighting energy = *LOUT x {[(Finc, OUT + 0.34) + (FCFL, OUT-0.21) x 0.27 + FLED, OUT x 0.30 + (FLF, OUT - 0.13) x 0.17] x 0.9 + 0.1 (kWh/yr)* (4.4)

In those equations, LHW is the baseline hard-wired lighting energy, LGAR is the baseline garage lighting energy and LOUT is the baseline exterior lighting energy. Finc and FCFL are the fractions of fixture with incandescent lamps and fluorescent lamps, respectively.

Table 4.5. Lighting fixture type fractions for the 2006, 2009 and 2012 IECC

	2006 IECC	2009 IECC	2012 IECC
Fraction Incandescent	0.66	0.5	0.25
Fraction CFL	0.21	0.37	0.62
Fraction Linear Fluorescent	0.13	0.13	0.13

Based on the Building America Simulation Protocols, when estimating the energy savings of the 2009 and 2012 IECC, a 10-percent take back is included in the form of an increase in operating hours to account for operational differences when incandescent lamps are replaced with energy-efficient lamps.

4.5 Infiltration and Ventilation

4.5.1 Infiltration

The infiltration rates are handled differently in each of the three versions of the IECC. The 2006 IECC does not require a blower door test nor does it include a detailed sealing inspection checklist. A benchmark construction infiltration rate of eight air changes at a 50 Pa pressure differential (ACH50) was established for the 2006 IECC based on the lower end of envelope leakage rates for typical new construction presented by Sherman (2007).[1]

The 2009 IECC provides two paths for compliance with its infiltration requirements. One is a standard blower door test with a seven-ACH50 limit and the other is inspection against a detailed air sealing checklist. This analysis assumes either path results in the same effective infiltration rate, so a leakage rate of seven-ACH50 is assumed for the 2009 IECC.

The 2012 IECC allows a maximum of five-ACH50 in Climate Zones 1 and 2, and three-ACH50 in Climate Zones 3 through 8, as determined by a standard blower door test. EnergyPlus contains multiple modules that can be used to model infiltration. The EnergyPlus *ZoneInfiltration: EffectiveLeakageArea* model, based on work done by Sherman and Grimsrud for smaller residential type of buildings[2], was used in this analysis. This model uses the effective leakage area (ELA) derived from a standard blower door test to model infiltration loads on the zone.

The input to EnergyPlus is the ELA at a 4 Pa reference pressure differential. In contrast, a standard blower door test yields a leakage rate in air changes per hour at a 50-Pa pressure differential (ACH50). This value is converted to the EnergyPlus input using equations 4.5, 4.6, and 4.7 below.[3]

$$cfm50 = \frac{ACH50\ x\ Volume\ of\ the\ House}{60} \tag{4.5}$$

$$C_{ela} = \frac{cfm50}{50^{0.65}} \tag{4.6}$$

$$ELA = 0.2833 * C_{ela} * (4^{0.65}) \tag{4.7}$$

[1] M. Sherman 'Trends in US Ventilation'
http://www.aivc.org/medias/pdf/07_USA.pdf
[2] *EnergyPlus* Input Output Reference
http://apps1.eere.energy.gov/buildings/energyplus/pdfs/inputoutputreference.pdf
[3] P. Fairey 'EnergyGauge Envelope Leakage and Infiltration Conversions'
http://www.energygauge.com/DOWNLOADS/EgUSA2802.pdf.

In those equations, *cfm*50 is the leakage flow-rate during the blower door test, C_{ela} is the leakage co-efficient, and *ELA* is the equivalent leakage area that is the input parameter to EnergyPlus. Table 4.6 lists the specific ELA values used in this analysis as input to EnergyPlus.

Table 4.6. Air Changes at 50 Pa and Effective Leakage Area by IECC Version

		Effective Leakage Area (in.^{2})	
Code	ACH50	Single-Family Prototype	Multifamily Prototype
2006 IECC	8	149.22	74.61
2009 IECC	7	130.57	65.28
2012 IECC Climate Zones 1-2	5	93.26	46.63
2012 IECC Climate Zones 3-8	3	55.96	27.98

4.5.2 Ventilation

The 2012 IECC sets mechanical ventilation requirements for one and two family dwelling units and townhomes based on the 2012 International Residential Code (IRC) and those for low-rise multifamily buildings based on the 2012 International Mechanical Code (IMC). The maximum five or three-ACH50 leakage requirements in the 2012 IECC, coupled with mechanical ventilation requirements of the 2012 IRC and the 2012 IMC, mandates mechanical ventilation for all homes built under the 2012 IECC.[1] The IRC allows the ventilation system to be either continuously operating with a lower required outdoor air flow-rate or intermittently operating with a higher required outdoor air flow-rate. The IMC requires ventilation air to be supplied continuously when the building is occupied.

For the single-family prototype, the minimum outdoor air flow-rates are based on conditioned floor area and number of bedrooms and are listed in table M1507.3.3(1) of the 2012 IRC. For the low-rise multifamily prototype, the minimum outdoor air flow-rates are based on occupant density and are listed in table 403.3 of the 2012 IMC. For the purpose of this analysis, a whole-house continuously operating ventilation system is assumed. Outdoor air flow rates required by the 2012 IRC and the 2012 IMC used in the simulations are summarized in Table 4.7.

Table 4.7. Outdoor Air Flow Rates Used in Simulations

Prototype	Outdoor Air Flow Rate used in Simulation (ft^3/min)
Single-Family	60
Multifamily	45

[1] Section R303.4 of the 2012 IRC actually requires ventilation only when envelope leakage is <u>less than</u> five ACH50. Ventilation is not required for a home with a leakage rate of <u>exactly</u> five ACH50. This analysis assumes that such homes are rare and that all 2012 IECC-compliant homes will fall under the ventilation requirement.

There is growing consensus among building scientists that a ventilation system is necessary in new residential buildings regardless of the vintage of the building energy code in order to ensure a reliable supply of fresh air to maintain indoor air quality. Specific comments from the ASHRAE Standard 90.2 committee for analyses conducted in support of the development of standard 90.2 suggested assuming the same mechanical ventilation rates for the 2006 IECC, even though the 2006 IECC does not specifically require mechanical ventilation.[1] Therefore, for this analysis, the same mechanical ventilation system and outdoor air flow-rates are assumed in all analyzed code versions.

Ventilation is modeled using the EnergyPlus Zone: Ventilation model using the outdoor flow rates from Table 4.7 and a continuous ventilation fan operation schedule.

4.6 Heating, Ventilation, and Air-Conditioning Systems

All homes are assumed to have a central forced-air distribution system served by either a heat pump or an electric air-conditioner coupled with an electric, natural-gas, or oil furnace.

4.6.1 Operating Conditions

Thermostat set-points for all models are based on the 2012 IECC performance path specifications (Table R405.5.2(1) in the 2012 IECC). The relevant set-points, which apply to both the standard reference design and proposed design, are a heating set-point of 72°F without a setback period and a cooling set-point of 75°F without a setup period.

4.6.2 HVAC System Efficiency

None of the IECC versions specifies efficiency requirements for heating, ventilation, and air conditioning (HVAC) systems. A federal equipment standards rulemaking process governs minimum heating and cooling equipment efficiencies at the manufacturing level.[2] Federal minimum baseline efficiencies in effect as of May 2012 for residential central air conditioners, heat pumps and furnaces are assumed to apply for the purpose of this analysis (10 CFR 430[3]). Table 4.8 shows the heating and cooling equipment efficiencies used in the analysis.

Table 4.8. Heating and Cooling Equipment Efficiencies used in this Analysis.

Equipment Efficiencies				
Air Conditioner SEER[(a)]	Heat Pump SEER	Gas Furnace AFUE[(b)]	Oil Furnace AFUE	Heat Pump HSPF[(c)]
13	13	78%	78%	7.7

(a) SEER = Seasonal Energy Efficiency Ratio.
(b) AFUE = Annual Fuel Utilization Efficiency.
(c) HSPF = Heating Seasonal Performance Factor.

[1] These comments were received during the web meeting held on March 22, 2012, for the development of the ASHRAE 90.2-2014 standard.
[2] Per the requirements of the National Appliance Energy Conservation Act of 1987 (NAECA), as amended.
[3] http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol3/pdf/CFR-2011-title10-vol3-sec430-32.pdf.

4.6.3 Air Distribution System and Duct Leakage Rates

All models in the analysis are assumed to have a centralized supply and return duct system. The air distribution system is modeled using the EnergyPlus *Airflownetwork*. The model has capabilities for modeling wind and pressure-driven air flows through the building shell as well as detailed thermal gains and losses and leakages through the air-distribution system.

The 2006 IECC does not specify a maximum allowable duct leakage rate. Research done by Building America indicates that typical new homes with ducts in attics or crawlspaces lose about 25 to 40 percent of the heating or cooling energy that passes through the ducts. In EnergyPlus, duct leakage is defined as a ratio of the total supply air flow-rate. A conservative baseline duct leakage rate of 15 percent on the supply side and 15 percent on the return side for the 2006 IECC is assumed in this analysis, based on research done by Building America.[1] The ducts are assumed to be located in the unconditioned attic space and all the leakage is assumed to take place in this zone. The 2009 and 2012 IECC specify limits on duct leakage in terms of cubic feet per minute (CFM) per 100 ft^2 conditioned floor area at a 25-Pa pressure differential. This value is converted into a ratio of duct leakage CFM to the total supply CFM for input to EnergyPlus. The leakage is assumed to be equally distributed between the supply and return air sides. These leakage inputs are summarized in

Table **4.9**.

Table 4.9. Duct Leakage Rates

Energy Code	Maximum Allowed Duct Leakage Rate (CFM/100 ft^2 conditioned floor area at a 25-Pa pressure differential)	Duct Leakage Ratio (percent of total supply CFM)
2006 IECC	Not specified	15% supply and 15% return
2009 IECC	8	10% supply and 10% return
2012 IECC	4	4% supply and 4% return

Some modules within the EnergyPlus *Airflownetwork* were still under development at the time of this analysis, thus requiring a workaround to complete the simulations. The impacts of duct leakage on heating and cooling energy were simulated separately from other building elements and added to the energy results through post-processing. A separate suit of 11,424 models was created with the duct-leakage rates set to the 2006, 2009, and 2012 IECC levels, respectively, and the rest of the requirements were maintained at the 2006 IECC level. This approach allowed the impact of duct leakage on heating and cooling energy to be isolated and captured. This impact was then added to the energy use results from the 2009 and 2012 IECC models through post-processing.

[1] Building America "Better Duct Systems for Home Heating and Cooling" http://www.nrel.gov/docs/fy05osti/30506.pdf.

4.7 Domestic Hot Water System

The domestic hot water system in all models is assumed to be a storage type water heater. For models that represent homes with fuel-fired furnaces as space-heating equipment, water heaters are modeled as gas-fired storage water heaters. For models that represent homes with electricity as the space heating fuel (electric furnace and heat pump), water heaters are assumed to be electric storage tank type water heaters.

The size of the storage tank is assumed to be 40 gal for gas-fired water heaters and 52 gal for electric water heaters. For the purpose of modeling, domestic hot water use is split into various end-uses such as baths, sinks, clothes washer, dishwasher, and showers using peak flow rates and schedules from the Building America House Simulation Protocols.

Commercially available residential size water heaters are rated in terms of an Energy Factor (EF). A federal rulemaking process determines minimum allowable EF values that depend on the equipment type and capacity (storage volume).[1] This analysis assumes EF values based on the federal rule in effect as of May 2012.

Table 4.10 summarizes the EF for gas-fired and electric water heaters used in this analysis.

Table 4.10. Water Heater Energy Factor used in the Analysis

Water Heater Type	Energy Factor
Gas fired storage type	0.594
Electric storage type	0.917

For modeling purposes, the EF has to be split into a burner thermal efficiency and standby losses. These calculations are carried out using equations from the Water Heater Analysis Model (WHAM) (Lutz et al. 1998). Table 4.11 summarizes thermal efficiency and shell losses for each case.

Table 4.11. Standby Losses and Burner Thermal Efficiencies for Water Heaters

Water Heater Type	Shell Losses-UA (Btu/hr-°F)	Burner Thermal Efficiency
Gas fired storage type	10.84	80%
Electric storage type	2.52	100%

The 2012 IECC specifies requirements for insulating hot water pipes for service water heating (faucets, showers, etc.). This insulation requirement did not exist in the 2006 or 2009 IECC. The savings from this requirement are variable, because they depend on system design and occupant behavior, and are not easy to capture with an energy model. Klein estimates the 2012 IECC requirements save from 10.2 to 27.4 percent of the overall hot water energy consumption for a typical household (Klein 2012). This analysis uses a conservative estimate of 10 percent hot water energy savings. These savings are applied to the simulated hot water energy consumption through post-processing.

[1] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf.

5.0 Energy Costs

5.1 Energy Use

EnergyPlus provides detailed end-use energy consumption estimates, potentially at high time resolution (monthly, hourly, or even sub-hourly). For this analysis, only annual end-use energy consumption, taken from the EnergyPlus ‘table.csv’ output report, is used. As specified in the cost-effectiveness methodology, energy savings for cost-effectiveness considerations are limited to heating, cooling, domestic hot water heating, and lighting to match the scope of the IECC.

5.2 Fuel Prices

Fuel prices and anticipated price escalation rates are needed to determine the energy cost savings from improved energy efficiency. This analysis uses the most recently available state-specific residential fuel prices from DOE’s Energy Information Administration.[1, 2, 3] Electricity prices vary by the heating or cooling season. For air conditioning, electricity prices from the summer are used, and for electric space heating, winter electricity prices are used. Fuel price escalation rates are obtained from the most recent *Annual Energy Outlook* to account for projected changes in energy prices. This analysis assumes an average fuel escalation rate of 2.2%. Table 5.1 lists the state specific prices used for electricity, gas and oil.

Table 5.1. Fuel Prices by State

State	Electricity ($/kWh) (Heating)	Electricity ($/kWh) (Cooling)	Gas ($/Therm)	Oil ($/MBtu)
Alabama	0.106	0.109	1.329	23.7
Alaska	0.166	0.171	0.839	23.7
Arizona	0.099	0.117	1.306	23.7
Arkansas	0.08	0.092	0.924	23.7
California	0.149	0.156	0.943	23.7
Colorado	0.104	0.118	0.714	23.7
Connecticut	0.181	0.192	1.244	23.86
Delaware	0.133	0.142	1.365	23.7
District of Columbia	0.135	0.143	1.202	23.7
Florida	0.117	0.117	1.532	23.7
Georgia	0.098	0.109	1.249	23.7
Hawaii	0.301	0.284	4.72	23.7
Idaho	0.078	0.084	0.869	23.7
Illinois	0.108	0.122	0.717	23.7

[1] U.S. Department of Energy (DOE). 2012a. *Electric Power Monthly*. DOE/EIA-0226. Washington, D.C. http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html
[2] U.S. Department of Energy (DOE). 2012b. *Natural Gas Monthly*. DOE/EIA-0130. Washington, D.C. http://www.eia.gov/oil_gas/natural_gas/data_publications/natural_gas_monthly/ngm.html
[3] U.S. Department of Energy (DOE). 2012c. *Petroleum Marketing Monthly*. DOE/EIA-0380. Washington, D.C. http://www.eia.gov/petroleum/marketing/monthly/

Table 5.1. (contd)

State	Electricity ($/kWh) (Heating)	Electricity ($/kWh) (Cooling)	Gas ($/Therm)	Oil ($/MBtu)
Indiana	0.094	0.093	0.804	23.7
Iowa	0.096	0.11	0.802	23.7
Kansas	0.095	0.105	0.815	23.7
Kentucky	0.086	0.087	0.858	23.7
Louisiana	0.081	0.092	0.933	23.7
Maine	0.158	0.155	1.353	22.21
Maryland	0.134	0.151	1.039	23.7
Massachusetts	0.148	0.149	1.405	24.06
Michigan	0.123	0.131	0.971	23.7
Minnesota	0.103	0.108	0.833	23.7
Mississippi	0.098	0.102	0.848	23.7
Missouri	0.082	0.103	0.973	23.7
Montana	0.091	0.096	0.795	23.7
Nebraska	0.079	0.102	0.762	23.7
Nevada	0.118	0.122	0.977	23.7
New Hampshire	0.164	0.163	1.299	22.47
New Jersey	0.163	0.172	1.162	23.7
New Mexico	0.099	0.116	0.791	23.7
New York	0.175	0.192	1.177	23.87
North Carolina	0.097	0.103	0.992	23.7
North Dakota	0.073	0.094	0.685	23.7
Ohio	0.104	0.118	0.93	23.7
Oklahoma	0.082	0.095	0.724	23.7
Oregon	0.091	0.092	1.174	23.7
Pennsylvania	0.125	0.133	1.101	23.41
Rhode Island	0.158	0.162	1.369	24.47
South Carolina	0.107	0.106	1.018	23.7
South Dakota	0.083	0.097	0.749	23.7
Tennessee	0.095	0.095	0.862	23.7
Texas	0.11	0.12	0.814	23.7
Utah	0.083	0.094	0.843	23.7
Vermont	0.158	0.155	1.433	23.13
Virginia	0.098	0.108	1.077	23.7
Washington	0.08	0.083	1.142	23.7
West Virginia	0.088	0.089	0.988	23.7
Wisconsin	0.124	0.126	0.918	23.7
Wyoming	0.084	0.093	0.747	23.7

6.0 Construction Cost Calculation

6.1 Requirements by Climate Zone for Each Code Level

The 2009 and 2012 IECC have more stringent energy efficiency requirements than the 2006 IECC. Some of the requirements are constant across climate zones while some requirements vary. Table 6.1 summarizes the prescriptive requirements of the three versions of IECC analyzed in this study that vary by climate zone. Table 6.2 summarizes mandatory and prescriptive requirements that do not vary by climate zone.

6.2 Incremental Cost Calculation

The analysis compares the energy savings and cost effectiveness of the 2009 and 2012 IECC compared to the 2006 IECC. Cost effectiveness is calculated using incremental first cost and energy savings resulting from improvements in the code. The following sections detail incremental cost calculation for each component.

There are several existing studies on construction cost impacts for improved energy efficiency in residential new construction. Cost data sources consulted include but are not limited to:

- Construction cost data collected by Faithful+Gould in 2011 and 2012 under contract with PNNL[1]
- RS Means Residential Cost Data (RS Means 2011)
- ASHRAE Research Project 1481 (NAHB 2009).

All the costs used in this analysis are documented in the BC3 database.[2]

6.2.1 Duct Testing and Improved Duct Sealing

Section 403.2.2 of the 2009 and 2012 IECC require air distribution systems, where any of the ducts pass outside of the conditioned space (in attics, garages, etc.), to be pressure tested against specified maximum leakage rates. Testing is not required if all ducts and air handlers are inside the building envelope (for example in heated basements). All three versions of the IECC require all ducts to be sealed even if they are located inside the envelope. However, the 2006 IECC does not require ducts to be pressure tested for leakage. Thus, for the 2009 and 2012 IECC, there is an additional incremental cost for the pressure test (e.g., a duct blaster® test) and for additional sealing to achieve the required leakage rates.

[1] Faithful+Gould "Prototype Estimate and Cost Data" http://bc3.pnnl.gov/wiki/images/f/fa/Residential_Report.pdf.
[2] http://bc3.pnnl.gov/wiki/index.php/Main_Page

Table 6.1. Prescriptive Code Requirements that Vary by Climate Zone

Climate Zone	IECC	Components: Ceiling (R-value)	Skylight (U-factor)	Fenestration (Windows and Doors): U-factor	Fenestration (Windows and Doors): SHGC	Wood Frame Wall (R-value)	Mass Wall[(a)] (R-value)	Floor (R-value)	Basement Wall[(b)] (R-value)	Tested Max Air Leakage Rate (air changes per hour)	Slab[(c)] (R-value and depth)	Crawl Space[(b)] (R-value)
	2006				0.4					NR		
1	2009	30	0.75	NR	0.3	13	3/4	13	NR	NR	NR	NR
	2012				0.25					5		
	2006	30	0.75	0.75	0.4					NR		
2	2009	30	0.75	0.65	0.3	13	4/6	13	NR	NR	NR	NR
	2012	38	0.65	0.4	0.25					5		
	2006	30	0.65	0.65	0.4	13	5/8		0	NR		
3	2009	30	0.65	0.5	0.3	13	5/8	19	5/13[(d)]	NR	NR	5/13
	2012	38	0.55	0.35	0.25	20	8/13		5/13[(d)]	3		
	2006	38	0.6	0.4	NR	13	5/13		10/13	NR		10/13
4	2009	38	0.6	0.35		13	5/10	19	10/13	NR	10, 2 ft	10/13
	2012	49	0.55	0.35	0.4	20	8/13		10/13	3		10/13
	2006	38	0.6	0.35		19	13/19		10/13	NR		10/13
5	2009	38	0.6	0.35	NR	20	13/17	30	10/13	NR	10, 2 ft	10/13
	2012	49	0.55	0.32		20	15/19		15/19	3		15/19
	2006		0.6	0.35		19	10/13		10/13	NR		10/13
6	2009	49	0.6	0.35	NR	20	15/19	30	15/19	NR	10, 4 ft	10/13
	2012		0.55	0.32		20+5	15/19		15/19	3		15/19
	2006		0.6	0.35		21		30	10/13	NR		10/13
7 and 8	2009	49	0.6	0.35	NR	21	19/21	38	15/19	NR	10, 4 ft	10/13
	2012		0.55	0.32		20+5		38	15/19	3		15/19

(a) The second number applies when more than half the insulation is on the interior side of the high mass material in the wall.
(b) The first number is for continuous insulation (e.g., a board or blanket directly on the foundation wall) and the second number is for cavity insulation (i.e., if there is a furred-out wall built against the foundation wall). Only one of these two has to be met.
(c) The first number is R-value. The second value refers to the vertical depth of the insulation around the perimeter.
(d) Basement wall insulation is not required in the warm-humid region of Zone 3 in the southeastern United States.
IECC = International Energy Conservation Code.
NR = Not required.
SHGC = Solar heat gain coefficient.

Table 6.2. Major Code Requirements that do not vary by Climate Zone

Requirement	2006 IECC	2009 IECC	2012 IECC
Building envelope sealing	Caulked and sealed verified by visual inspection	Caulked and sealed verified by visual inspection against a more detailed checklist	Caulked and sealed verified by visual inspection and a pressure test against a stringent leakage requirement
Ducts and air handlers	Sealed verified by visual inspection	Sealed, verified by visual inspection, and pressure tested or all ducts must be inside building envelope	Sealed, verified by visual inspection, and pressure tested against a more stringent leakage requirement or all ducts must be inside building envelope
Supply ducts in attics	R-8	R-8	R-8
Return ducts in attics and all ducts in crawlspaces, unheated basements, garages, or otherwise outside the building envelope	R-8	R-6	R-6
Insulation on hot water pipes for service water heating systems	None	None	R-3 except where pipe run length is below a diameter-dependent threshold
Insulation on hot water pipes for hydronic (boiler) space heating systems	R-3	R-3	R-3
High-efficacy lamps (percent of lighting in the home)	None	50% of lamps	75% of lamps or 75% of fixtures
Certificate of insulation levels and other energy efficiency measures	Yes	Yes	Yes

Faithful+Gould reports a cost of $135 for duct testing when done as part of the construction process rather than as a one-off site visit test. Hammon and Modera (2009) estimate a cost of $131 to $163 for testing, and suggest costs will be even lower in a mature market. The *Journal of Light Construction* quotes a cost of $220 for testing (Uniacke 2003). An Appalachian State University study (Appalachian State University 2010) reports a cost of $175 to $250. It is important to note that the IECC allows the ducts to be tested by the HVAC contractor immediately after the ducts are installed. This should help keep both costs and construction timeline impacts to a minimum. A cost of $135 per duct blaster test is assumed in this analysis. Each dwelling unit within the multifamily building is assumed to have its own duct distribution system and thus a separate test would be conducted for each.

The second cost is the cost associated with further improvements in duct sealing to ensure the duct complies with the air leakage limits set in the code of interest. This is expected to be mostly labor costs. Hammon and Modera (1999) estimate a cost of $214 for materials and labor for improved duct sealing. The developers of Energy Star Home requirements estimated a cost of $0.10/ft^2 of conditioned home floor area for improved duct sealing (EPA 2011). This results in a cost of $240 for a 2400-ft^2 home and $120 for a 1200-ft^2 dwelling unit. A conservative estimate of $240 per home and $120 per dwelling unit is used in this analysis for single-family and multifamily buildings, respectively.

The total cost for duct testing and improved duct sealing for the 2009 IECC thus works out to be $375 for a typical new single-family home and $255 for a typical dwelling unit in a multifamily building, relative to the 2006 IECC. The 2012 IECC has lower allowable duct leakage rates compared to the 2009 IECC. An additional $100 is estimated for further improvements in duct sealing for the 2012 IECC, increasing the total sealing and testing cost to $475 for single-family homes and $355 for each dwelling unit within a multifamily building relative to the 2006 IECC.

6.2.2 Building Envelope Testing and Improved Envelope Sealing

Section 402.4.2 of the 2009 IECC provides two options for demonstrating envelope air tightness: a pressure test to verify that the leakage rate is below the specified leakage rate or a visual inspection option accompanied with a checklist (Table 402.4.2). This analysis assumes that either option would result in the same envelope leakage rate.

Section R402.4.1.2 of the 2012 IECC requires the building envelope to be pressure tested to verify that the leakage rate is at or below specified maximum leakage rates. Faithful+Gould reports a cost of $135 for envelope testing when done as part of the construction process rather than as a one-off site visit test. Similar to the duct blaster test for the multifamily prototype building, it is assumed that each dwelling unit will be tested for envelope leakage separately, thus costing $135 per dwelling unit.

The developers of Energy Star Home Requirements estimated a cost of $0.25/ft^2 of home floor area for improved envelope sealing (EPA 2011). This is a cost of $600 for a 2400-ft^2 home and a cost of $300 for a 1200-ft^2 dwelling unit. This analysis assumes this to be the total cost of improved envelope sealing for 2012 IECC over 2006 IECC. The cost for improved envelope sealing for the 2009 IECC is calculated proportionally as $0.05/ft^2 of home floor area. Thus, the cost of improved envelope sealing is $120 for the single-family prototype building and $60 for each dwelling unit in the multifamily prototype building for the 2009 IECC over the 2006 IECC.

The cost of pressure testing the envelope and improved sealing is assumed to be $735 for the single-family prototype and $435 for each dwelling unit in the multifamily prototype building for the 2012 IECC over the 2006 IECC.

6.2.3 Window Improvements (U-Factor and Solar Heat Gain Reduction)

The thermal performance of windows is described using two parameters: the effective heat transfer co-efficient (U-factor) and the Solar Heat Gain Coefficient (SHGC). The 2009 and 2012 IECC require varying degrees of improvement of these two parameters over the 2006 IECC across various climate zones. These prescriptive requirements are summarized along with other envelope requirements in Table 6.1. Table 6.3 also presents these requirements for windows in the three versions of the IECC. The single-family and multifamily building prototype models do not have skylights; hence, the requirements for skylights are not analyzed in this study.

It is challenging to assign a cost for the improvement in window U-factor and SHGC because these two parameters are properties of the window assembly as a whole and can be achieved with a wide variety of window products with a similarly wide range of costs. Although a variety of window products and technologies can be used to comply with the requirements of the 2006, 2009 and 2012 IECC, it is expected that the most common method will have the same basic features and will be used in all climate zones. The common use of a low-emissivity (i.e., low-E) coating has the effect of lowering both the U-factor and the SHGC. Thus, the same double-paned window with a low-E coating and a non-aluminum frame (typically wood or vinyl) often will meet both the low U-factor requirements in northern climate zones and the low SHGC requirements in southern climate zones.

Table 6.3. U-Factor and SHGC Requirements for Windows in the 2006, 2009, and 2012 IECC

Climate Zone	IECC	Skylight (U-Factor)	Fenestration (Windows and Doors)	
			U-Factor	SHGC
	2006			0.4
1	2009	0.75	NR	0.3
	2012			0.25
	2006	0.75	0.75	0.4
2	2009	0.75	0.65	0.3
	2012	0.65	0.4	0.25
	2006	0.65	0.65	0.4
3	2009	0.65	0.5	0.3
	2012	0.55	0.35	0.25
	2006	0.6	0.4	NR
4	2009	0.6	0.35	
	2012	0.55	0.35	0.4
	2006	0.6	0.35	
5	2009	0.6	0.35	NR
	2012	0.55	0.32	
	2006	0.6	0.35	
6	2009	0.6	0.35	NR
	2012	0.55	0.32	
	2006	0.6	0.35	
7 and 8	2009	0.6	0.35	NR
	2012	0.55	0.32	

Faithful+Gould report a cost separately for improving the U-factor and for improving the SHGC. The Faithful+Gould cost for SHGC improvement is used to cost the improvements in glazed fenestration requirements in climate zones 1 through 3. The reduction of SHGC from 0.40 to 0.30 costs $2.77/ft^2$ and the reduction of SHGC from 0.30 to 0.25 costs $1.38/ft^2$. Because the low-E coating technology commonly used to achieve lower SHGC also lowers the U-factor, no additional cost is assumed for the improvements to U-factor required by the 2009 and 2012 IECC in climate zones 1 through 3. The improvement of U-factor from 0.35 to 0.32 in climate zones 4 through 8 is assumed to cost $0.18/ft^2$ based on the Faithful+Gould cost estimate. The modest improvement in U-factor and SHGC in climate zone 4 required in the 2009 and 2012 IECC are assumed to have no incremental cost increase as most double-pane low-E windows will comply with the 2012 IECC requirements here.

6.2.4 Above-Grade Wall Insulation

Above grade walls in the single-family and multifamily building prototype models are assumed to be wood framed with fiberglass batt insulation. As such, all incremental cost calculations are carried out for fiberglass batt insulation. The 2009 IECC requires an increase of wall insulation from R-19 to R-20[1] in climate zones 5 and 6 compared to the 2006 IECC. Because fiberglass batts are not commonly manufactured at the R-20 level, the cost for R-21 batts is used. The incremental material cost of R-21 fiberglass batt insulation compared to R-19 was identified as $0.19/ft^2 from the Home Depot website.[2] A 10-percent markup is added to account for the installers profit (RS Means 2011). This results in an incremental cost of $0.21/ft^2 used in this analysis. The ASHRAE 90.2 database (NAHB 2009) reports a similar cost of $0.18/ft^2.

The 2012 IECC requires R-20 wall insulation in climate zones 3 and 4. This is an increase from R-13 in the 2006 and 2009 IECC. Wall insulation up to R-13 can be installed using 2×4-in. wood framing members. 2×4-in. framing members are assumed to be spaced 16 in. on-center. R-20 cavity insulation has a greater thickness than R-13 and necessitates using 2×6 wood framing members. As 2×6-in. framing allows for more structural stability, framing members are assumed to be spaced 24 in. on-center. RS Means indicates the change from 2×4-in. framing to 2×6-in. framing with larger spacing has zero cost. Based on data from RS Means, the incremental cost for R-19 fiberglass batts over R-13 batts is $0.06/ft^2. Thus, the total incremental cost for R-21 wall insulation over R-13 wall insulation is $0.27/ft^2.

The 2012 IECC requires R-20 cavity insulation plus R-5 continuous insulation in climate zones 6 through 8. The 2006 and 2009 IECC do not require R-5 continuous insulation in these zones. Faithful+Gould reports a cost of $0.79/ft^2 for a full layer of R-5 extruded polystyrene continuous insulation. This cost has been used here. The R-5 insulation is assumed to be in addition to structural sheathing such as oriented strand board (OSB) or plywood over the entire wall area. Alternative construction methods may allow the continuous insulation to replace some or all of the structural sheathing using bracing techniques such metal straps or using a combination of wood panel and insulating sheathing at corners of walls. This may allow lower construction costs, but may also modestly decrease energy efficiency. These alternatives are not analyzed here.

6.2.5 Basement Wall Insulation

The 2009 and 2012 IECC require basement walls to be insulated with either R-5 continuous insulation or R-13 cavity insulation in climate zone 3 above the “warm humid” line (e.g., northern Alabama and Mississippi) if the basement is conditioned. The 2006 IECC does not require basement wall insulation in this region. All versions of the IECC require basement wall insulation in climate zones 4 through 8.

This analysis has assumed R-13 fiberglass batt or blanket products would be most likely used to meet basement wall insulation requirements in the IECC. Basement wall insulation is only required if the basement is conditioned, and if the basement is conditioned it is most likely to be finished. Hence, this analysis assumes no additional cost for finishing a basement. Faithful+Gould estimates the installed cost kraft-faced R-13 fiberglass batt at $0.517/ft^2. Hence, an incremental cost of $0.51/ft^2 of basement wall area is assumed in this analysis for R-13 insulation.

[1] The IECC permits the R-20 requirements to be met by R-13 cavity insulation plus R-5 continuous insulation.
[2] http://www.homedepot.com/. Last accessed February 27, 2012.

The 2009 IECC requires R-15 continuous or R-19 cavity insulation in basement walls in climate zones 6 through 8. The 2012 IECC extends this requirement to apply to climate zone 5 as well. This requirement also applies to crawlspace walls if the crawlspace is conditioned. The 2006 IECC only requires R-10 continuous or R-13 cavity insulation in these zones. Faithful+Gould estimate an incremental cost of $0.26/ft^2$ of basement wall area for R-19 cavity insulation compared to R-13. This estimate includes the additional cost of switching from 2×4-in. to 2×6-in. framing and is used in this analysis.

6.2.6 Ceiling and Floor Insulation

The 2009 and 2012 IECC require improved ceiling and floor insulation over the 2006 IECC in certain cliamte zones. Faithful+Gould estimates an incremental cost of $0.24/ft^2$ for R-38 floor insulation compared to R-30. For ceiling insulation, Faithful+Gould estimates an incremental cost of $0.28/ft^2$ for R-38 insulation compared to R-30 and $0.28/ft^2$ for R-49 compared to R-38. These costs are used in this analysis.

6.2.7 Lighting

The 2006 IECC does not contain any requirements for high- efficacy lamps. The 2009 and 2012 IECC require 50 percent and 75 percent, respectively, of lamps in permanently installed lighting fixtures to be high efficacy. Compact flourescent lamps (CFLs) will comply with the IECC high-efficacy lamp requirement. The high efficacy lighting requirements in the 2009 and 2012 IECC will become less relevant as the requirements of federal law, which will require improved efficiency in light bulbs sold in the United States, take effect in 2012 to 2014.

A study of 604 new single-family homes in the Pacific Northwest found that the average home has 49 light fixtures containing 77 bulbs (RLW Analytics 2007). The lighting energy use for the single-family and multifamily prototype building models is based on Building America house simulation protocols (Hendron and Engebrecht 2010). The protocols assume 16 percent of the lighting energy is plug-in. As the high-efficacy lighting requirement impacts permanently installed fixtures alone, the remaining 84 percent of lighting energy is assumed to be impacted by this requirement. This reduces the number of lamps impacted by the 2009 and 2012 IECC to 65 for the single-family home. Furthermore, the protocols assume 34 percent of all lighting in the *benchmark* home is already high efficacy. The benchmark home corresponds to the 2006 IECC case in this analysis. This translates to an estimate of 10 light bulbs being replaced with CFLs in the 2009 IECC cases and 27 bulbs in the 2012 IECC cases.

Faithful+Gould estimates standard incandescent bulbs cost $0.55 to $0.78 per bulb and CFL spiral lamps cost $3.87 or less per bulb. An incremental estimate of $3.00 per bulb is assumed in this analysis for high-efficiency lighting. These results in an incremental cost of $30 per house for the 2009 IECC and $81 per house for the 2012 IECC for high-efficacy lighting compared to incandescent lighting.

According to the Building America House Simulation Protocols, the lighting energy for the 1200-ft^2 dwelling unit in the multifamily prototype is 57 percent of the lighting energy of the 2400-ft^2 single-family prototype. The incremental lighting costs for multifamily are therefore scaled down to $14 per house for the 2009 IECC and $47 per house for the 2012 IECC.

6.2.8 Hot Water Pipe Insulation

The 2006 and 2009 IECC have no requirements for hot water pipe insulation for non-circulating service water heating systems. The 2012 IECC requires R-3 insulation on most hot water pipes for service water use. The Lowes website[1] reports a cost of $5.98 for 6 ft of R-3 pipe insulation, or about $1/ft. Assuming there are 200 ft of hot water pipe in a 2400-ft^2 home, the material cost would be $200.

Klein (2012) reports costs of $136.40 to $322.50 for R-3 insulation installed on hot water pipes in a new 2400-ft^2 home and $123.20 to $168.00 for pipe insulation in a 1200-ft^2 dwelling unit. A conservative estimate of $400 (materials and labor) in incremental costs for the single-family prototype and $200 for each dwelling unit in the multifamily prototype is used in this analysis for meeting the hot water piping insulation requirements in the 2012 IECC.

6.2.9 Total Incremental Construction Costs – 2006 to 2009 IECC

Table 6.4 and Table 6.5 summarize the incremental costs for the 2009 IECC over the 2006 IECC for the single-family and multifamily prototypes, respectively. Table 6.6 and Table 6.7 summarize the incremental costs for the 2012 IECC over the 2009 IECC for the single-family and multifamily prototypes, respectively.

6.3 Location Indices

The incremental construction costs are defined on a national average basis for each code improvement. Location multipliers for residential construction developed by Faithful+Gould are applied to the national average construction costs to derive the modified costs for a particular location.[2] The location factors take into urban/rural factors, and regional construction pricing factors. Table 6.8 indicates the location multipliers for each state.

[1] Lowes http://www.lowes.com/. Last accessed February 28, 2012.
[2] Faithful+Gould Residential Energy Efficiency Measures: Location Factors http://bc3.pnnl.gov/wiki/images/7/7f/Location_Factors_Report.pdf.

Table 6.4. Incremental Costs for the 2009 IECC over the 2006 IECC for the Single-family Prototype

Climate Zone	Foundation Type	Duct Sealing and Testing	Improved Air Sealing	R-19 to R-20 Walls	Windows 0.30 SHGC and Lower U	Windows U-0.40 to 0.35	R-30 to R-38 Floors	R-19 Basement Wall Insulation	50% Energy Efficient Lighting	**Total**
1	All	$375	$120		$989				$30	**$1,514**
2	All	$375	$120		$989				$30	**$1,514**
3 – South	All	$375	$120		$989				$30	**$1,514**
3 – North	Heated basements	$375	$120		$989			$500	$30	**$2,014**
3 – North	All but heated basements	$375	$120		$989				$30	**$1,514**
4	All	$375	$120			$104			$30	**$629**
5	All	$375	$120	$414					$30	**$939**
6	Heated basements	$375	$120	$414				$255	$30	**$1,194**
6	All but heated basements	$375	$120	$414					$30	**$939**
7 and 8	Heated basements	$375	$120					$255	$30	**$780**
7 and 8	Floors over unconditioned spaces	$375	$120				$288		$30	**$813**
7 and 8	Slab on grade	$375	$120						$30	**$525**

Table 6.5. Incremental Costs for the 2009 IECC over the 2006 IECC for the Multifamily Prototype

Climate Zone	Foundation Type	Duct Sealing and Testing	Improved Air Sealing	R-19 to R-20 walls	Windows 0.30 SHGC and Lower U	Windows U-0.40 to 0.35	R-30 to R-38 Floors	R-19 Basement Wall Insulation	50% Energy Efficient Lighting	**Total**
1	All	$255	$60		$327				$18	**$660**
2	All	$255	$60		$327				$18	**$660**
3 – South	All	$255	$60		$327				$18	**$660**
3 – North	Heated basements	$255	$60		$327			$73	$18	**$733**
3 – North	All but heated basements	$255	$60		$327				$18	**$660**
4	All	$255	$60			$34			$18	**$367**
5	All	$255	$60	$149					$18	**$482**
6	Heated basements	$255	$60	$149				$37	$18	**$519**
6	All but heated basements	$255	$60	$149					$18	**$482**
7 and 8	Heated basements	$255	$60					$37	$18	**$370**
7 and 8	Floors over unconditioned spaces	$255	$60				$96		$18	**$429**
7 and 8	Slab on grade	$255	$60						$18	**$333**

Table 6.6. Incremental Costs for the 2012 IECC over the 2009 IECC for the Single-Family Prototype

Climate Zone	Foundation Type	Envelope Sealing	Blower Door Test	Windows - 0.25 SHGC and Lower U	Increased Ceiling Insulation	Increased Wall Insulation	Hot Water Pipe Insulation	Further Duct Sealing	75% Energy Efficient Lighting	R-19 Basement Wall Insulation	Total
1	All	$480	$135	$493			$400	$100	$51		**$1,659**
2	All	$480	$135	$493	$336		$400	$100	$51		**$1,995**
3	All	$480	$135	$493	$336	$533	$400	$100	$51		**$2,528**
4	All	$480	$135		$336	$533	$400	$100	$51		**$2,035**
5	Heated basement	$480	$135	$64	$336		$400	$100	$51	$255	**$1,821**
5	All but heated basement	$480	$135	$64	$336		$400	$100	$51		**$1,566**
6, 7 and 8	All	$480	$135	$64		$1,567	$400	$100	$51		**$2,797**

Table 6.7. Incremental Costs for the 2012 IECC over the 2009 IECC for the Multifamily Prototype

Climate Zone	Foundation Type	Envelope Sealing	Blower Door Test	Windows - 0.25 SHGC and Lower U	Increased Ceiling Insulation	Increased Wall Insulation	Hot Water Pipe Insulation	Further Duct Sealing	75% Energy Efficient Lighting	R-19 Basement Wall Insulation	Total
1	All	$240	$135	$163			$200	$100	$29		**$867**
2	All	$240	$135	$163	$112		$200	$100	$29		**$979**
3	All	$240	$135	$163	$112	$191	$200	$100	$29		**$1,170**
4	All	$240	$135		$112	$191	$200	$100	$29		**$1,007**
5	Heated basement	$240	$135	$21	$112		$200	$100	$29	$37	**$874**
5	All but heated basement	$240	$135	$21	$112		$200	$100	$29		**$837**
6, 7 and 8	All	$240	$135	$21		$562	$200	$100	$29		**$1,287**

Table 6.8. Construction Cost Multiplier by State

State	Multiplier
Alabama	0.842
Alaska	1.336
Arizona	0.928
Arkansas	0.839
California	1.142
Colorado	0.972
Connecticut	1.124
Delaware	1.053
District of Columbia	0.999
Florida	0.884
Georgia	0.882
Hawaii	1.288
Idaho	0.918
Illinois	1.069
Indiana	0.99
Iowa	0.946
Kansas	0.869
Kentucky	0.929
Louisiana	0.853
Maine	0.916
Maryland	0.956
Massachusetts	1.141
Michigan	0.989
Minnesota	1.06
Mississippi	0.833
Missouri	1.005
Montana	0.936
Nebraska	0.905
Nevada	1.063
New Hampshire	0.967
New Jersey	1.156
New Mexico	0.903
New York	1.093
North Carolina	0.838
North Dakota	0.888
Ohio	0.967
Oklahoma	0.852
Oregon	1.038
Pennsylvania	1.025
Rhode Island	1.082
South Carolina	0.808
South Dakota	0.829
Tennessee	0.863
Texas	0.837
Utah	0.883
Vermont	0.933

Table 6.8. (contd)

State	Multiplier
Virginia	0.887
Washington	1.034
West Virginia	0.979
Wisconsin	1.01
Wyoming	0.886

7.0 Cost-Effectiveness Calculations

7.1 Cost-Effectiveness Methodology

DOE supports the development and adoption of more efficient building energy codes that are cost effective. The cost-effectiveness methodology lays out the entire procedure for computing cost effectiveness of the codes analyzed in this study.

7.2 Calculation Structure

Three cost-effectiveness metrics are computed as defined in the cost-effectiveness methodology: 1) LCC, 2) simple payback, and 3) annual consumer cash flow. LCC is the primary metric used by DOE to assess the cost effectiveness of a code. Simple payback and cash flow details are provided to assist states in assessing new codes.

LCC is computed using the annual energy savings and the incremental first cost associated with the efficiency improvements of a code. The LCC calculation is an assessment of the net benefit of code changes in present value terms over a defined period of analysis. Annualized cash flows are a component of the LCC calculation, but are presented year by year without discounting to present value. They help in determining the number of years needed to achieve positive cash flow (i.e., how long before the annual cost savings outweigh the incremental mortgage payments). Simple payback is the simple calculation of the number of years it would take the annual energy savings to break even with the incremental first cost. It does not account for the time-value of money or any other mortgage calculations.

The economic parameters used in the economic calculations are defined in the cost-effectiveness methodology. These are summarized again in Table 7.1. The cost-effectiveness methodology provides more details on the reasoning behind the selection of each value.

7.3 Aggregation of Results

The economic results from the 11,424 energy models are aggregated to three levels: 1) state, 2) climate zone, and 3) national. The aggregated results are based on weighted averages of the individual results, in which weightings are defined by the relative prevalence of foundation types, heating system types, and building types (single-family vs. multifamily) at the three levels. Weighting factors are developed from multiple data sources as documented in the cost-effectiveness methodology.

Figure 7.1 provides a high level overview of the aggregation process. The weighting factors used in this analysis are further described in the following sections.

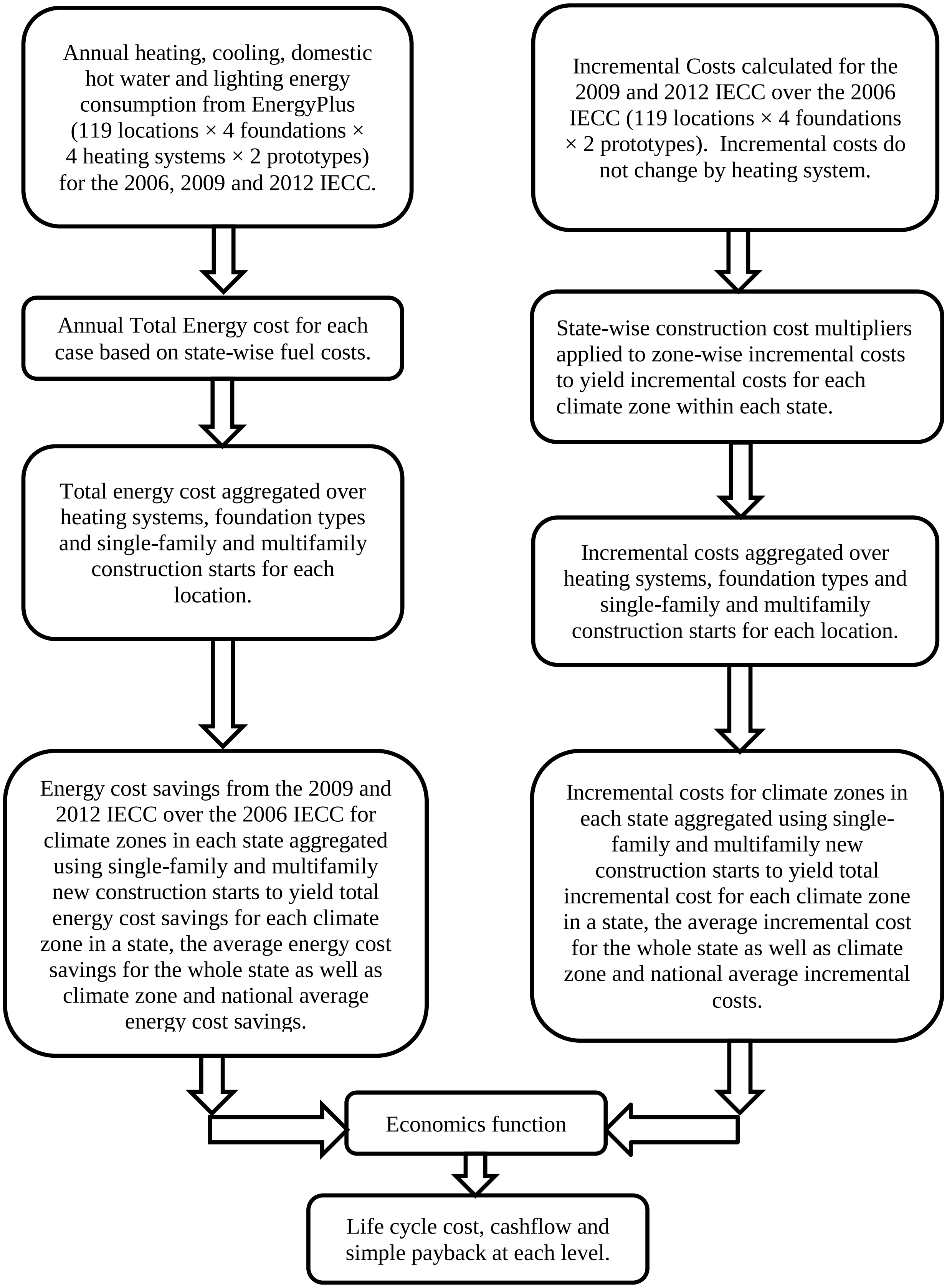

Figure 7.1. Overview of the Aggregation Process

Table 7.1. Economic Parameters Used in LCC Calculations

Parameter	Symbol	Current Estimate
Mortgage Interest Rate	R_{MI}	5%
Loan Term	T	30 years
Down Payment Rate	R_{DP}	10% of home price
Points and Loan Fees	R_{MF}	0.7% (non-deductible)
Discount Rate	R_d	5% (equal to Mortgage Interest Rate)
Period of Analysis	P	30 years
Property Tax Rate	R_{PT}	0.9% of home price/value
Income Tax Rate	R_{IT}	25% federal, state values vary
Home Price Escalation Rate	E_H	Equal to Inflation Rate
Inflation Rate	R_{INF}	1.6% annual
Fuel Prices and Escalation Rates	Latest state average residential prices are based on current Energy Information Administration data and projections (as of the end of 2011; fuel price escalation rates are from the 2012Annual Energy Outlook. (An average nominal escalation rate of 2.2% is used in this analysis).	

7.3.1 Aggregation Across Foundation Types

Residential buildings typically have one of three foundation types: 1) basement, 2) crawlspace, or 3) slab-on-grade. The basement may be heated or unheated. Data from DOE's 2009 Residential Energy Consumption Survey[1] are used to establish foundation shares for both single-family and multifamily buildings. Table 7.2 details the foundation shares used in this analysis.

Table 7.2. Share of Foundation Types (percent)

State	Slab-on-Grade	Heated Basement	Unheated Basement	Crawlspace
Connecticut, Rhode Island, Vermont, New Hampshire, Maine	16.8	23.8	45.5	13.9
Massachusetts	15.8	21.2	51.9	11.2
New York	20.4	25.9	41.7	12
New Jersey	26.9	18.3	30.6	24.2
Pennsylvania	28.9	24.6	32.8	13.7
Illinois	22.5	39.4	14.1	24.1
Ohio and Indiana	27.5	29.9	21.2	21.4
Michigan	15.7	36.2	27.3	20.8
Wisconsin	14.9	45	29.7	10.4
Minnesota, Iowa, North Dakota, South Dakota	22.1	46.9	15.5	15.5
Kansas and Nebraska	29.8	32.7	14.9	22.5
Missouri	24.8	36.4	20.8	17.9

[1] 2009 RECS Survey Data 'Structural and Geographic Characteristics' http://www.eia.gov/consumption/residential/data/2009/#undefined

Table 7.2. (contd)

State	Slab-on Grade	Heated Basement	Unheated Basement	Crawlspace
Virginia	33.2	24.2	9.8	32.8
Maryland, Delaware, and West Virginia	28	30.7	18.3	23
Georgia	57.1	6.6	9.7	26.7
North Carolina and South Carolina	38.7	2.3	4.1	54.9
Florida	87.7	0	0.4	11.8
Alabama, Mississippi, Kentucky	44.1	8.6	10.6	36.7
Tennessee	35.3	7.2	9	48.4
Arkansas, Louisiana, and Oklahoma	66.9	0.6	2.9	29.7
Texas	79.6	0.3	0.4	19.8
Colorado	30.7	28.2	9.9	31.2
Utah, Wyoming, Montana, Idaho	26.7	36.6	11	25.6
Arizona	90.7	0.6	3.1	5.6
Nevada and New Mexico	86.1	2.5	0.8	10.7
California	59	1.2	4.9	34.9
Washington, Oregon, Alaska, Hawaii	37	8.9	3.1	51

7.3.2 Aggregation Across Heating System Types

The next level of aggregation is done by heating system shares. Heating system shares used in DOE's analyses are taken from National Association of Home Builders survey data (NAHB 2009). The shares by heating system type for new construction in each census division for single-family and multifamily homes are shown in Table 7.3 and Table 7.4, respectively.

Table 7.3. Share of Heating Systems – Single-Family Home (percent)

Census Division	Electric Heat Pump	Gas Heating	Oil Heating	Electric Furnace
New England	10.8	57	31.1	1.1
Middle Atlantic	24.5	69.2	4.6	1.7
East North Central	22.5	76.2	0.5	0.7
West North Central	39.6	56.7	0.2	3.4
South Atlantic	78.9	19	0.1	2
East South Central	68.9	28.9	0	2.1
West South Central	37.5	48.1	0	14.5
Mountain	19.4	77.8	0.2	2.6
Pacific	34	62.9	0.2	2.9

Table 7.4. Share of Heating Systems – Multifamily Home (percent)

Census Division	Electric Heat Pump	Gas Heating	Oil Heating	Electric Furnace
New England	3	66	30.4	0.7
Middle Atlantic	39.5	49.6	6.1	4.9
East North Central	3.3	96.5	0.1	0.1
West North Central	24.8	68	3	4.3
South Atlantic	74.9	24.2	0	1.1
East South Central	94.1	1.8	0	4.1
West South Central	6.9	10.1	52.9[1]	30.2
Mountain	2.8	97.2	0	0
Pacific	14.9	84.2	0.2	0.8

7.3.3 Aggregation Across Building Types

Finally, new housing construction starts from the census data at the county level for 2010[2] are used to estimate single-family and multifamily shares within each climate location within each state. Table 7.5 shows the single-family and multifamily building new housing construction starts for each state - climate zone combination.

Table 7.5. New Housing Construction Starts from the 2010 Census Data

State	Climate Zone	Single Family Permits	Multifamily Permits
Alabama	2	1,577	94
Alabama	3	5,531	764
Alabama	3WH	1,594	798
Alaska	7	601	41
Alaska	8	65	0
Arizona	2	9,409	719
Arizona	3	696	28
Arizona	4	307	58
Arizona	5	343	88
Arkansas	3	3,454	1,512
Arkansas	3WH	51	5
Arkansas	4	1,143	119
California	2	102	0
California	3B	21,167	6,513
California	3C	3,585	3,416
California	4B	384	3

[1] DOE believes there is either an error or an anomaly in the source table resulting in a large overstatement in oil heating use in the West South Central region. The value, 52.9 percent, is set to zero, and the shares for the other fuel/equipment types are renormalized to sum to 100% for purposes of DOE's analyses.
[2] United States Census Bureau Building Permits; Accessed April 27, 2012 at http://censtats.census.gov/bldg/bldgprmt.shtml.

Table 7.5 (contd)

State	Climate Zone	Single Family Permits	Multifamily Permits
California	4C	196	13
California	5	233	21
California	6	26	0
Colorado	4	23	1
Colorado	5	7,760	1,514
Colorado	6	462	8
Colorado	7	545	26
Connecticut	5	2,632	569
Delaware	4	2,673	258
District Of Columbia	4	177	364
Florida	1	2,045	1,680
Florida	2	27,995	3,909
Georgia	2	2,915	501
Georgia	3	9,245	931
Georgia	3WH	1,487	133
Georgia	4	1,132	44
Hawaii	1	2,203	515
Idaho	5	2,669	154
Idaho	6	899	169
Illinois	4	1,736	538
Illinois	5	5,888	2,757
Indiana	4	1,924	188
Indiana	5	7,849	2,135
Iowa	5	4,956	1,100
Iowa	6	996	62
Kansas	4	3,926	796
Kansas	5	48	22
Kentucky	4	5,983	1,296
Louisiana	2	7,723	481
Louisiana	3	20	1
Louisiana	3WH	2,467	251
Maine	6	2,636	89
Maine	7	75	8
Maryland	4	8,394	2,227
Maryland	5	95	0
Massachusetts	5	5,839	1,417
Michigan	5	6,041	830
Michigan	6	1,426	84
Michigan	7	236	12
Minnesota	6	5,440	1,839
Minnesota	7	1,613	117
Mississippi	2	1,765	351
Mississippi	3	1,769	91

Table 7.5 (contd)

State	Climate Zone	Single Family Permits	Multifamily Permits
Mississippi	3WH	893	96
Missouri	4	6,660	1,922
Missouri	5	241	42
Montana	6	1,322	387
Nebraska	5	3,779	1,139
Nevada	3	4,623	471
Nevada	5	738	128
New Hampshire	5	1,146	213
New Hampshire	6	744	128
New Jersey	4	5,024	1,873
New Jersey	5	2,354	824
New Mexico	3	953	130
New Mexico	4	1,282	115
New Mexico	5	927	46
New York	4	1,810	2,964
New York	5	5,702	987
New York	6	2,447	257
North Carolina	3	9,552	2,358
North Carolina	3WH	3,657	373
North Carolina	4	12,419	2,263
North Carolina	5	419	80
North Dakota	6	789	191
North Dakota	7	1,295	1,037
Ohio	4	953	213
Ohio	5	9,650	1,968
Oklahoma	3	6,864	824
Oklahoma	4	2	0
Oregon	4	4,435	852
Oregon	5	741	36
Pennsylvania	4	3,821	540
Pennsylvania	5	12,472	710
Pennsylvania	6	593	0
Rhode Island	5	727	91
South Carolina	3	7,979	574
South Carolina	3WH	4,712	287
South Dakota	5	171	28
South Dakota	6	2,015	505
Tennessee	3	1,463	576
Tennessee	4	10,167	2,559
Texas	2B	44,064	7,604
Texas	2A	870	56
Texas	3B	314	234
Texas	3A	15,908	3,887
Texas	3AWH	5,181	1,842

Table 7.5 (contd)

State	Climate Zone	Single Family Permits	Multifamily Permits
Texas	4B	636	280
Utah	3	873	11
Utah	5	5,084	857
Utah	6	9,26	398
Vermont	6	980	148
Virginia	4	13,820	1,948
Washington	4	10,550	2,464
Washington	5	3,889	845
Washington	6	263	3
West Virginia	4	1,139	150
West Virginia	5	657	237
Wisconsin	6	6,735	2,216
Wisconsin	7	952	15
Wyoming	5	18	4
Wyoming	6	1,366	388
Wyoming	7	162	24

8.0 Summary of Results

8.1 Energy Cost Savings

Table 8.1 through Table 8.3 summarize the combined energy cost savings of the single-family and multifamily prototypes for the 2009 and 2012 IECC compared to the 2006 IECC at the national, climate zone, and state levels. Table 8.4 through Table 8.6 summarize the combined energy cost savings for the 2012 IECC compared to the 2009 IECC. The savings calculation includes only space heating, space cooling, domestic water heating, and lighting energy costs.

Table 8.1. National Energy Cost Savings for the 2009 and 2012 IECC Compared to the 2006 IECC

	2009 IECC	2012 IECC
National Energy Cost Savings over the 2006 IECC	10.8% ($ 168)	32.1% ($ 500)

Table 8.2. Energy Cost Savings by Climate Zone for the 2009 and 2012 IECC Compared to the 2006 IECC

Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
Zone 1	9.6	213	25.1	557
Zone 2	12.8	186	26.3	383
Zone 3	12.3	164	34	454
Zone 4	9.4	143	32.7	498
Zone 5	9.5	167	33	577
Zone 6	10	200	36.2	725
Zone 7	10	215	37.6	807
Zone 8	10.3	502	38.3	1862

Table 8.3. Energy Cost Savings by State and Climate Zone for the 2009 and 2012 IECC Compared to the 2006 IECC

State - Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
Alabama-2AWH	11.9	173	26.1	380
Alabama-3A	11.9	177	34.3	509
Alabama-3AWH	11.1	139	31.5	395
Alabama	11.8	168	32.4	462
Alaska-7A	10.1	324	37.2	1190
Alaska-8A	10.3	502	38.3	1862
Alaska	10.1	340	37.3	1251
Arizona-2B	13.8	240	27.5	478
Arizona-3B	12.8	220	37.7	650
Arizona-4B	9.1	131	33	473
Arizona-5B	8.6	117	28.6	391

Table 8.3. (contd)

State - Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
Arizona	13.5	231	28.3	486
Arkansas-3A	11.7	146	35.9	448
Arkansas-3AWH	11.7	149	34.8	441
Arkansas-4A	10	151	35.7	539
Arkansas	11.3	147	35.8	466
California-2B	14.3	294	28.1	578
California-3B	13.8	138	28.5	286
California-3C	12.3	116	35.2	331
California-4B	8.5	144	29.7	504
California-4C	9.2	119	29.8	385
California-5B	8.9	163	28.9	531
California-6B	9.4	219	34.3	799
California	13.4	135	29.8	301
Colorado-4B	9.9	141	34.1	486
Colorado-5B	9.3	116	30.3	377
Colorado-6B	9.6	146	33.7	514
Colorado-7B	9.4	148	34.3	540
Colorado	9.3	119	30.7	392
Connecticut-5A	9.6	237	32.7	811
Connecticut	9.6	237	32.7	811
Delaware-4A	10.3	249	35.8	865
Delaware	10.3	249	35.8	865
DistrictofColumbia-4A	8.7	125	29.9	429
District of Columbia	8.7	125	29.9	429
Florida-1AWH	9.3	115	25	309
Florida-2AWH	13.3	190	25.1	360
Florida	12.9	182	25.1	355
Georgia-2AWH	12.2	166	26.1	354
Georgia-3A	12.3	184	35.4	530
Georgia-3AWH	11.6	168	32.8	474
Georgia-4A	8.5	125	29.7	436
Georgia	12	175	32.9	481
Hawaii-1A	9.7	347	25.1	897
Hawaii	9.7	347	25.1	897
Idaho-5B	9.1	108	31.1	369
Idaho-6B	9.9	133	35.8	481
Idaho	9.3	114	32.4	399
Illinois-4A	9.5	136	32.6	466
Illinois-5A	9.3	129	31.3	437
Illinois	9.3	130	31.6	443
Indiana-4A	9.6	130	34	459
Indiana-5A	9.5	131	33	454
Indiana	9.5	130	33.1	454
Iowa-5A	9.8	172	33.8	595
Iowa-6A	10.3	234	38.1	865
Iowa	9.8	181	34.5	635
Kansas-4A	9.9	155	34.9	544
Kansas-5A	9.4	133	32.4	461
Kansas	10	155	34.9	543
Kentucky-4A	10.1	143	34.9	492
Kentucky	10.1	143	34.9	492

Table 8.3. (contd)

State - Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
Louisiana-2AWH	12.2	149	26.9	330
Louisiana-3A	12	152	34.9	443
Louisiana-3AWH	11.8	151	34.8	444
Louisiana	12	149	28.9	358
Maine-6A	10.2	294	37.7	1086
Maine-7A	10.2	370	39.1	1423
Maine	10.2	297	37.7	1097
Maryland-4A	9.7	202	33.3	691
Maryland-5A	9.8	274	34	954
Maryland	9.8	203	33.3	694
Massachusetts-5A	10.1	243	35.9	864
Massachusetts	10.1	243	35.9	864
Michigan-5A	10	206	34.9	717
Michigan-6A	10.4	233	37.4	836
Michigan-7A	10.3	248	38.1	921
Michigan	10.1	212	35.5	744
Minnesota-6A	10	192	36.3	700
Minnesota-7A	10.3	260	38.8	983
Minnesota	10	205	36.9	754
Mississippi-2AWH	11.9	146	25.8	317
Mississippi-3A	12.5	186	35.2	524
Mississippi-3AWH	11.8	161	33.3	456
Mississippi	12.1	164	31.2	422
Missouri-4A	9.6	142	34.1	504
Missouri-5A	9.4	168	33.8	605
Missouri	9.6	143	34.1	507
Montana-6B	9.6	125	34.1	444
Montana	9.6	125	34.1	444
Nebraska-5A	9.3	133	32	458
Nebraska	9.3	133	32	458
Nevada-3B	13.5	219	36.3	590
Nevada-5B	8.9	126	29.5	419
Nevada	12.8	205	35.4	565
NewHampshire-5A	9.3	223	33.1	795
NewHampshire-6A	9.9	265	35.8	959
New Hampshire	9.5	239	34.2	859
NewJersey-4A	10.1	216	34.5	741
NewJersey-5A	9.5	201	32.1	681
New Jersey	9.9	211	33.8	722
NewMexico-3B	13.3	191	38	545
NewMexico-4B	9	112	31.3	388
NewMexico-5B	8.9	110	27.7	343
New Mexico	10.5	137	32.7	425
NewYork-4A	9.3	161	31.2	543
NewYork-5A	10	269	34.5	925
NewYork-6A	10.2	277	36.4	985
New York	9.9	234	34.1	808
NorthCarolina-3A	11.6	151	33.5	437
NorthCarolina-3AWH	11.6	152	32.7	429
NorthCarolina-4A	8.8	118	30	403
NorthCarolina-5A	9.2	153	32.2	537

Table 8.3. (contd)

State - Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
North Carolina	10.2	136	31.7	422
NorthDakota-6A	10	169	36.6	620
NorthDakota-7A	9.5	141	36.1	535
North Dakota	9.6	149	36.2	560
Ohio-4A	10	159	35.1	556
Ohio-5A	9.3	136	31.3	460
Ohio	9.4	139	31.7	469
Oklahoma-3A	12.5	190	39	591
Oklahoma-4B	10.1	145	35.4	508
Oklahoma	12.5	190	39	591
Oregon-4C	8.7	100	30.2	346
Oregon-5B	9.6	153	33.7	534
Oregon	8.8	106	30.8	370
Pennsylvania-4A	10.1	192	35.3	671
Pennsylvania-5A	9.3	204	33.1	724
Pennsylvania-6A	10	250	37.3	931
Pennsylvania	9.5	203	33.8	718
RhodeIsland-5A	9.8	249	34.6	878
Rhode Island	9.8	249	34.6	878
SouthCarolina-3A	11.8	176	34	507
SouthCarolina-3AWH	11.8	166	32.3	456
South Carolina	11.8	173	33.4	488
SouthDakota-5A	10	173	35.6	617
SouthDakota-6A	10.1	168	36.4	609
South Dakota	10	168	36.4	609
Tennessee-3A	12.1	154	34.7	442
Tennessee-4A	8.9	118	31.1	410
Tennessee	9.4	123	31.6	415
Texas-2AWH	12.4	182	26.6	389
Texas-2BWH	12.9	207	27.1	434
Texas-3A	12.2	180	36.4	537
Texas-3AWH	12	192	35.7	571
Texas-3B	12.4	165	33.9	452
Texas-4B	9.8	152	34.2	529
Texas	12.3	183	29.7	442
Utah-3B	14.7	198	37	498
Utah-5B	8.8	103	29.7	349
Utah-6B	8.9	97	31.3	340
Utah	9.5	112	30.8	363
Vermont-6A	10.2	297	37.3	1089
Vermont	10.2	297	37.3	1089
Virginia-4A	9.1	138	31.9	482
Virginia	9.1	138	31.9	482
Washington-4C	9.1	97	31.8	339
Washington-5B	9.8	148	34.7	522
Washington-6B	9.7	175	36.6	662
Washington	9.4	112	32.9	392
WestVirginia-4A	9.5	141	33.7	501
WestVirginia-5A	8.9	126	31.8	450
West Virginia	9.3	135	32.9	480
Wisconsin-6A	9.7	189	35.4	688

Table 8.3. (contd)

State - Climate Zone	Energy Cost Savings over the 2006 IECC			
	2009 IECC		2012 IECC	
	Savings (%)	Savings ($)	Savings (%)	Savings ($)
Wisconsin-7A	10.4	274	38.9	1022
Wisconsin	9.8	197	35.8	720
Wyoming-5B	9.5	123	32.8	426
Wyoming-6B	10.3	129	36.7	458
Wyoming-7B	9.6	144	36.2	540
Wyoming	10.3	131	36.6	466

Table 8.4. National Energy Cost Savings for the 2012 IECC Compared to the 2009 IECC

	2012 IECC
National Energy Cost Savings over the 2009 IECC	23.9% ($ 332)

Table 8.5. Energy Cost Savings by Climate Zone for the 2012 IECC Compared to the 2009 IECC

Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
Zone 1	17.1	344
Zone 2	15.5	197
Zone 3	24.8	290
Zone 4	25.7	355
Zone 5	25.9	410
Zone 6	29.2	525
Zone 7	30.6	592
Zone 8	31.2	1360

Table 8.6. Energy Cost Savings by State and Climate Zone for the 2012 IECC Compared to the 2009 IECC

State – Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
Alabama-2AWH	16.1	207
Alabama-3A	25.4	332
Alabama-3AWH	22.9	256
Alabama	23.4	294
Alaska-7A	30.1	866
Alaska-8A	31.2	1360
Alaska	30.3	911
Arizona-2B	15.9	238
Arizona-3B	28.6	430
Arizona-4B	26.3	342
Arizona-5B	21.9	274

Table 8.6. (contd)

State – Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
Arizona	17.2	255
Arkansas-3A	27.4	302
Arkansas-3AWH	26.1	292
Arkansas-4A	28.6	388
Arkansas	27.6	319
California-2B	16.1	284
California-3B	17.1	148
California-3C	26.1	215
California-4B	23.2	360
California-4C	22.7	266
California-5B	21.9	368
California-6B	27.5	580
California	19	166
Colorado-4B	26.9	345
Colorado-5B	23.1	261
Colorado-6B	26.7	368
Colorado-7B	27.5	392
Colorado	23.6	273
Connecticut-5A	25.6	574
Connecticut	25.6	574
Delaware-4A	28.4	616
Delaware	28.4	616
DistrictofColumbia-4A	23.2	304
District of Columbia	23.2	304
Florida-1AWH	17.3	194
Florida-2AWH	13.7	170
Florida	14.1	173
Georgia-2AWH	15.8	188
Georgia-3A	26.3	346
Georgia-3AWH	24	306
Georgia-4A	23.2	311
Georgia	23.8	306
Hawaii-1A	17	550
Hawaii	17	550
Idaho-5B	24.2	261
Idaho-6B	28.8	348
Idaho	25.5	285
Illinois-4A	25.5	330
Illinois-5A	24.3	308
Illinois	24.6	313
Indiana-4A	27	329
Indiana-5A	25.9	323
Indiana	26.1	324
Iowa-5A	26.6	423
Iowa-6A	31	631
Iowa	27.4	454
Kansas-4A	27.7	389
Kansas-5A	25.5	328
Kansas	27.7	388

Table 8.6. (contd)

State – Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
Kentucky-4A	27.6	349
Kentucky	27.6	349
Louisiana-2AWH	16.8	181
Louisiana-3A	26.1	291
Louisiana-3AWH	26.1	293
Louisiana	19.2	209
Maine-6A	30.6	792
Maine-7A	32.3	1053
Maine	30.7	800
Maryland-4A	26.1	489
Maryland-5A	26.8	680
Maryland	26.1	491
Massachusetts-5A	28.7	621
Massachusetts	28.7	621
Michigan-5A	27.7	511
Michigan-6A	30.1	603
Michigan-7A	31	673
Michigan	28.3	532
Minnesota-6A	29.3	508
Minnesota-7A	31.8	723
Minnesota	29.9	549
Mississippi-2AWH	15.8	171
Mississippi-3A	26	338
Mississippi-3AWH	24.4	295
Mississippi	21.7	258
Missouri-4A	27.1	362
Missouri-5A	26.9	437
Missouri	27.1	364
Montana-6B	27.1	319
Montana	27.1	319
Nebraska-5A	25	325
Nebraska	25	325
Nevada-3B	26.4	371
Nevada-5B	22.6	293
Nevada	25.9	360
NewHampshire-5A	26.3	572
NewHampshire-6A	28.7	694
New Hampshire	27.3	620
NewJersey-4A	27.2	525
NewJersey-5A	25	480
New Jersey	26.5	511
NewMexico-3B	28.5	354
NewMexico-4B	24.5	276
NewMexico-5B	20.6	233
New Mexico	24.7	288
NewYork-4A	24.2	382
NewYork-5A	27.2	656
NewYork-6A	29.2	708
New York	26.9	574

Table 8.6. (contd)

State – Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
NorthCarolina-3A	24.8	286
NorthCarolina-3AWH	23.9	277
NorthCarolina-4A	23.3	285
NorthCarolina-5A	25.4	384
North Carolina	24	286
NorthDakota-6A	29.6	451
NorthDakota-7A	29.4	394
North Dakota	29.4	411
Ohio-4A	27.8	397
Ohio-5A	24.3	324
Ohio	24.6	330
Oklahoma-3A	30.3	401
Oklahoma-4B	28.2	363
Oklahoma	30.3	401
Oregon-4C	23.5	246
Oregon-5B	26.6	381
Oregon	24.1	264
Pennsylvania-4A	28	479
Pennsylvania-5A	26.2	520
Pennsylvania-6A	30.3	681
Pennsylvania	26.8	515
RhodeIsland-5A	27.5	629
Rhode Island	27.5	629
SouthCarolina-3A	25.2	331
SouthCarolina-3AWH	23.3	290
South Carolina	24.4	315
SouthDakota-5A	28.5	444
SouthDakota-6A	29.3	441
South Dakota	29.3	441
Tennessee-3A	25.7	288
Tennessee-4A	24.3	292
Tennessee	24.5	292
Texas-2AWH	16.2	207
Texas-2BWH	16.3	227
Texas-3A	27.6	357
Texas-3AWH	26.9	379
Texas-3B	24.5	287
Texas-4B	27	377
Texas	19.8	259
Utah-3B	26.1	300
Utah-5B	23	246
Utah-6B	24.6	243
Utah	23.5	251
Vermont-6A	30.2	792
Vermont	30.2	792
Virginia-4A	25.1	344
Virginia	25.1	344
Washington-4C	25	242
Washington-5B	27.6	374

Table 8.6. (contd)

State – Climate Zone	Energy Cost Savings of the 2012 IECC over the 2009 IECC	
	Savings (%)	Savings ($)
Washington-6B	29.8	487
Washington	25.9	280
WestVirginia-4A	26.7	360
WestVirginia-5A	25.2	324
West Virginia	26.1	345
Wisconsin-6A	28.4	499
Wisconsin-7A	31.8	748
Wisconsin	28.8	523
Wyoming-5B	25.7	303
Wyoming-6B	29.4	329
Wyoming-7B	29.4	396
Wyoming	29.4	335

8.2 Cost Effectiveness

Table 8.7 and Table 8.8 summarize the life cycle cost savings of the 2009 and 2012 IECC compared to the 2006 IECC at the climate zone and state levels. Table 8.9 summarizes the life cycle cost savings of the 2012 IECC compared to the 2009 IECC.

Table 8.7. Life Cycle Cost Savings by Climate Zone for the 2009 and 2012 IECC compared to the 2006 IECC (2012 dollars)

	Life Cycle Cost Savings over the 2006 IECC ($)	
Climate Zone	2009 IECC	2012 IECC
Zone 1	2,877	8,256
Zone 2	2,443	4,763
Zone 3	1,944	5,720
Zone 4	2,259	7,706
Zone 5	2,486	9,229
Zone 6	3,114	11,366
Zone 7	3,622	13,166
Zone 8	9,147	33,105

Table 8.8. Life Cycle Cost Savings by State and Climate Zone for the 2009 and 2012 IECC compared to the 2006 IECC (2012 dollars)

	Life Cycle Cost Savings over the 2006 IECC ($)	
State - Climate Zone	2009 IECC	2012 IECC
Alabama-2AWH	2,149	4,666

Table 8.8. (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
Alabama-3A	2,250	6,992
Alabama-3AWH	1,679	5,113
Alabama	2,117	6,182
Alaska-7A	5,537	19,525
Alaska-8A	9,124	32,986
Alaska	5,861	20,745
Arizona-2B	3,386	6,339
Arizona-3B	2,946	9,353
Arizona-4B	2,017	7,223
Arizona-5B	1,538	5,727
Arizona	3,245	6,550
Arkansas-3A	1,814	6,167
Arkansas-3AWH	1,707	5,627
Arkansas-4A	2,491	8,742
Arkansas	1,948	6,679
California-2B	4,109	7,557
California-3B	1,187	1,711
California-3C	994	3,259
California-4B	2,106	7,168
California-4C	1,622	4,832
California-5B	2,251	7,978
California-6B	3,355	12,100
California	1,192	2,136
Colorado-4B	2,162	7,233
Colorado-5B	1,469	5,246
Colorado-6B	1,963	6,820
Colorado-7B	2,261	7,641
Colorado	1,528	5,435
Connecticut-5A	3,793	13,709
Connecticut	3,793	13,709
Delaware-4A	4,316	14,778
Delaware	4,316	14,778
District of Columbia-4A	2,024	6,852
District of Columbia	2,024	6,852
Florida-1AWH	1,203	3,870
Florida-2AWH	2,453	4,141
Florida	2,320	4,147
Georgia-2AWH	2,024	4,167
Georgia-3A	2,326	7,222
Georgia-3AWH	2,012	6,095
Georgia-4A	1,900	6,471
Georgia	2,210	6,415
Hawaii-1A	5,150	14,238

Table 8.8. (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
Hawaii	5,150	14,238
Idaho-5B	1,322	5,116
Idaho-6B	1,821	6,629
Idaho	1,444	5,515
Illinois-4A	2,058	6,839
Illinois-5A	1,728	6,419
Illinois	1,784	6,506
Indiana-4A	1,934	6,685
Indiana-5A	1,782	6,804
Indiana	1,781	6,764
Iowa-5A	2,655	9,764
Iowa-6A	3,773	14,134
Iowa	2,823	10,416
Kansas-4A	2,571	8,850
Kansas-5A	1,979	7,371
Kansas	2,556	8,828
Kentucky-4A	2,279	7,646
Kentucky	2,279	7,646
Louisiana-2AWH	1,665	3,621
Louisiana-3A	1,708	5,508
Louisiana-3AWH	1,722	5,622
Louisiana	1,663	4,107
Maine-6A	5,054	18,719
Maine-7A	6,798	25,830
Maine	5,109	18,944
Maryland-4A	3,453	11,627
Maryland-5A	4,620	16,781
Maryland	3,473	11,688
Massachusetts-5A	3,914	14,777
Massachusetts	3,914	14,777
Michigan-5A	3,255	12,029
Michigan-6A	3,707	13,331
Michigan-7A	4,241	15,263
Michigan	3,363	12,346
Minnesota-6A	2,905	10,737
Minnesota-7A	4,448	16,385
Minnesota	3,196	11,817
Mississippi-2AWH	1,716	3,605
Mississippi-3A	2,393	7,196
Mississippi-3AWH	1,955	5,933
Mississippi	2,022	5,400
Missouri-4A	2,224	7,766
Missouri-5A	2,494	9,779
Missouri	2,229	7,826

Table 8.8. (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2006 IECC ($) 2009 IECC	2012 IECC
Montana-6B	1,668	5,920
Montana	1,668	5,920
Nebraska-5A	1,908	7,141
Nebraska	1,908	7,141
Nevada-3B	2,720	7,616
Nevada-5B	1,565	5,846
Nevada	2,543	7,352
New Hampshire-5A	3,616	13,673
New Hampshire-6A	4,423	16,024
New Hampshire	3,925	14,573
New Jersey-4A	3,638	12,221
New Jersey-5A	3,078	11,094
New Jersey	3,445	11,877
NewMexico-3B	2,472	7,501
NewMexico-4B	1,631	5,483
NewMexico-5B	1,368	4,650
New Mexico	1,835	5,897
NewYork-4A	2,675	8,890
NewYork-5A	4,474	16,071
NewYork-6A	4,537	16,124
New York	3,870	13,677
NorthCarolina-3A	1,830	5,738
NorthCarolina-3AWH	1,769	5,399
NorthCarolina-4A	1,826	6,050
NorthCarolina-5A	2,354	8,878
North Carolina	1,844	5,911
NorthDakota-6A	2,545	9,518
NorthDakota-7A	2,283	8,416
North Dakota	2,353	8,719
Ohio-4A	2,561	8,834
Ohio-5A	1,887	6,939
Ohio	1,959	7,120
Oklahoma-3A	2,526	8,621
Oklahoma-4B	2,318	7,958
Oklahoma	2,526	8,621
Oregon-4C	1,341	4,428
Oregon-5B	2,139	8,217
Oregon	1,422	4,917
Pennsylvania-4A	3,187	10,923
Pennsylvania-5A	3,160	11,996
Pennsylvania-6A	4,009	15,015
Pennsylvania	3,189	11,845
RhodeIsland-5A	4,043	15,074
Rhode Island	4,043	15,074

Table 8.8. (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2006 IECC ($)	
	2009 IECC	2012 IECC
SouthCarolina-3A	2,276	7,034
SouthCarolina-3AWH	2,071	5,999
South Carolina	2,215	6,650
SouthDakota-5A	2,734	10,369
SouthDakota-6A	2,583	9,473
South Dakota	2,583	9,514
Tennesse-3A	1,863	5,795
Tennesse-4A	1,804	6,114
Tennessee	1,809	6,102
Texas-2AWH	2,394	4,933
Texas-2BWH	2,821	5,705
Texas-3A	2,558	8,117
Texas-3AWH	2,637	8,363
Texas-3B	2,127	6,069
Texas-4B	2,536	8,705
Texas	2,433	5,942
Utah-3B	2,420	6,280
Utah-5B	1,278	4,863
Utah-6B	1,163	4,102
Utah	1,385	4,879
Vermont-6A	5,133	18,861
Vermont	5,133	18,861
Virginia-4A	2,186	7,487
Virginia	2,186	7,487
Washington-4C	1,255	4,223
Washington-5B	2,059	8,029
Washington-6B	2,502	9,533
Washington	1,498	5,299
WestVirginia-4A	2,184	7,627
WestVirginia-5A	1,729	6,852
West Virginia	1,996	7,301
Wisconsin-6A	2,883	10,652
Wisconsin-7A	4,731	17,223
Wisconsin	3,056	11,272
Wyoming-5B	1,675	6,404
Wyoming-6B	1,754	6,268
Wyoming-7B	2,238	7,977
Wyoming	1,809	6,441

Table 8.9. Life Cycle Cost Savings by State and Climate Zone for the 2012 IECC compared to the 2009 IECC (2012 dollars)

State - Climate Zone	Life Cycle Cost Savings over the 2009 IECC ($)
Alabama-2AWH	2447
Alabama-3A	4672
Alabama	3996
Alaska-7A	13922
Alaska-8A	23806
Alaska	14819
Arizona-2B	2926
Arizona-3B	6322
Arizona-4B	5146
Arizona-5B	4187
Arizona	3255
Arkansas-3A	4294
Arkansas-3AWH	3850
Arkansas-4A	6222
Arkansas	4680
California-2B	3377
California-3B	438
California-3C	2200
California-4B	4995
California-4C	3139
California-5B	5706
California-6B	8721
California	878
Colorado-4B	5019
Colorado-5B	3768
Colorado-6B	4833
Colorado-7B	5343
Colorado	3895
Connecticut-5A	9903
Connecticut	9903
Delaware-4A	10409
Delaware	10409
District of Columbia-4A	4796
District of Columbia	4796
Florida-1AWH	2641
Florida-2AWH	1639
Florida	1769
Georgia-2AWH	2088

Table 8.9 (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2009 IECC ($)
Georgia-3A	4822
Georgia-3AWH	3998
Georgia-4A	4523
Georgia	4136
Hawaii-1A	9044
Hawaii	9044
Idaho-5B	3786
Idaho-6B	4798
Idaho	4057
Illinois-4A	4726
Illinois-5A	4687
Illinois	4704
Indiana-4A	4704
Indiana-5A	5032
Indiana	4966
Iowa-5A	7105
Iowa-6A	10349
Iowa	7573
Kansas-4A	6235
Kansas-5A	5403
Kansas	6234
Kentucky-4A	5321
Kentucky	5321
Louisiana-2AWH	1911
Louisiana-3A	3726
Louisiana-3AWH	3818
Louisiana	2386
Maine-6A	13639
Maine-7A	18995
Maine	13803
Maryland-4A	8127
Maryland-5A	12162
Maryland	8169
Massachusetts-5A	10848
Massachusetts	10848
Michigan-5A	8753
Michigan-6A	9591
Michigan-7A	10993
Michigan	8972
Minnesota-6A	7821

Table 8.9 (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2009 IECC ($)
Minnesota-7A	11880
Minnesota	8592
Mississippi-2AWH	1847
Mississippi-3A	4723
Mississippi-3AWH	3908
Mississippi	3334
Missouri-4A	5496
Missouri-5A	7262
Missouri	5539
Montana-6B	4244
Montana	4244
Nebraska-5A	5224
Nebraska	5224
Nevada-3B	4806
Nevada-5B	4288
Nevada	4736
New Hampshire-5A	10054
New Hampshire-6A	11570
New Hampshire	10635
New Jersey-4A	8546
New Jersey-5A	8009
New Jersey	8393
New Mexico-3B	4954
New Mexico-4B	3803
New Mexico-5B	3293
New Mexico	4015
New York-4A	6175
New York-5A	11593
New York-6A	11543
New York	9777
North Carolina-3A	3846
North Carolina-3AWH	3546
North Carolina-4A	4189
North Carolina-5A	6521
North Carolina	4022
North Dakota-6A	6946
North Dakota-7A	6102
North Dakota	6345
Ohio-4A	6209
Ohio-5A	5044

Table 8.9 (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2009 IECC ($)
Ohio	5151
Oklahoma-3A	6025
Oklahoma-4B	5593
Oklahoma	6025
Oregon-4C	3055
Oregon-5B	6076
Oregon	3450
Pennsylvania-4A	7697
Pennsylvania-5A	8844
Pennsylvania-6A	10990
Pennsylvania	8632
Rhode Island-5A	11011
Rhode Island	11011
South Carolina-3A	4690
South Carolina-3AWH	3842
South Carolina	4366
SouthDakota-5A	7634
South Dakota-6A	6862
South Dakota	6910
Tennessee-3A	3865
Tennessee-4A	4280
Tennessee	4217
Texas-2AWH	2505
Texas-2BWH	2828
Texas-3A	5485
Texas-3AWH	5662
Texas-3B	3886
Texas-4B	6118
Texas	3456
Utah-3B	3789
Utah-5B	3580
Utah-6B	2895
Utah	3479
Vermont-6A	13699
Vermont	13699
Virginia-4A	5255
Virginia	5255
Washington-4C	2922
Washington-5B	5983
Washington-6B	6999

Table 8.9 (contd)

State - Climate Zone	Life Cycle Cost Savings over the 2009 IECC ($)
Washington	3778
West Virginia-4A	5393
West Virginia-5A	5126
West Virginia	5270
Wisconsin-6A	7738
Wisconsin-7A	12445
Wisconsin	8186
Wyoming-5B	4722
Wyoming-6B	4475
Wyoming-7B	5702
Wyoming	4592

8.3 Cost-Effectiveness Reports

National and state IECC cost-effectiveness results from this analysis are published online and are available for download on the energy codes website.[1]

[1] http://www.energycodes.gov/development/residential/iecc_analysis.

9.0 References

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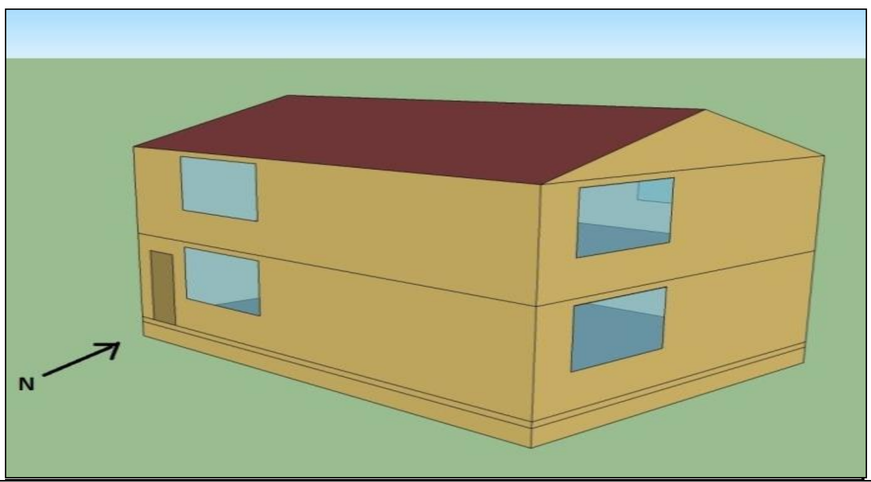
Appendix A

Building Energy Model Description

A.1 Single-Family Prototype Modeling Description

	Item	Description	Data Source
General			
	Vintage	New Construction	
	Locations	See under the '2.2 Climate Locations'	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Available fuel types	Natural Gas/Electricity/Fuel Oil	
	Building Type (Principal Building Function)	Residential	
	Building Prototype	Single-family Detached	
Form			
	Total Floor Area (sq. feet)	2,400 (30' x 40' x 2 stories)	
	Building shape		Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Aspect Ratio	1.33	

	Item	Description	Data Source
	Number of Floors	2	
	Window Fraction (Window-to-Floor Ratio)	Average Total: 15.0% divided equally among all facades	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Window Locations	All facades	
	Shading Geometry	none	
	Orientation	Back of the house faces North (see image)	
	Thermal Zoning	The house is divided into three thermal zones: 'living space', 'attic' and 'crawlspace', 'heated basement', 'unheated basement' when applicable.	
	Floor to ceiling height	8.5’	
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2x4 16" O.C. or 2x6 24" O.C.) 1" Stucco + Building Paper Felt + Insulating Sheathing (if applicable) + 5/8" Oriented Strand Board + Wall Insulation + 1/2" Drywall	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Walls, above grade, Wood Frame	IECC
	Dimensions	40' x 8'6" and 30' x 8'6"	
	Tilts and orientations	Vertical	
	Roof		
	Construction	Asphalt Shingles	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Ceiling R value	IECC

	Item	Description	Data Source
	Tilts and orientations	Gabled Roof with a Slope of 4/12	
	Window		
	Dimensions	based on window fraction, location, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	IECC Requirements Residential; Glazing	IECC
	SHGC (all)		
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Four Foundation Types are Modeled- i. Slab-on Grade ii. Vented Crawlspace Depth 2' iii. Heated Basement - Depth 7' iv. Unheated Basement- Depth 7'	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Insulation level	IECC Requirements for floors, slabs and basement walls	IECC
	Dimensions	based on floor area and aspect ratio	
	Internal Mass	8 lbs/ft2 of floor area	IECC 2006 section 404

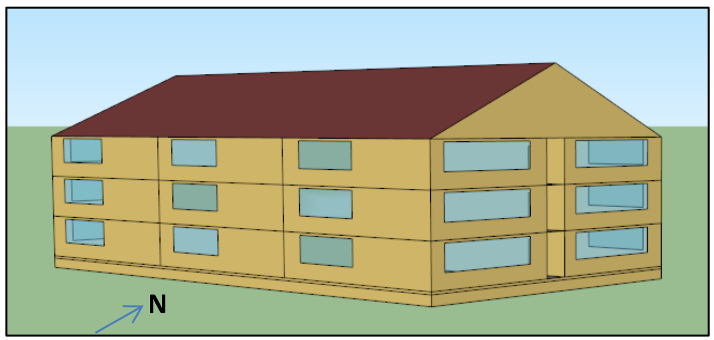
	Item	Description	Data Source
	Infiltration (ACH)	2006 IECC: 8 Air Changes/Hour at 50 Pa 2009 IECC: 7 Air Changes/Hour at 50 Pa 2012 IECC: 5 or 3 Air Changes/Hour at 50 Pa depending on climate zone	
HVAC			
	System Type		
	Heating type	Four Heating System Types are Modeled- i. Gas Furnace ii. Oil Furnace iii. Electric Furnace iv. Heat Pump	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Cooling type	Central DX Air-Conditioner/Heat Pump	
	HVAC Sizing		
	Cooling	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	SEER 13	Federal minimum efficiency
	Heating	AFUE 78% / HSPF 7.7	Federal minimum efficiency
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/72°F Heating	
	Thermostat Setback	No setback	
	Supply air temperature	Maximum 110 F, Minimum 52 F	

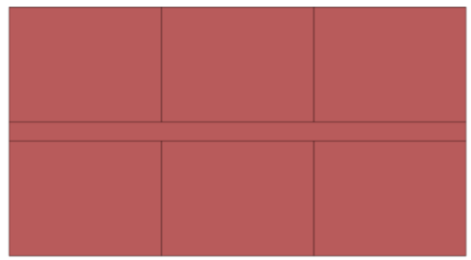
	Item	Description	Data Source
	Ventilation	60 CFM Outdoor Air; Continuous Supply	2012 IRC
	Supply Fan		
	Fan schedules	See Appendix A.4	
	Supply Fan Total Efficiency (%)	Fan Efficiency 58%; Motor efficiency 65% (PSC motor)	Residential Furnaces aand Centralized Air Condtioners and Heat Pumps Direct Final Rule Technical Support Document.[1]
	Supply Fan Pressure Drop	1.6" w.g.	
	Domestic Hot Water		
	DHW type	Individual Residential Water Heater with Storage Tank	
	Fuel type	Natural Gas/Electricity	
	Thermal efficiency (%)	EF = 0.59 for Gas-fired Water Heaters EF = 0.917 for Electric Water Heaters	Federal minimum efficiency
	Tank Volume (gal)	40 for Gas-fired Water Heaters 52 for Electric Water Heaters	Reference: Building America Research Benchmark
	Water temperature set-point	120 F	
	Schedules	See Appendix A.4	
Internal Loads & Schedules			
	Lighting		
	Average interior power density (W/ft^2)	Living space: Lighting Power Density is 0.68 W/sq.ft for the 2006 IECC - See '4.4 Lighting' for the detailed calculations	Reference: 2010 Building America House Simulation Prototcols

[1] Residential Furnaces and Central Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document – Chapter 7 'Energy Use Characterization' http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/hvac_ch_07_energy-use_2011-04-25.pdf

	Item	Description	Data Source
	Interior Lighting Schedule	See Appendix A.4	
	Internal Gains		
	Load (Btu/day)	17,900 + 23.8 x CFA + 4104 x Nbr See under '4.3 Internal Gains' for the detailed calculations	Reference: IECC 2006 and Building America Research Benchmark
	Internal gains Schedule(s)	See Appendix A.4	
	Occupancy		
	Number of people	3	
	Occupancy Schedule	See Appendix A.4	
	Exterior Lighting		
	Annual Energy (kWh)	348 for the 2006 IECC	Reference: 2010 Building America House Simulation Prototcols
	Exterior lighting Schedule	See Appendix A.4	
	Garage Lighting		
	Annual Energy (kWh)	40 for the 2006 IECC	Reference: 2010 Building America House Simulation Prototcols
	Garage Lighting Schedule	See Appendix A.4	

A.2 Multifamily Prototype Modeling Description

	Item	Description	Data Source
General			
	Vintage	New Construction	
	Location	See under '2.2 Climate Locations'	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Available Fuel Types	Natural Gas/Electricity/Fuel Oil	
	Building Type	Residential	
	Building Prototype	Low-rise Multifamily	
Form			
	Total Floor Area	Whole Building- 23,400 sq.ft Each Dwelling Unit - 1200 sq.ft	
	Building Shape		Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Aspect Ratio	Whole Building- 1.85 Each Dwelling Unit - 1.33	
	Number of Floors	3	
	Number of Units per Floor	6	
	Orientation	Back of the house faces North (see image)	
	Dimensions	Whole Building - 120' x 65' x 25'6" Each Dwelling Unit - 40' x 30' x 8'6"	
	Conditioned Floor Area	Each Dwelling Unit- 1200 sq.ft	

	Item	Description	Data Source
	Window Area (Window-to- Exterior Wall Ratio)	23% WWR (Does not include breezeway walls)	
	Exterior Door Area	Each Dwelling Unit - 21 sq.ft Whole Building - 378 sq.ft	
	Shading Geometry	None	
	Thermal Zoning	Each floor has 6 dwelling units with a breezeway in the center. Each dwelling unit is modeled as a separate zone. The other thermal zones are: attic, breezeway and foundation (basements and crawlspace only) 	
	Floor to ceiling height	8.5’	
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2x4 16" O.C. or 2x6 24" O.C.) 1" Stucco + Building Paper Felt + Insulating Sheathing (if applicable) + 5/8" Oriented Strand Board + Wall Insulation + 1/2" Drywall	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Wood Frame Wall R-Value	IECC
	Dimensions	Each Dwelling Unit: 40' x 8'6" and 30' x 8'6"	
	Tilts and orientations	Vertical	
	Roof		

	Item	Description	Data Source
	Construction	Asphalt Shingles	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Ceiling R value	IECC
	Tilts and orientations	Gabled Roof with a Slope of 4/12	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below.	
	U-factor (Btu / h * ft^2 * °F)	IECC Requirements Fenestration U-Factor & SHGC	
	SHGC (all)		
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Four Foundation Types are Modeled- i. Slab-on Grade ii. Vented Crawlspace Depth 2' iii. Heated Basement - Depth 7' iv. Unheated Basement- Depth 7'	Reference: Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes
	Insulation level	IECC Requirements for floors, slabs and basement walls	
	Dimensions	based on floor area and aspect ratio	
	Internal Mass	8 lbs/ft2 of floor area	IECC 2006 section 404

	Item	Description	Data Source
	Infiltration (ACH)	2006 IECC: 8 Air Changes/Hour at 50 Pa 2009 IECC: 7 Air Changes/Hour at 50 Pa 2012 IECC: 5 or 3 Air Changes/Hour at 50 Pa depending on climate zone	
HVAC			
	System Type		
	Heating type	Four Heating System Types are Modeled- i. Gas Furnace ii. Oil Furnace iii. Electric Furnace iv. Heat Pump	
	Cooling type	Central DX Air-Conditioner/Heat Pump (1 per unit)	
	HVAC Sizing		
	Cooling	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		
	Air Conditioning	SEER 13	Federal Minimum Equipment Efficiency for Air Conditioners and Condensing Units
	Heating	AFUE 78% / HSPF 7.7	Federal Minimum Equipment Efficiency
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/72°F Heating	
	Thermostat Setback	No setback	
	Supply air temperature	Maximum 110 F, Minimum 52 F	
	Ventilation	45 CFM Outdoor Air per dwelling unit; Continuous Supply	2012 International Mechanical Code (IMC)
	Supply Fan		
	Fan schedules	See Appendix A.4	

	Item	Description	Data Source
	Supply Fan Total Efficiency (%)	Fan efficiency 58%; Motor efficiency 65% (PSC motor)	Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document[1]
	Supply Fan Pressure Drop	1.6" w.g.	
	Service Water Heating		
	SWH type	Individual Residential Water Heater with Storage Tank	
	Fuel type	Natural Gas / Electricity	
	Thermal efficiency (%)	EF = 0.59 for Gas-fired Water Heaters EF = 0.917 for Electric Water Heaters	Federal Minimum Equipment Efficiency
	Tank Volume (gal)	40	
	Water temperature set-point	120 F	
	Schedules	See Appendix A.4	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	Dwelling unit units: Lighting Power Density is 0.82 W/sq.ft (For interior lighting) for the 2006 IECC See '4.4 Lighting' for the detailed calculations	2010 Building America House Simulation Prototcols
	Interior Lighting Schedule	See Appendix A.4	
	Internal Gains		
	Internal Gains (Btu/day per Dwelling Unit)	17,900 + 23.8 x CFA + 4104 x N_{br} See '4.3 Internal Gains' for the detailed calculations	

[1] Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document: Chapter 7 'Energy Use Characterization' Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document

	Item	Description	Data Source
	Internal Gains Schedule(s)	See under Appendix A.4	
	Occupancy		
	Average people	2	
	Occupancy Schedule	See Appendix A.4	
Misc.			
	Exterior Lighting		
	Annual energy (kWh)	174 for the 2006 IECC	
	Exterior Lighting Schedule	See Appendix A.4	
	Garage Lighting		
	Annual energy (kWh)	24 for the 2006 IECC	
	Garage Lighting Schedule	See Appendix A.4	

A.3 Internal Gains Assumptions

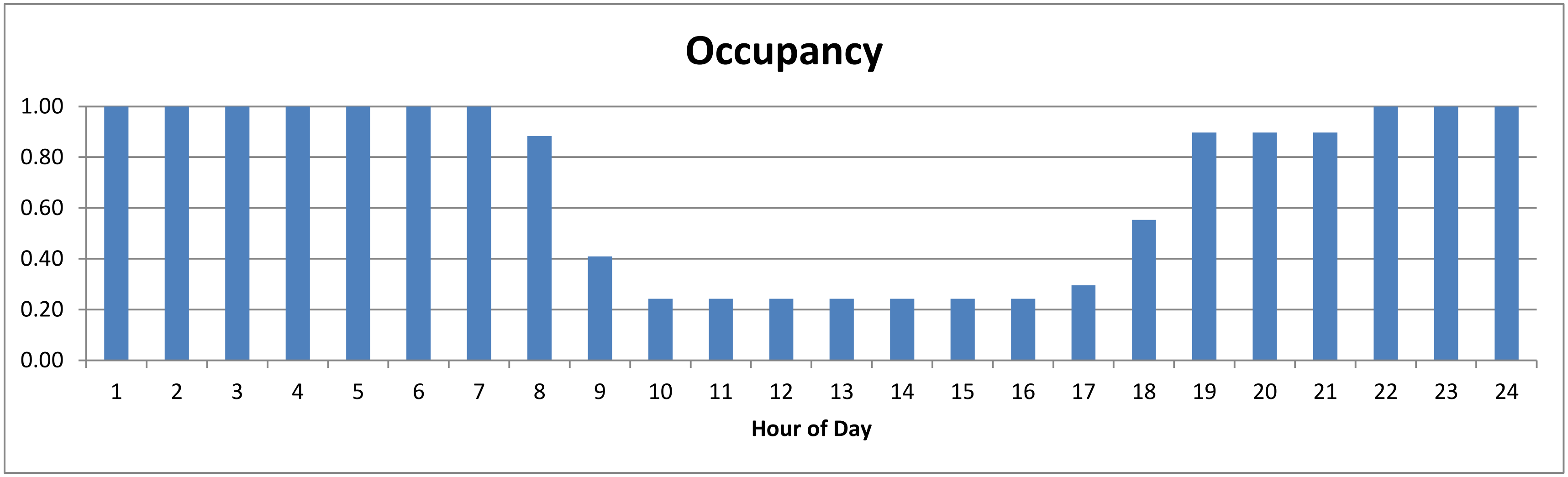
A.3.1 Total Internal Gains for the single-family prototype for the 2006, 2009 and 2012 IECC

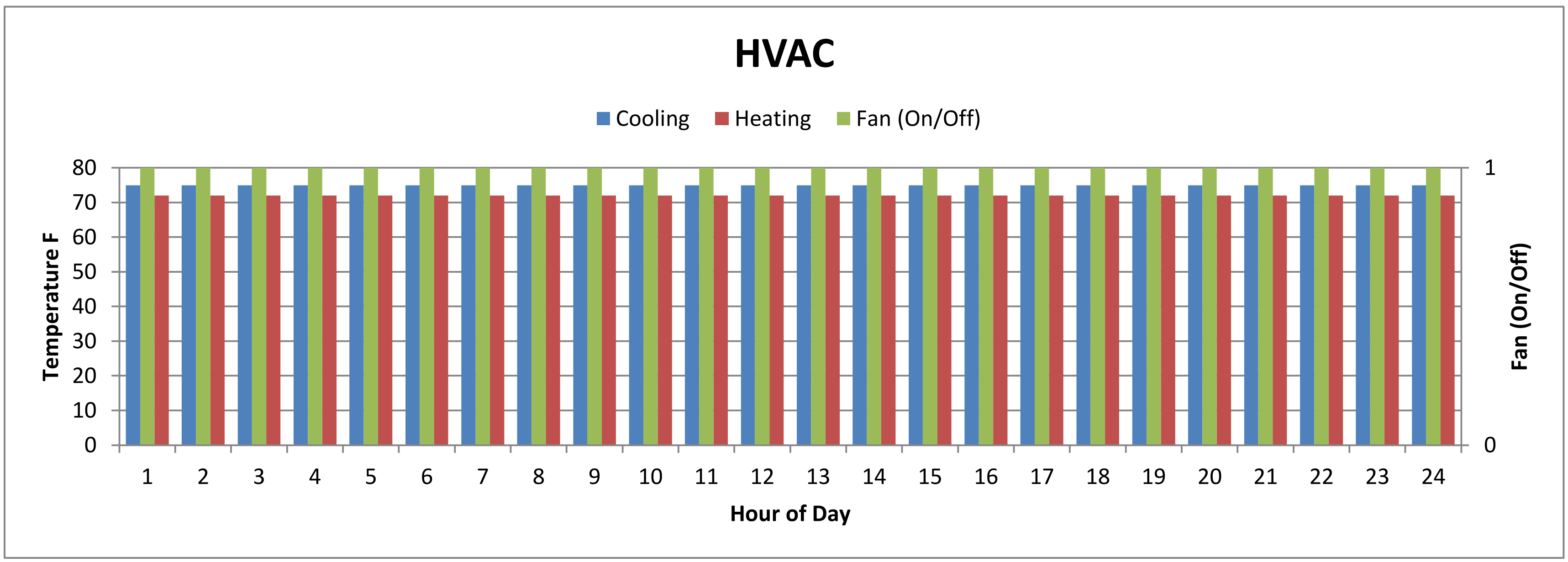
Appliance	**Power**	**Total Electricity (kWh/yr)**	**Fraction Sensible**	**Fraction Latent**	**Fraction of electricity use not turned into heat**	**Internal Heat Gains (kWh/yr)**		
						2006 IECC	**2009 IECC**	**2012 IECC**
Refrigerator	91.09 W	668.90	1.00	0.00	0.00	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.20	87	87	87
Clothes Dryer	222.11 W	868.15	0.15	0.05	0.80	174	174	174
Dishwasher	68.33 W	214.16	0.60	0.15	0.25	161	161	161
Range	248.97 W	604.90	0.40	0.30	0.30	423	423	423
Misc. Plug Load	0.228 W/sq.ft	3238.13	0.69	0.06	0.25	2429	2429	2429
Miscellaneous Electric Loads	182.5 W	1598.00	0.69	0.06	0.25	1199	1199	1199
IECC adjustment factor	0.0275 W/sq.ft	390.56	0.69	0.06	0.25	293	293	293
Lighting			1.00	0.00	0.00	1635	1345	1164
Occupants	3 Occupants					2123	2123	2123
Total					**kWh/yr**	**9192**	**8902**	**8721**
					kBtu/yr	**31362**	**30373**	**29755**
					Btu/day	**85924**	**83213**	**81522**

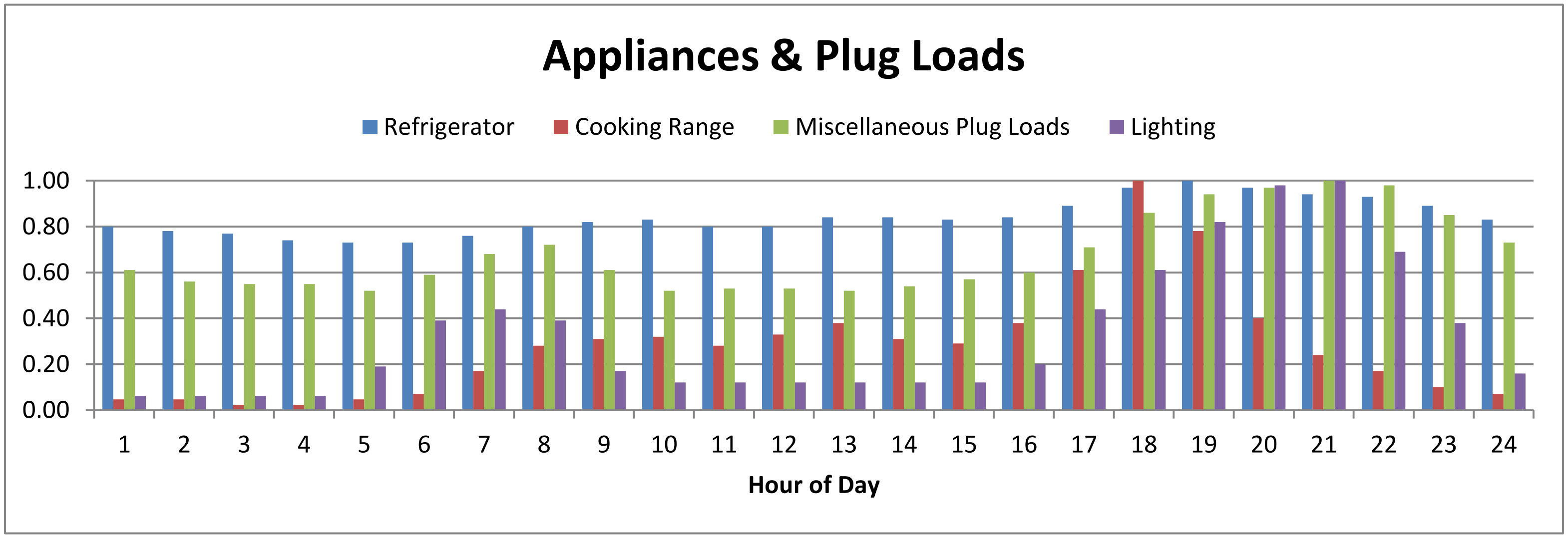
A.3.2 Total Internal Gains for the multifamily prototype for the 2006, 2009 and 2012 IECC (per dwelling unit)

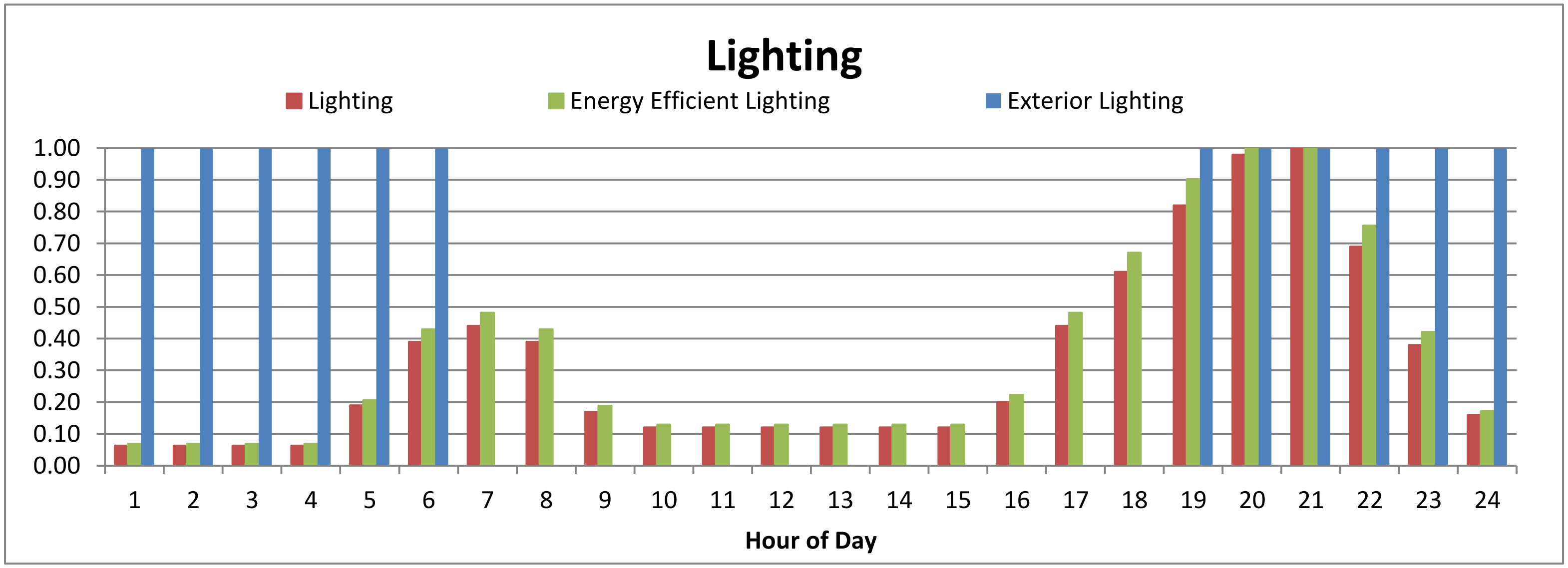
Appliance	Power	Total Electricity (kWh/yr)	Fraction Sensible	Fraction Latent	Fraction of electricity use not turned into heat	Internal Heat Gains (kWh/yr)		
						2006 IECC	2009 IECC	2012 IECC
Refrigerator	91.09 W	668.90	1.00	0.00	0	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.2	87	87	87
Clothes Dryer	222.11 W	868.15	0.15	0.05	0.8	174	174	174
Dishwasher	68.33 W	214.16	0.60	0.15	0.25	161	161	161
Range	248.97 W	604.00	0.40	0.30	0.3	423	423	423
Misc. Plug Load	0.228 W/sq.ft	1619.00	0.69	0.06	0.25	1214	1214	1214
Miscellaneous Electric Loads	121.88 W	1067.00	0.69	0.06	0.25	800	800	800
IECC adjustment factor	0.0275 W/sq.ft	195.28	0.69	0.06	0.25	146	146	146
Lighting			1.00	0.00	0	493	405	351
Occupants	2 Occupants					1416	1416	1416
Total					**kWh/yr**	**5582**	**5495**	**5440**
					kBtu/yr	**19046**	**18748**	**18562**
					Btu/Day	**52181**	**51364**	**50855**

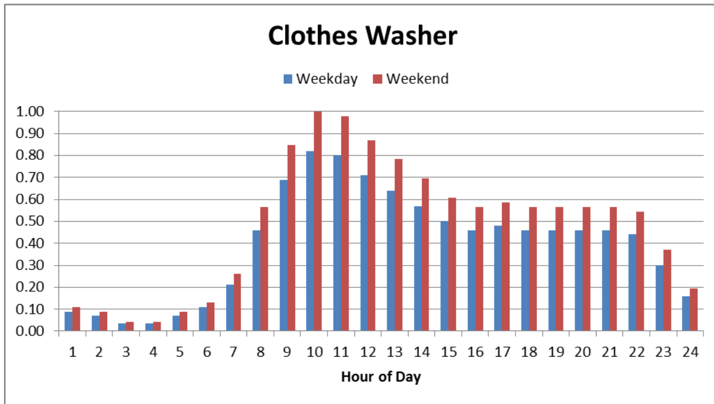
A.4 Schedules

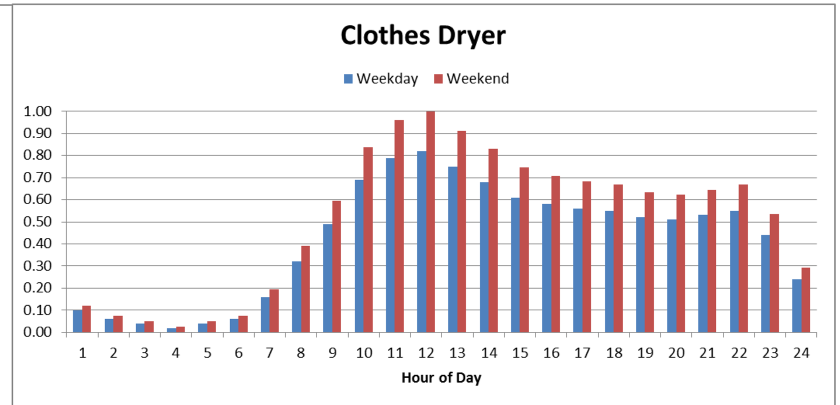


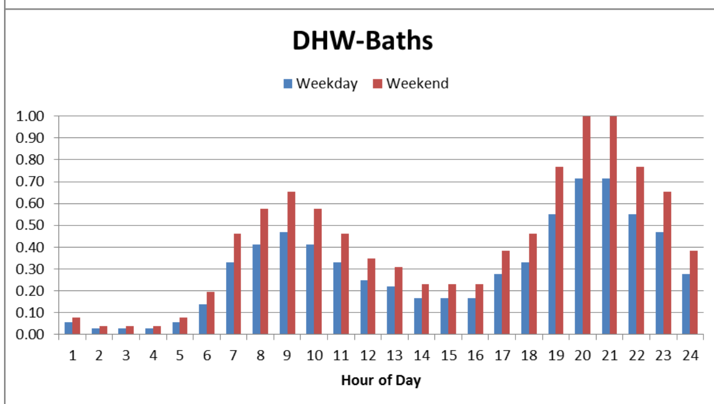


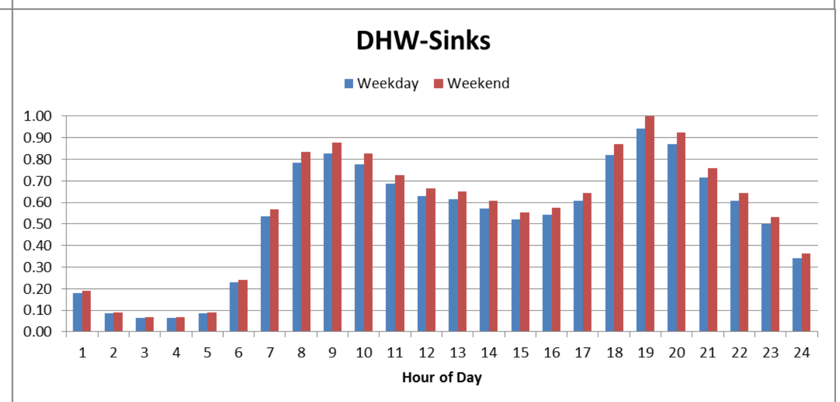

Appliances & Plug Loads
Refrigerator
Cooking Range
Miscellaneous Plug Loads
Lighting
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

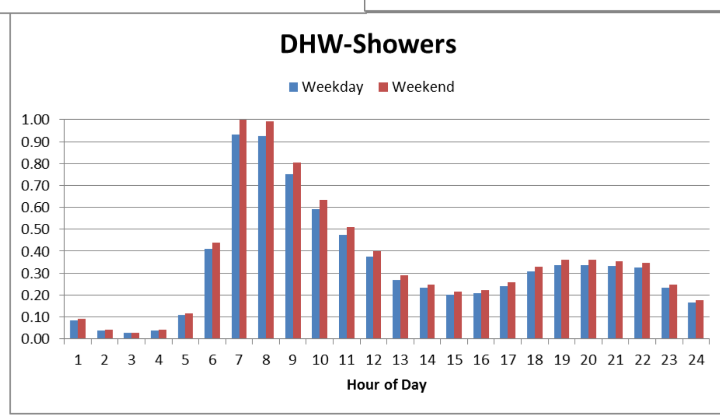

Lighting
Lighting
Energy Efficient Lighting
Exterior Lighting
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


Clothes Washer
Weekday
Weekend
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


Clothes Dryer
Weekday
Weekend
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


DHW-Baths
Weekday
Weekend
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


DHW-Sinks
Weekday
Weekend
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day


DHW-Showers
Weekday
Weekend
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day

Appendix B

Major Prescriptive Code Requirements for the 2006 IECC, the 2009 IECC, and the 2012 IECC

Table B.1.

Climate Zone	IECC	Components: Ceiling (R-value)	Skylight (U-factor)	Fenestration (Windows and Doors): U-factor	Fenestration (Windows and Doors): SHGC	Wood Frame Wall (R-value)	Mass Wall[a] (R-value)	Floor (R-value)	Basement Wall[b] (R-value)	Tested Max Air Leakage Rate (air changes per hour)	Slab[c] (R-value and depth)	Crawl Space[b] (R-value)
	2006				0.4					NR		
1	2009	30	0.75	NR	0.3	13	3/4	13	NR	NR	NR	NR
	2012				0.25					5		
	2006	30	0.75	0.75	0.4					NR		
2	2009	30	0.75	0.65	0.3	13	4/6	13	NR	NR	NR	NR
	2012	38	0.65	0.4	0.25					5		
	2006	30	0.65	0.65	0.4	13	5/8		0	NR		
3	2009	30	0.65	0.5	0.3	13	5/8	19	5/13[d]	NR	NR	5/13
	2012	38	0.55	0.35	0.25	20	8/13		5/13[d]	3		
	2006	38	0.6	0.4	NR	13	5/13		10/13	NR		10/13
4	2009	38	0.6	0.35		13	5/10	19	10/13	NR	10, 2 ft	10/13
	2012	49	0.55	0.35	0.4	20	8/13		10/13	3		10/13
	2006	38	0.6	0.35		19	13/19		10/13	NR		10/13
5	2009	38	0.6	0.35	NR	20	13/17	30	10/13	NR	10, 2 ft	10/13
	2012	49	0.55	0.32		20	15/19		15/19	3		15/19
	2006		0.6	0.35		19	10/13		10/13	NR		10/13
6	2009	49	0.6	0.35	NR	20	15/19	30	15/19	NR	10, 4 ft	10/13
	2012		0.55	0.32		20+5	15/19		15/19	3		15/19
	2006		0.6	0.35		21		30	10/13	NR		10/13
7 and 8	2009	49	0.6	0.35	NR	21	19/21	38	15/19	NR	10, 4 ft	10/13
	2012		0.55	0.32		20+5		38	15/19	3		15/19

(a) The second number applies when more than half the insulation is on the interior side of the high mass material in the wall.
(b) The first number is for continuous insulation (e.g., a board or blanket directly on the foundation wall) and the second number is for cavity insulation (i.e., if there is a furred-out wall built against the foundation wall). Only one of these two has to be met.
(c) The first number is R-value. The second value refers to the vertical depth of the insulation around the perimeter.
(d) Basement wall insulation is not required in the warm-humid region of Zone 3 in the southeastern United States.
IECC = International Energy Conservation Code.
NR = Not required.
SHGC = Solar heat gain coefficient.

Appendix C

Custom State Requirements and Analyses

Appendix C

Custom State Requirements and Analyses

C.1 Introduction

Not at all states adopt the International Energy Conservation Code (IECC) without any modifications. Some states adopt modified versions of the IECC. Pacific Northwest National Laboratory conducted customized state analyses for the District of Columbia, Georgia, Michigan, Minnesota, Montana, Oklahoma, Virginia, Vermont, and Wisconsin to account for changes that these states made to the IECC in their existing code. This section describes the customizations analyzed for each state. The EnergyPlus models and output files and the state cost-effectiveness reports for all the above states are available for download on the energy codes website.[1, 2]

C.2 District of Columbia

The District of Columbia Energy Conservation Code is an amended version of the 2009 IECC with the following changes:

- The DC Energy Conservation Code requires R-18 above-grade wall insulation. The DC Energy Conservation Code requires R-49 ceiling insulation, which is more stringent than the 2012 IECC ceiling insulation requirements.
- The DC Energy Conservation Code requires R-2 hot water piping insulation.

C.3 Georgia

Georgia has three climate zones (climate zones 2, 3, and 4) as defined by the IECC. The Georgia State Code is an amended version of the 2009 IECC. This analysis assesses the cost effectiveness of the 2012 IECC over the Georgia state energy code. Table C.1 below summarizes prescriptive requirements of the Georgia code that contain differences to the 2009 IECC.

Table C.1. Residential Prescriptive Code Requirements for the State of Georgia

Climate Zone	Fenestration U-Factor (Btu/hr-ft^2-F)	Fenestration SHGC	Slab Insulation R-value and Insulation Depth
2	0.5	0.3	0
3	0.5	0.3	0
4	0.35	0.3	0

[1] EnergyPlus models and output files – http://www.energycodes.gov/development/residential/iecc_models.
[2] State Cost-effectiveness Reports – http://www.energycodes.gov/development/residential/iecc_analysis.

Additionally, the Georgia code does not explicitly mention the exception for basement wall insulation in warm-humid climates. Thus, the analysis assumes that basement wall insulation is required by the state code in the representative warm-humid location of Macon. Georgia also does not allow the use of electric resistance as the primary heating source. To address this prohibition, electric resistance heating is not analyzed for Georgia and the weights for electric resistance heat are reassigned proportionally to natural gas heating and heat pumps during the aggregation process.

C.4 Michigan

Michigan has three climate zones (climate zones 5, 6, and 7) as defined by the IECC. The Michigan Uniform Energy Code is based on the 2009 IECC but does not require duct pressure testing. This analysis assesses the cost effectiveness of the 2012 IECC over the Michigan state energy code by accounting for the savings and incremental costs for duct sealing requirements in 2012 IECC.

C.5 Minnesota

Minnesota has two climate zones (climate zones 6 and 7) as defined by the IECC. The Minnesota State code is similar to the 2006 IECC but it requires R-38 ceiling insulation in climate zone 6 and R-44 in climate zone 7. It also requires R-19 above grade wall insulation in climate zone 7. The 2006 IECC has more stringent ceiling and above grade wall insulation requirements than the Minnesota state code. This analysis assesses the cost effectiveness of the 2009 and 2012 IECC over the Minnesota state code.

There is some evidence that the typical envelope leakage rates achieved by builders in Minnesota are lower than the assumed 8 50-Pa pressure differential (ACH50) for the 2006 IECC. A proposed code change (RE-12) to the 1322 Advisory Committee for the State of Minnesota in 2012 from the Builders Association of Minnesota reports that recently built homes in Minnesota had an average air leakage of 1.7 ACH50, substantially better than required by any version of the IECC. Additional analysis is conducted assuming 1.7 ACH50 rate for the current Minnesota state code, the 2009 IECC, and the 2012 IECC.

C.6 Montana

Montana has only one climate zone (climate zone 6) as defined by the IECC. The Montana State energy code is based on the 2009 IECC with some minor modifications. It requires a fenestration U-factor of 0.33 Btu/hr-ft^2-F and R-21 above grade wall insulation. These requirements are more stringent than the fenestration and above grade wall insulation requirements in the 2009 IECC. This analysis assesses the cost effectiveness of the 2012 IECC over the Montana State energy code.

C.7 Oklahoma

Oklahoma has two climate zones (climate zone 3 and 4) as defined by the IECC. Oklahoma has adopted the 2009 International Residential Code (IRC). The 2009 IRC requires a glazed fenestration solar heat gain coefficient (SHGC) of 0.35 in climate zone 3. This glazed fenestration SHGC requirement for climate zone 3 is 0.30 in the 2009 IECC. This analysis assesses the cost effectiveness of the 2012 IECC over the Oklahoma state energy code.

C.8 Virginia

Virginia has only one climate zone (climate zone 4) as defined by the IECC. The Virginia state code is based on the 2009 IECC but does not require duct pressure testing. This analysis assesses the cost effectiveness of the 2012 IECC over the Virginia state energy code by assuming no savings and no incremental costs from duct sealing requirement in 2009 IECC.

C.9 Vermont

Vermont has only one climate zone (climate zone 6) as defined by the IECC. The Vermont state energy code is based on the 2009 IECC with a number of modifications. The Vermont Energy Code has four packages in the "Fast Track" compliance method. This analysis assesses the cost effectiveness of the 2012 IECC over package 1 of the Vermont State Energy Code, which has many of the same prescriptive requirements as the 2009 IECC but with a few differences. This analysis accounts for the following modifications to the 2009 IECC:

- The fenestration U-factor requirement in the Vermont Energy Code is 0.32 instead of the 2009 IECC requirement of 0.35.
- Slab perimeter insulation is required to be R-15 instead of the IECC's R-10.
- The maximum allowable duct leakage rates are lower than allowed by the 2009 IECC.

The Vermont code requires mechanical ventilation with fan capacity dependent on whether the system is flow tested. If the flow-rate is verified by testing, the Vermont code would require a 60-cubic feet per minute (cfm) fan for the three-bedroom home analyzed here. An untested system would have to be rated at 100 cfm. This analysis assumes 60 cfm ventilation rate for the Vermont code for a single-family home and 45 cfm for the multifamily building because it results in conservatively low estimates of energy savings and cost effectiveness for the 2012 IECC. The 2012 IECC also requires mechanical ventilation and the same ventilation rates are assumed for the 2012 IECC as for the state code.

The Vermont Energy Code has other differences from the IECC, such as special requirements for log homes and combustion safety requirements. Additionally, the fast track methods cannot be used if the glazing area is greater than 20% of the wall area. These differences are not examined in this analysis.

C.10 Wisconsin

Wisconsin has two climate zones (climate zone 6 and 7) as defined by the IECC. The Wisconsin State energy code is equivalent to the 2006 IECC with the following modifications:

- The 2006 IECC requires U-0.35 glazed fenestration whereas the Wisconsin state code requires U-0.30 glazed fenestration.
- The 2006 IECC requires R-10 basement walls whereas the Wisconsin state code requires R-15 basement walls.
- The 2006 IECC requires R-19 above-grade walls in Zone 6 and R-21 in Zone 7 whereas the Wisconsin state code requires R-21 above-grade walls for the entire state

This analysis assesses the cost effectiveness of the 2009 and 2012 IECC over the Wisconsin State Energy Code.

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

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