U.S. DEPARTMENT OF ENERGY

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

Limited Distribution
PNNL-19367

An Estimate of Residential Energy Savings From IECC Change Proposals Recommended for Approval at the ICC's Fall, 2009, Initial Action Hearings

ZT Taylor
RG Lucas

May 2010

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Limited Distribution
PNNL-19367

An Estimate of Residential Energy Savings From IECC Change Proposals Recommended for Approval at the ICC's Fall, 2009, Initial Action Hearings

ZT Taylor
RG Lucas

May 2010

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

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

The U.S. Department of Energy (DOE) has established ambitious goals to improve the energy efficiency requirements of the International Code Council (ICC) International Energy Conservation Code (IECC) for residential buildings.[1] DOE has established near- and long-term goals of 30% and 50% energy efficiency improvements, respectively, compared to the 2006 IECC.

This report presents the Department's approach to calculating residential energy consumption for the purpose of estimating energy savings attributable to improvements in the code. This approach is then used to estimate the national average energy savings, relative to the 2006 IECC, resulting from the proposed improvements DOE has submitted and is supporting for the 2012 IECC. **DOE estimates a total reduction in energy use of 30.6%** for the projected requirements[2] of the 2012 IECC as compared to the 2006 IECC, assuming the use of the primary compliance option that involves standard-efficiency equipment. Were the high-equipment efficiency option used, the projected savings would be 0.9% higher, at 31.5%.

This report covers only anticipated savings should the code change proposals recommended for approval in the International Code Council's (ICC's) Initial Action hearings prevail at the Final Action hearings scheduled for October-November, 2010.

[1] Residential buildings in the IECC are one- and two-family attached and detached homes, townhouses, modular homes and multi-family buildings (condominiums, cooperatives, apartments) three stories or less in height.

[2] Projected requirements are those DOE believes, based on the outcome of the first of two public hearings on proposed changes to the 2009 IECC, are likely to be approved at the second hearing in October 2010 by the ICC governmental membership for inclusion in the 2012 IECC.

Table of Contents

Summary ... iii
Overall Framework for Estimating Impacts ... 1
  Code Compliance Approach ... 1
  Time Window ... 2
  Energy Consumption Metric ... 3
  End Use Baseline ... 4
Building Energy Use Simulation Assumptions and Methodology ... 7
  Prototypes ... 7
  Weather Locations ... 8
  Default Assumptions ... 10
Weighting Factors ... 11
  Building Types ... 11
  Foundation Types ... 11
  Equipment/Fuel Types and Energy Costs ... 12
  Air Duct Systems ... 12
  Envelope Air Leakage ... 13
  Mechanical Ventilation ... 14
Calculation of Energy Savings from Projected Requirements of the 2012 IECC ... 17
  Energy Cost Savings for Single-Family Housing ... 19
  Energy Cost Savings for Multifamily Housing ... 20
  Combined National Average Energy Savings ... 21
  Energy Savings by Foundation Type ... 21
References ... 23
Appendix - Calculating Energy Savings from New Code Provisions that Expand the Scope of the Code ... A-1

Figures

Figure 1. Energy Cost Savings (%) by Climate Zone – Single Family 19
Figure 2. Energy Cost Savings (%) by Climate Zone – Multifamily 21
Figure 3. Percent Energy Savings by Foundation Type 22
Figure A- 1. Illustration of Energy Savings from a Code Change................................. A-2

Tables

Table 1. Single-Family Prototype Characteristics 7
Table 2. Housing Start Shares by Climate Zone.. 9
Table 3. Climate Locations Used in Energy Simulations with 9
Table 4. Building Type Shares (percent) 11
Table 5. Foundation Type Shares (percent) by Census Zone 11
Table 6. Foundation Type Shares (percent) by 2006 IECC Climate Zone 12
Table 7. Annual Energy Cost Impacts of Exhaust Only Ventilation 15
Table 8. Code Improvements in the Projected 2012 18
Table 9. Energy Cost Savings (%) by Climate Zone Representative Cities 20

Overall Framework for Estimating Impacts

DOE's 30% savings goal is a simple metric that tracks progress of improvements and enhancements to the IECC that involve a complex set of interacting phenomena. It attempts to summarize in a single number the impact of changing a code with multiple compliance paths, involving numerous building components and systems with dissimilar useful lives, and affecting homes heated and cooled with various fuel types and built on various foundation types. Further, code changes can have multiple impacts (e.g., energy consumption, carbon releases) and some changes can expand the scope (in terms of energy end uses) of the code. It is therefore necessary to explain the primary assumptions behind the simple percent-savings metric reported here. The four major assumptions involved are:

- *Code compliance approach*. The prescriptive method based on Table 402.1.1 of the 2006 (and 2009) IECC is used. Energy savings may vary to some degree if the simulated performance or U/UA compliance approaches were used.
- *Time window*. The time window covered by the calculation of energy savings is a 1-year period after construction. This mirrors the approach currently used in the IECC's simulated performance approach for determining code compliance. This methodology will not account for long-term energy use impacts associated with the different life times of energy conservation measures (for example, light bulbs, windows, air conditioners).
- *Energy consumption metric*. Annual energy cost has been selected as the metric. While energy cost is not a direct measure of energy use, it:
    - is the metric used in the IECC simulated performance alternative,
    - is the metric most relevant to consumers (home occupants), and
    - is an adequate proxy for total (source) energy use.
- *Energy end uses considered in the percent savings calculation*. This methodology calculates IECC energy cost savings as a percentage of the energy end uses in the scope of the 2006 IECC.

These assumptions are documented in more detail below.

Code Compliance Approach

DOE Assumption: The *prescriptive (R-value) compliance path* is used.

Discussion: The IECC offers several compliance paths that give the code user flexibility in building a home that will comply with the code's intent. The simplest but least flexible approach is prescriptive in nature, listing specific requirements for individual building components. The major requirements of the prescriptive approach are given in

Table 402.1.1 of the IECC, which contains the insulation R-value (thermal resistance) and fenestration U-factor (thermal transmittance) and solar heat gain coefficient (SHGC) requirements. Other notable requirements relate to sealing the envelope to minimize infiltration, sealing ducts to limit air leakage, and insulating ducts to limit conductive heat losses and gains.

Simple alternatives to the prescriptive approach include a U-factor alternative for each opaque building assembly (wall, floor, roof/ceiling) and a total UA alternative for the entire building thermal envelope, both of which allow more flexibility in meeting building thermal envelope insulation requirements. The performance approach in Section 404 of the 2006 IECC (Section 405 of the 2009 IECC) takes this a step further, allowing almost unlimited flexibility in allowing compliance of any home with an estimated annual energy use equal to or lower than that assuming the subject home were built to just satisfy the minimum prescriptive requirements.

The analysis in this report uses the prescriptive (R-value) requirements because these provide the simplest and clearest basis for comparison when examining code improvements. Using any of the alternative compliance options would require selecting from among the almost unlimited configurations permitted by those paths, which would substantially complicate the analysis without necessarily improving the result. Moreover, because the prescriptive requirements form the foundation for all the thermal requirements, it is logical to use them for this analysis. It is assumed that the requirements of the various compliance approaches in the IECC are generally consistent with one another because they have the same underlying basis. However, in part because of the different nature of the compliance approaches, energy use comparisons of the different code editions could give modestly different results.

Time Window

DOE Assumption: DOE will account for energy savings over a *1-year period immediately after construction*.

Discussion: Possible time windows include first-year energy savings or savings occurring over various periods of analysis. Analysis periods might be chosen to represent the life of the home (50+ years), the life of a typical home mortgage (30 years), or the life of key energy-saving measures (e.g., 10 years for water heating equipment, 15 years for heating, ventilation, and air-conditioning (HVAC) equipment, longer periods for most envelope measures).

Assessing savings in terms of first-year energy consumption is the most straightforward approach. It avoids issues of measure life altogether and requires the simplest calculation. However, in doing so it effectively assumes that the energy performance of the building today will be maintained indefinitely. It is equivalent to assuming that all measures have infinite life or that, when replaced, they will be replaced with identically performing products.

Assessing savings over the life of the efficiency measures involved, while more accurate in accounting for long-term energy impacts, is complicated in several ways. First, it requires some prognostication about future replacements. For example, if low-solar gain windows are installed today, will that influence the SHGC of future replacements? If the code allows insulation R-values to be traded down for high-efficiency equipment, will future equipment replacements be proportionally more efficient than they otherwise would be? Second, the expected life of efficiency measures is not always directly controlled by the code. For example, while the code may mandate a particular ceiling R-value at the time of construction, it makes no distinction between products, even if some may be subject to R-value degradation over time. Finally, accounting for performance over time implies the need to account for maintenance-related performance degradation that may impact some efficiency measures. While it may be reasonable to assume that some measures will degrade, the magnitude of such degradation often depends on how well a homeowner maintains the home, and requires some guesswork to assemble such assumptions.

Energy Consumption Metric

DOE Assumption: DOE has chosen *energy cost* as the metric for comparison.

Discussion: The *metric* refers to the quantity used in the percent-savings calculations. Different metrics can give different savings percentages when more than one energy source is used in a home (most commonly, electricity and natural gas are used for cooling and heating, respectively). Possible metrics include site energy use, source energy use, energy cost, or even a predefined metric such as a home energy rating system (HERS) score.

None of the potential metrics is without drawbacks. Site energy is the most straightforward to calculate, but ignores the significant differences in conversion efficiency between major energy sources and the related differences in emissions of carbon and other pollutants associated with those sources. It is similarly removed from the common experience of homeowners and renters, often placing too little importance on cooling costs in hot climates.

Using source energy in the calculations solves most of the problems associated with site energy and in many ways is DOE's preferred metric. However, it can be difficult and controversial to select appropriate source-site conversion efficiencies. Regional differences in the source(s) for electricity generation, for example, can vary significantly and some sources (e.g., hydro, wind) defy identification of a defensible conversion efficiency.

DOE has selected energy cost as a reasonable surrogate for source energy. It is a familiar metric that the IECC specifies for its performance compliance path, it captures the major regional variations in source-site efficiency and, because it relates reasonably to the experience of homeowners, provides a reasonable basis for evaluating the cost-effectiveness of potential code changes. Its primary disadvantage is the temporal instability of fuel prices, which could potentially render an improvement deemed successful in achieving the goal in 1 year unsuccessful in the next (or vice-versa). A second disadvantage is that energy cost includes expenditures other than for energy consumption, such as local infrastructure costs and investments, profits to investor-owned utilities, etc. However, when fuel prices are taken at aggregate levels (e.g., state averages), calculated energy costs are a sufficient and convenient metric for this analysis.

End Use Baseline

DOE Assumption: DOE will use the energy *end uses covered by the 2006 IECC* as the baseline for its comparisons.

Discussion: The *end use baseline* refers to the level of the savings metric used in the denominator of the percent-savings calculation. It answers the question, "percent better than what?" Possible baseline definitions include whole-house energy cost, the portion of energy cost regulated by the 2006 IECC, or the portion of energy cost regulated by a future version of the IECC. These differ in the way progress toward the 30% or 50% goal is impacted by changes in the scope of the IECC. The scope of the provisions of the 2006 IECC that apply to residential buildings is essentially limited to heating, cooling, and water heating. A key example of a scope expansion is the 2009 IECC's addition of lighting requirements for residential buildings.

The most stable baseline would be whole-house energy cost, which would provide for an unchanging baseline as energy savings progresses toward DOE's goal(s), even in the face of IECC scope expansions. However, including all energy end uses in the baseline is problematic because many end uses cannot plausibly be regulated by a building construction code. Appliances and electronic equipment (televisions, computers, etc.) that are not permanently attached to the home are generally not included as part of a new home and, even if they are, can be swapped out at will by homeowners or to a lesser degree by renters. Therefore, under a whole-house baseline metric, achieving 30% improvement requires improving the end uses actually regulated by the code by more than 30%. In some mild climates (for example, Hawaii), this can be very difficult if not nearly impossible because so little of a home's energy consumption is attributable to heating and cooling. Further, defining baseline efficiency levels for appliances and end uses that have no requirements in the 2006 IECC can be difficult, requiring identification of typical practice or some other surrogate for what the 2006 code implied. However, as discussed in the appendix, typical practice differs from minimum code, and using it as baseline for those out-of-scope elements represents a philosophical departure from how the in-scope improvements are accounted for. Conversely, assuming the worst possible efficiency level for an end use unregulated by the 2006 code can lead to artificially high percent-savings values.

A second possible baseline definition would include all end uses that are in the scope of any newer version of the IECC. For example, the 2009 IECC percent savings calculation would include lighting in the denominator, with the nonexistent lighting requirements of the 2006 IECC estimated based on what is found to be standard practice. This scheme potentially changes the baseline with every expansion of scope in the code. This presents two potential problems. First, it muddies the presentation of progress toward DOE's goals because the addition of a new end use to the code's scope can potentially *lower* the overall percent savings value, even if the scope expansion saves energy. While the effect may be small for conceivable new scope additions, as the code progresses toward 50% improvement, the smaller end uses will represent an increasingly larger fraction of overall energy consumption. Second, expanding the code's scope doesn't necessarily establish minimum code requirements for the new end use that exceed prior typical practice. For example, if a particular appliance—say refrigerators—were added to the code's scope, with a minimum efficiency requirement that was *lower than average* but higher than the worst available refrigerators, the new code would save energy by eliminating the low-end products, even with a requirement that was below average.

A third option is to define the baseline in terms of the end uses in scope of the 2006 IECC, but account for *all* savings, including those related to scope expansions, in the numerator. This approach results in an oddly defined "percent improvement" value, and retains some of the problems of identifying end use baselines for expanded scope elements, but guarantees a meaningful way to track progress through time and across scope changes. Each scope expansion can be dealt with independently to fairly estimate its true impact on affected homes, without requiring an up-front definition of the baseline consumption of all end uses.

Because DOE's 30% and 50% goals are primarily tools to motivate code improvements and track progress toward substantial increases in residential efficiency in pursuit of DOE's higher goal of net-zero energy buildings, the advantages of a stable, if oddly defined, baseline metric outweigh the potential downsides of a cleaner baseline that could potentially mask the real benefits of expansions in the scope of the code. Because the goals are relative to the 2006 IECC, it seems reasonable to use the end uses covered by that code as that stable baseline.

Building Energy Use Simulation Assumptions and Methodology

The energy performance of most energy-efficiency measures regulated by the IECC can be estimated by computer simulation. DOE uses an hour-by-hour simulation tool to calculate annual energy consumption for relevant end uses. Two prototype buildings are developed—one that exactly complies with the 2006 IECC and an otherwise identical building that exactly complies with the newer IECC version under analysis—and simulated in a variety of locations to estimate the overall (national average) energy impact of the new code. The inputs and assumptions used in those simulations are discussed in this section.

Prototypes

Separate analyses are conducted for single-family and multifamily buildings. The prototypes used in the simulations are intended to represent a typical new one- or two-family home or townhouse and a low-rise multifamily building (apartment, cooperative, or condominium). Four foundation types are examined for single-family homes: vented crawlspace, slab-on-grade, heated basement with wall insulation, and unheated basement with insulation in the floor above the basement. Table 1 shows the assumed characteristics for the single-family prototype.

Table 1. Single-Family Prototype Characteristics

Parameter	Assumption	Notes
Conditioned floor area	2400 ft^2	Characteristics of New Housing, U.S. Census Bureau
Footprint and height	30 ft by 40 ft, two-story, 8.5 ft high ceilings	
Area above unconditioned space	1200 ft^2	Over a vented crawlspace
Area below roof/ceilings	1200 ft^2, 70% with attic, 30% cathedral	
Perimeter length	140 ft	
Gross wall area	2380 ft^2	
Window area (relative to gross wall area)	15%	
Door area	42 ft^2	
Internal gains	91,436 Btu/day	2006 IECC, Section 404
Heating system	Natural gas furnace, 78 annual fuel utilization efficiency (AFUE)	Minimum manufacturing standards. Two-thirds of new houses are heated by natural gas. (Characteristics of New Housing, U.S. Census Bureau)
Cooling system	Central electric air conditioning (AC), 13 seasonal energy efficiency ratio (SEER)	Minimum manufacturing standards
Water heating	Natural gas	

For the multifamily building prototype, U.S. Census data (2006) show that the size and number of dwelling units per building in new construction varies greatly. The median number of dwelling units per building is in the range of 20 to 29 with the median floor area per unit in the range of 1000 to 1199 ft^2. The multifamily prototype characteristics used here are:

- A rectangular two-story building containing dwelling units with 1200 ft^2 of conditioned floor area.
- 600 ft^2 floor area and roof/ceiling area per dwelling unit
- The average exterior wall perimeter per dwelling unit is 43 ft, which is set to a 20 by 23 ft rectangle in the simulations. With 8.5 ft ceilings, the wall area is 731 ft^2 per dwelling unit. The 43 ft perimeter is based on assuming a 20-unit building that is 30-ft wide and 400-ft long, yielding an 860-ft perimeter, which averages 43 ft per dwelling unit. (The dimensions used here represent average values of both middle and end units, yielding a hypothetical dwelling unit with dimensions that do not exactly match the conditioned floor area.)
- 42 ft^2 of exterior door area per dwelling unit
- 54668 Btu/day internal gains per dwelling unit (2006 IECC)
- Window area is estimated at 14% of the conditioned floor area
- The heating, cooling, and water heating systems characteristics are the same as for the single-family prototype (each dwelling unit has its own separate heating and cooling equipment).

Weather Locations

Simulations (and other analyses as appropriate) are conducted in one weather location per climate zone in the code, including a separate location for each moisture regime. Simulation results from the climate zones are weighted based on new residential building permit data for the year 2000 (Census 2000). Table 2 shows the shares of national construction by IECC primary climate zone. More than 90% of the construction occurred in zones 2 through 5. Climate zones 7 and 8 are combined here, because zone 8 (northern Alaska) represents only a tiny fraction of the national construction activity.

Within a climate zone, simulation results from different moisture regimes are weighted based on population densities estimated from USGS Populated Places data. Table 3 shows the climate locations, each of which is represented by a TMY2[1] file. The final column shows the final weight to be applied to each Typical Meteorological Year (TMY2) location, based on a combination of the within-zone weight of the previous column and the by-zone housing starts of Table 3.

[1] See http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/ .

Table 2. Housing Start Shares by Climate Zone

Climate Zone	Percentage of Building Permits
1	2
2	19
3	27
4	19
5	27
6	6
7 & 8	0.3

Table 3. Climate Locations Used in Energy Simulations with Climate Zone and Moisture Regime Weights

Climate Zone	Moisture Regime	Representative Location				Regime Weight within Zone (percent)	Overall Location Weight (percent)
		State	City	HDD(65)*	CDD(65)**		
1	Moist	Florida	Miami	139	4157	100	2
2	Dry	Arizona	Phoenix	1350	4162	17	3.2
	Moist	Texas	Houston	1371	3012	83	15.8
3	Dry	Texas	El Paso	2708	2094	47	12.7
	Marine	California	San Francisco	3005	65	13	3.5
	Moist	Tennessee	Memphis	3082	2118	40	10.8
4	Dry	New Mexico	Albuquerque	4562	941	3	0.6
	Marine	Oregon	Salem	4927	247	10	1.9
	Moist	Maryland	Baltimore	4068	1608	87	16.5
5	Dry	Idaho	Boise	5861	754	13	3.5
	Moist	Illinois	Chicago	5753	989	87	23.5
6	Dry	Montana	Helena	8031	386	11	0.7
	Moist	Vermont	Burlington	7771	388	89	5.3
7		Minnesota	Duluth	9169	223	100	0.2
8		Alaska	Fairbanks	13697	44	100	0.1

* HDD = heating degree-days, base 65F
** CDD = cooling degree-days, base 65F

The locations in Table 3 were selected to be reasonably representative of their respective climate zones by Briggs et al. (2002).

Default Assumptions

Input values for building components that do not differ between the two subject editions of the IECC will be set to match a shared code requirement if one exists, to match standard reference design specifications from the code's performance path if the component has such specifications, or to match best estimates of typical practice otherwise. Because such component inputs are used in both pre- and post-change simulations, it is important only that they be reasonable estimates of typical construction.

In some cases, there is no pre-change code requirement corresponding to a new post-change code provision. The usual example is a new code requirement that expands the IECC's scope to cover a new area such as lighting. But some new requirements that don't formally expand the code's scope nonetheless have no pre-change requirement that can characterize the associated element in the energy simulations. Two such changes of particular importance are the proposed new requirements for pressure testing of ducts and building thermal envelopes. Although sealing of both ducts and envelopes was required in the 2006 IECC, testing was not required for either element, so there is no straightforward "test result" to assume for the pre-change simulations. In these cases, direct simulation of the new change is not always sensible. The situation is discussed in some detail in the Appendix, and the specific approaches to estimating energy savings from these two elements are discussed below.

Weighting Factors

Building Types

Building permit data for 2004 and 2005 indicates that 20% of new construction in terms of total dwelling units is multifamily (Census 2006). 22% of these new multifamily dwelling units are in buildings of four stories or more in height and fall under the IECC's commercial (Chapter 5) provisions (Census 2006). Therefore, about 16% of all dwelling units in the residential building classification of the IECC are in multifamily buildings. This figure is used to aggregate single-family and multifamily simulation results.

Table 4. Building Type Shares (percent)

Building Type	Weighting Factor (percent)
Single-Family	84
Multifamily	16

Foundation Types

Single-family simulations are based on a vented crawlspace foundation except in cases that deal explicitly with changes to requirements for other foundation types. In the latter cases, foundation-specific energy changes are weighted by an estimate of foundation shares in each climate zone. These shares are estimated from the Census Bureau data for 2004 housing characteristics data (Census 2005) shown in Table 5.

Table 5. Foundation Type Shares (percent) by Census Zone

Zone	Basement	Slab	Crawlspace
Northeast	84	13	3
Midwest	76	17	6
South	12	70	17
West	15	65	20
Total	31	54	15

These data provide the fraction of new residences having basements, but do not distinguish conditioned from unconditioned basements. We estimate the shares of conditioned and unconditioned based on data from the DOE Residential Energy Consumption Survey (DOE 2005).

Because foundation share data is available only for census zones, not 2006 IECC climate zones, it is necessary to estimate the climate zone shares from census data and general knowledge about regional construction techniques (e.g., basements are almost never used in the far south). Table 6 shows the shares assumed for DOE's percent-savings estimates.

Table 6. Foundation Type Shares (percent) by 2006 IECC Climate Zone

Climate Zone	Heated Basement	Crawlspace	Slab-on-Grade	Unheated Basement
1	0	0	100	0
2	0	5	95	0
3	10	15	70	5
4	30	20	40	10
5	45	20	20	15
6	65	10	5	20
7 & 8	70	5	5	20

Equipment/Fuel Types and Energy Costs

The impacts of code changes are estimated based on a typical gas-heated, electrically-cooled home. 65% of new single-family homes in 2008 used natural gas for heating.[1] Electricity is assumed to cost 12 cents/kWh and natural gas is assumed at $1.20 per therm nationwide based on recent residential prices from the DOE Energy Information Agency.[2] Code improvements will save substantial amounts of energy for each of space heating, space cooling, and water heating so the impact of equipment/fuel type and fuel price assumptions on the overall building percent-savings calculation is small.

Air Duct Systems

The analysis of air ducts deserves special attention because a major improvement from the 2006 IECC to the projected 2012 IECC is improved sealing of air ducts.

The 2006 IECC requires ducts to be sealed, but permits compliance to be confirmed by visual inspection only. Multiple studies have shown that visual inspection of ducts is not an adequate method of determining proper duct sealing and major energy losses regularly occur because of ducts leaking air in attics, crawlspaces, garages, etc. Ducts are often located in these difficult to access areas, making cracks and other leakage points in ducts difficult or impossible to see because they are covered by insulation, hidden from view, or simply too small to be readily apparent to the human eye. Testing of completed homes in Washington state, where the Washington State Energy Code's (WSEC) prescriptive code requirements for duct sealing apply, "showed no significant improvement" over non-code homes (Washington State University 2001). Another study from Washington state concluded: "Comparisons to air leakage rates reported elsewhere for homes built

[1] http://www.census.gov/const/www/highanncharac2008.html
[2] http://www.eia.doe.gov/

before the implementation of the 1991 WSEC show no significant improvement by the general population" despite years of training emphasizing duct sealing (Hales et al. 2003). The new requirement to meet a specific and tested leakage limit will result in improving the buildings that would have had the leakiest ducts. The Appendix explains this effect.

Numerous other studies around the nation show substantial duct leakage in new homes, including those in states with codes requiring duct sealing. For example, a 2001 study of 186 houses built under the Model Energy Code (MEC) in Massachusetts reported that "serious problems were found in the quality of duct sealing in about 80% of these houses" (Xenergy 2001). Pressurization tests in 22 of these houses found an average leakage to the outside of the house of 183 cfm, or 21.6% of the system flow, at a pressure of 25 Pascals.

Section 403.2.2 of the 2009 IECC requires air duct systems, where any of the ducts pass outside of the conditioned space (into attics, garages, etc.), to be pressure tested to verify the duct leakage does not exceed the allowable rate. Code change proposal EC13-09/10 decreases these maximum allowed leakage rates to no more than 6 cfm per 100 ft^2 of conditioned floor area at a test pressure of 25 Pascals and, if approved, would memorialize those rates in the 2012 IECC. For a 2400 ft^2 house, this is 144 cfm total leakage. If a 4-ton air conditioning system is installed with a flow rate of 400 cfm per ton, the allowable leakage rate is 9% of the flow rate. This requirement of low leakage rates verified by testing is expected to result in a substantial improvement in energy efficiency in most homes. Testing may not be required if all ducts are inside the building envelope (for example in heated basements), although all ducts are still required to be sealed to prevent air leaks.

For the analysis of building energy use, the duct system is assumed to be located in the attic. The supply duct surface area is assumed to be 480 ft^2; the return duct surface area is 280 ft^2 (Hendron 2008). A **12% reduction in heating and cooling energy use is assumed to result from the improved duct sealing** from the low leakage rates specified in EC13 compared to the 2006 IECC. This is an estimated average across all new homes that attempts to capture the effect of the new testing requirements improving the worst performing homes (see discussion in the Appendix). Actual savings will vary greatly depending on how well the home would have been sealed without the testing requirement, among other factors.

Envelope Air Leakage

The IECC has always required the building envelope to be caulked and sealed to prevent air leakage between conditioned and unconditioned spaces or the outdoors. The level of detail in the code was expanded in 2009, although the basic intent was the same: Seal all potential sources of leaks. However, code change proposal EC13-09/10 introduces a major change to the IECC because it requires maximum allowable envelope air leakage to be verified by testing using envelope pressurization techniques (using equipment commonly referred to as a "blower door"). EC13, as approved at the ICC Initial Action hearings (the first of two public hearings in the process to create the 2012 IECC), requires air leakage rates of not more than 5 air changes per hour (ACH) when tested at a pressure of 50 Pascals (ACH50) in climate zones 1 and 2 and not more than 3 ACH in climate zones 3 through 8. An alternative path allows these rates to be increased by 2 ACH if high-efficiency heating and/or cooling equipment is installed.

Selecting a baseline (2006 IECC) envelope leakage rate is difficult for similar reasons, as discussed with respect to duct leakage. For this energy analysis, we have chosen 7 ACH at 50 Pascals as a reasonable value to represent the 2006 IECC, which only requires visual inspection of sealing and contains no test requirement. This is based on estimation by Lawrence Berkeley National Laboratory of 6 to 8 ACH per hour for the typical new home (Sherman 2008). A higher leakage rate might be justifiable to account for improving the worst performing homes (see discussion in the Appendix), but the overall distribution of leakage rates is not known.

Mechanical Ventilation

As sealing of the building envelope improves, the need for a mechanical ventilation system to introduce fresh outside air into the building increases. At what level of building envelope tightness mechanical ventilation is needed is a topic of considerable debate and controversy. An informal rule of thumb accepted by some is that mechanical ventilation is needed if the "natural" infiltration rate resulting from air leakage through the building envelope and other sources such as opening doors and window drops below 0.35 ACH (Sherman 2008), which translates to pressure test result of roughly 7 ACH at 50 Pascals for a typical house. Therefore, if the 2012 IECC incorporates the EC13 proposed requirements for low ACH rates, many believe that mechanical ventilation systems will be necessary to help provide proper indoor air quality and address moisture issues that can arise.[1]

It is debatable what impact the improved air leakage control requirements in the IECC will have on mechanical ventilation energy use. Arguably, mechanical ventilation systems may already be needed in new homes even without the new code requirements for low air leakage levels. This is because of the tight levels of air sealing already being achieved in the best performing houses that meet codes relying on air sealing requirements similar to those in the 2006 IECC (no testing). While the typical ACH level for new homes that do not have to comply with a test requirement is about 7 ACH50, many new homes—possibly half of them, depending on the actual distribution of leakage rates—are below this rate. Therefore, a considerable fraction of new homes are already sufficiently tight that many experts believe mechanical ventilation is needed. Without air

[1] Note that building and mechanical codes do require exhaust systems for bathrooms, kitchens and other sources of moisture and indoor contaminants that would address some of the air quality and moisture issues.

leakage testing, there is no way to know which houses are particularly tight and therefore the only way to ensure proper indoor air quality is to provide mechanical ventilation systems for all new homes. Following this logic, all new homes should already be incorporating mechanical ventilation and the EC13 air leakage control improvements would not impact the need for mechanical ventilation in homes built to the 2012 IECC requirements.

However, because EC13's allowable leakage rate is quite low at 3 ACH50, building scientists would likely agree that a mechanical ventilation system is needed, and DOE considers it reasonable to assume that new homes built under such requirements will necessarily include mechanical ventilation. Because there is little evidence that such ventilation systems are ubiquitous under current codes, the impact of mechanical ventilation on energy use is accounted for in this analysis.

Building Science Corporation has conducted an extensive simulation analysis of whole-house ventilation systems (Lstiburek et al. 2007). Our analysis is based on results from that research for a basic exhaust-only ventilation system running continuously at 50 cfm. Energy cost impacts were adjusted to reflect current national average residential rates of $1.20/therm for natural gas heating and 12 cents/kWh for air conditioning and fan energy.

Table 7 shows the net impacts on energy costs of this mechanical ventilation system and the modest increase in ventilation rate that it provides. Because there is only a small variation in ventilation costs by climate, we have adopted a constant assumption of $80 in annual costs for the incremental mechanical ventilation required to improve indoor air quality to acceptable levels for the single-family prototype ($50 is assumed for multifamily). In reality, the impacts of mechanical ventilation systems on energy costs will vary greatly depending on the ventilation system design and operation, the home design, and other factors.

Table 7. Annual Energy Cost Impacts of Exhaust Only Ventilation

	heat	cool	vent	total	Increase in natural ACH rate
Houston	$18	$52	$19	$89	0.10
Phoenix	$18	$24	$19	$61	0.11
Charlotte	$31	$24	$19	$74	0.08
Kansas City	$55	$26	$19	$84	0.08
Seattle	$47	$2	$19	$68	0.08
Minneapolis	$59	$9	$19	$87	0.06

Calculation of Energy Savings from Projected Requirements of the 2012 IECC

This section identifies the energy savings from the projected requirements of the 2012 IECC in comparison to the baseline of the 2006 IECC using the assumptions provided earlier in this report. This includes the improvements in the 2009 IECC and most of the proposed improvements to the IECC approved at the first hearings in the current ICC code development cycle. Most notable is proposal EC13, submitted by DOE, which contained a number of significant energy-efficiency improvements. Additional code changes approved at the first hearings and accounted for in the analysis are EC34 (fenestration U-factors), EC47 (improved wall insulation), and EC50 (basement wall insulation). The differences analyzed here are summarized in Table 8.

The energy savings estimate herein is expected to be somewhat conservative because the analysis does not account for some code improvements that are particularly difficult to quantify. Notable examples include:

- EC123-09/10 (approved in code development hearings), which would ban pure (without heat pump) electric space heating in most cases. Based on Census Construction data, pure electric resistance is estimated to be used in 8% of all new residential dwelling units and replacement with air-source heat pumps, which are effectively twice as efficient at rated conditions, will save considerable energy.
- The elimination of envelope-equipment trade-offs as a compliance option. This is expected to result in savings in two ways: First, envelopes that would have been made less efficient in trade for better HVAC equipment will be more efficient. It is expected that at least some of these homes will continue to use higher-efficiency equipment even in the absence of trade-off credit. Second, energy saved by better equipment accrues over a shorter time span—typically 15 or 20 years for the life of HVAC equipment—while savings from envelope options accrues for longer periods of 30, 50, even 100 years.
- Other code changes initially approved at the first hearings that modestly improve energy savings, such as EC31, which would cap the allowable fenestration area at 20% of conditioned floor area in the prescriptive compliance path.

Table 8. Code Improvements in the Projected 2012 IECC Considered in this Analysis

Building Element	Code Improvement (2006 to 2012 IECC)
Window U-factors	Vertical fenestration: Zone 1: U-1.20 to 0.50 Zone 2: U-0.75 to 0.40 Zone 3: U-0.65 to 0.35 Zone 4: U-0.40 to 0.35 Zones 5-8: U-0.35 to 0.32
Window maximum solar heat gain coefficient (SHGC)	Climate zones 1, 2, and 3: 0.40 to 0.30
Ceiling insulation	Zone 3: R-30 to R-38 Zone 5: R-38 to R-49
Above-grade wall insulation	Zones 3 and 4: R-13 to R-20 Zone 5: R-19 to R-20 Zone 6: R-19 to R-20+R-5 Zones 7 and 8: R-21 to R-20+R-5
Basement wall insulation	Zone 3 (excluding warm-humid locations) – R-0 to R-5 Zones 5-8: R-13 to R-19
Floor insulation	Zones 7 and 8: R-30 to R-38
Envelope sealing	Leakage limits verified by testing. Because 2009 IECC lacks quantifiable requirements, we estimate a baseline of 7 ACH50, which matches the optional test requirement of the 2009 IECC.[1]
Duct sealing	Leakage limits verified by testing required if any ducts pass outside the conditioned space
Space heating, air conditioning, and water heaters	Trade-offs between equipment efficiency and envelope measures are no longer permitted in the IECC.
Lighting	At least 50% of installed lighting must be as efficient as compact fluorescent lights.
Heating and cooling equipment efficiency	Optional improved efficiency for furnaces, boilers, heat pumps, and air conditioners.

[1] The 2009 IECC requires either a whole-house pressure test or a visual inspection against a checklist of infiltration-related home features.

Energy Cost Savings for Single-Family Housing

Figure 1 shows the energy cost savings as percentages for the 2400 ft^2 single-family house with a crawlspace foundation. Both of the two prescriptive options in code change proposal EC13 are displayed: a primary package dominated by strict duct and envelope leakage requirements, and a high-efficiency equipment alternative with somewhat relaxed duct and envelope requirements. Table 9 shows these same savings. The national weighted average savings is 30.5% for the primary package and 32% for the high-efficiency equipment alternative.

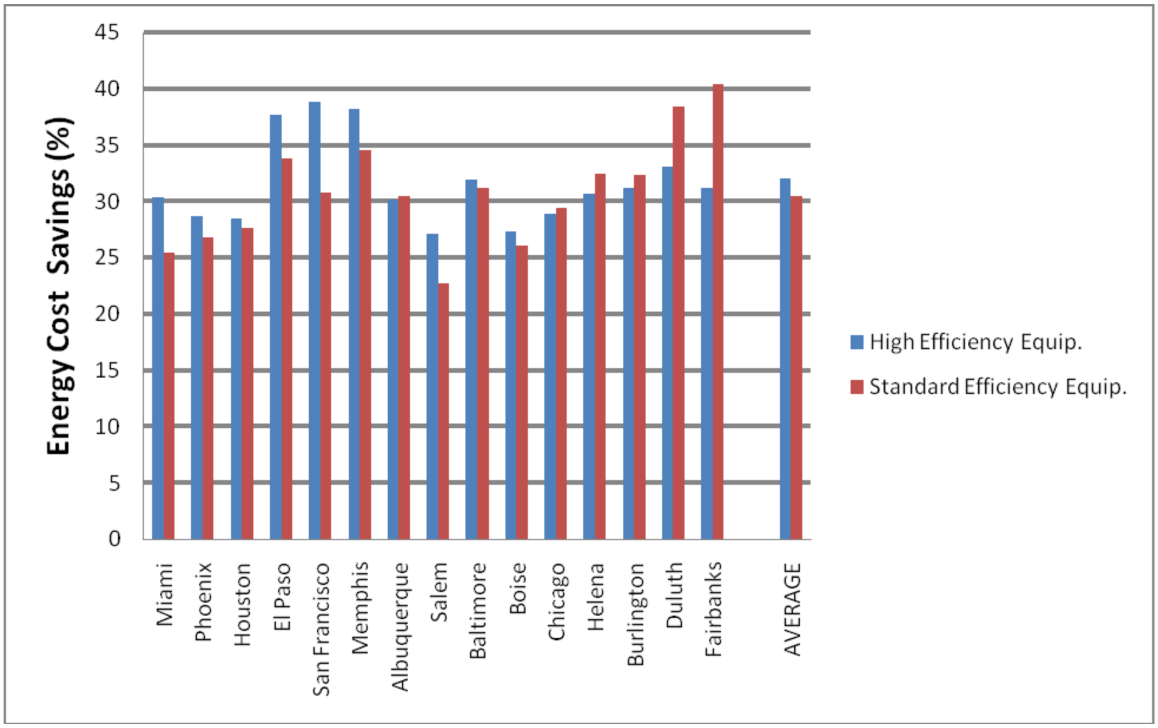

Figure 1. Energy Cost Savings (%) by Climate Zone – Single Family

Table 9. Energy Cost Savings (%) by Climate Zone Representative Cities

City	Zone	Percent Savings	
		High-Efficiency Equipment	Standard-Efficiency Equipment
Miami	1	30.3	25.4
Phoenix	2	28.7	26.8
Houston	2	28.5	27.6
El Paso	3	37.7	33.8
San Francisco	3	38.8	30.8
Memphis	3	38.2	34.5
Albuquerque	4	30.1	30.5
Salem	4	27.1	22.7
Baltimore	4	31.9	31.2
Boise	5	27.3	26.1
Chicago	5	28.9	29.4
Helena	6	30.7	32.4
Burlington	6	31.2	32.3
Duluth	7	33.1	38.4
Fairbanks	8	31.2	40.4
AVERAGE		**32**	**30.5**

Energy Cost Savings for Multifamily Housing

Figure 2 shows the energy cost savings for the multifamily prototype. The weighted national average savings is 31.1% for the primary package and 28.8% for the high-equipment efficiency alternative.

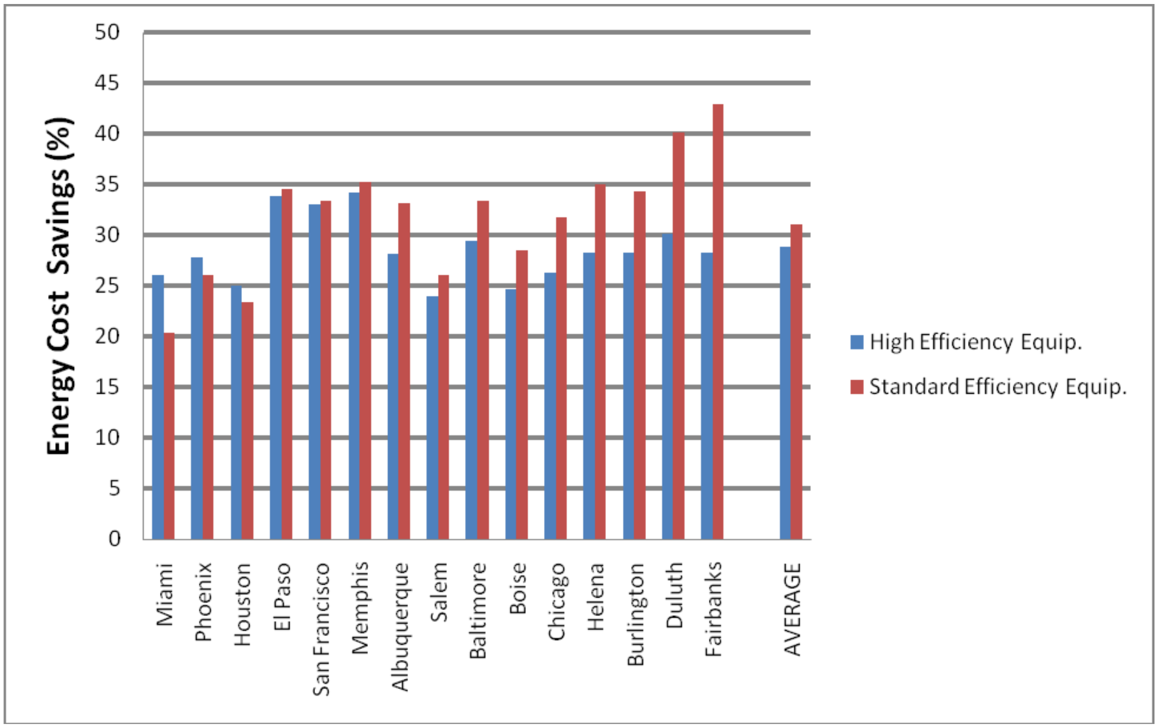

Figure 2. Energy Cost Savings (%) by Climate Zone – Multifamily

Combined National Average Energy Savings

Accounting for market share of new dwelling units, as discussed earlier in this report, the national average savings for the IECC code improvements analyzed here for both single-family and multifamily is 30.6%, assuming builders always use the primary (standard-equipment efficiency) compliance option. Were the high-equipment efficiency alternative always used, the national average savings would be 0.9% higher, at 31.5%.

Energy Savings by Foundation Type

The results in the previous section were calculated for a single foundation type (crawlspace). Figure 3 shows the relative energy cost savings for the 2400 ft^2 single-family house across the four common foundation types: Crawlspace, heated basements, unheated basements, and slab-on-grade. For heated basements, code requirements are assumed to be met with basement wall insulation; unheated basements and crawlspace are insulated to meet floor over unconditioned space requirements.

Savings are relatively consistent across foundation type. This is expected because most of the proposed code changes do not affect foundation insulation requirements. The exception is an increase in savings for heated basements in zone-3 cities (El Paso, San Francisco, and Memphis). The reason for this difference is that the 2009 IECC added a requirement for R-5 basement wall insulation in the northern part of zone 3, while the 2006 IECC does not require any basement wall insulation in these locations. Consequently, the crawlspace-based national average savings values shown earlier may be slightly conservative, although the effect is small because heated basements account for only about 10% of homes in this zone.

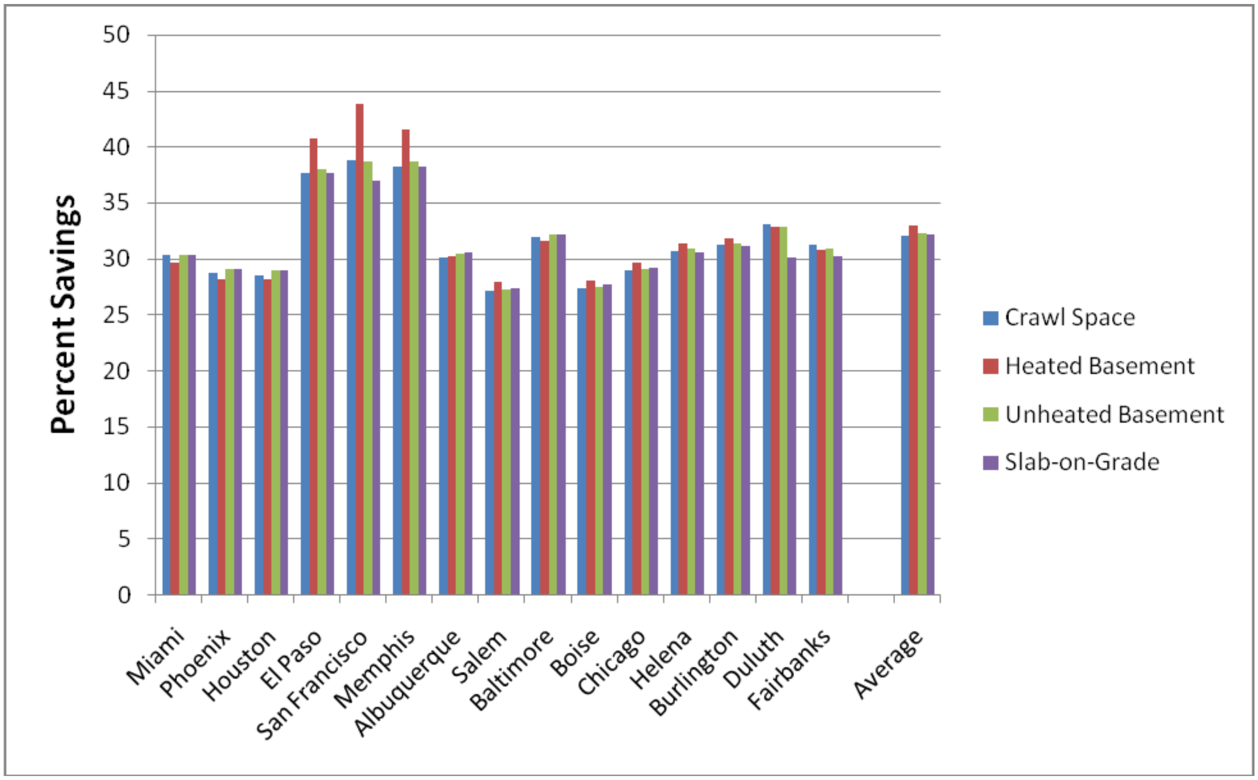

Figure 3. Percent Energy Savings by Foundation Type

References

Briggs, R. S., R. G. Lucas, and Z. T. Taylor. 2002. *Climate Classification for Building Energy Codes and Standards: Part 2 – Zone Definitions, Maps, and Comparisons.* ASHRAE Transactions, Vol. 109, Part 1. Atlanta, Georgia.

Hales, D., A. Gordon, and M. Lubliner. 2003. *Duct Leakage in New Washington State Residences: Findings and Conclusions.* ASHRAE transactions. KC-2003-1-3.

Hendron R. 2008. *Building America Research Benchmark Definitions.* NREL/TP-550-44816. National Renewable Energy Laboratory, Golden, Colorado.

Lstiburek, J., B. Pettit, A. Rudd, M. Sherman, and I. Walker. 2007. Whole-House Ventilation System Options – Phase 1 Simulation Study. Building Science Corporation, Boston Massachusetts.

Sherman, M. 2008. *Trends in US Ventilation*. International Workshop on Trends in National Building Ventilation Markets and Drivers for Change. Ghent, Belgium, March 2008.
http://www.aivc.net/frameset/frameset.html?../Conferences/workshop_ghent2008.html~mainFrame

U.S. Census Bureau. 2000 Building Permits.
http://www.census.gov/const/www/permitsindex.html

U.S. Census Bureau. 2006 Characteristics of New Housing.
http://www.census.gov/const/www/charindex.html

U.S. DOE. 2005. Residential Energy Consumption Survey (Table HC5.2).
http://www.eia.doe.gov/emeu/recs2005/hc2005 tables/detailed tables2005.html

Washington State University. 2001. *Washington State Energy Code Duct Leakage Study Report*. WSUCEEP01105. Washington State University Cooperative Extension Energy Program, Olympia, Washington.

Xenergy. 2001. Impact Analysis Of The Massachusetts 1998 Residential Energy Code Revisions. http://www.mass.gov/Eeops/docs/dps/inf/inf_bbrs_impact_analysis_final.pdf

APPENDIX

Calculating Energy Savings from New Code Provisions that Expand the Scope of the Code

Appendix - Calculating Energy Savings from New Code Provisions that Expand the Scope of the Code

Some building components and/or energy conservation measures do not lend themselves to straightforward pre- and post-change simulation of energy consumption. For example, the use of hourly simulation is of dubious value in assessing the energy savings of duct testing because the 2006 IECC had no testing requirements from which a meaningful baseline leakage rate can be established. In this case, the majority of the uncertainty is in the decision of what pre-2009 leakage rate should be used as a baseline. For example, there are undoubtedly homes with extremely high duct leakage rates that were approved as complying with the 2006 IECC, but it is misleading to assume, for example, a 75% leakage rate as the 2006 baseline.

Similarly, whole-house envelope air leakage has no code-defined baseline, nor does interior lighting. In all such cases, there is evidence (in the form of various independent studies) that show a wide variation in the leakage rates and installed wattages achieved by builders who are not subject to mandatory testing or installed capacity limits. The exercise of hour-by-hour simulation may only cloud the importance of those initial assumptions in these cases, and it is sometimes more efficacious to estimate energy savings by other means.

In the examples above, there is doubtful value in comparing the simulated energy savings of a new requirement with that of a nonexistent previous requirement. Although it may be possible to discern an average pre-requirement duct leakage rate, for example, it may be misleading to estimate the effect of a testing requirement by comparing the *maximum allowable* duct leakage rate in a new code against the prior *average* leakage rate. For example, it is conceivable that the average leakage rate under a code with no air leakage testing requirement would be comparable to the tested value now required in the 2009 IECC. In such a case, using the average leakage rate as the baseline in a simulation would result in the nonsensical estimate of zero savings. In reality, the likely effect of such a code change would be to improve all homes that would have tested worse than average without impacting homes that would have tested better. This is illustrated in Figure A-1, where the shaded region shows energy savings from a hypothetical new requirement that is less efficient than the pre-code average.

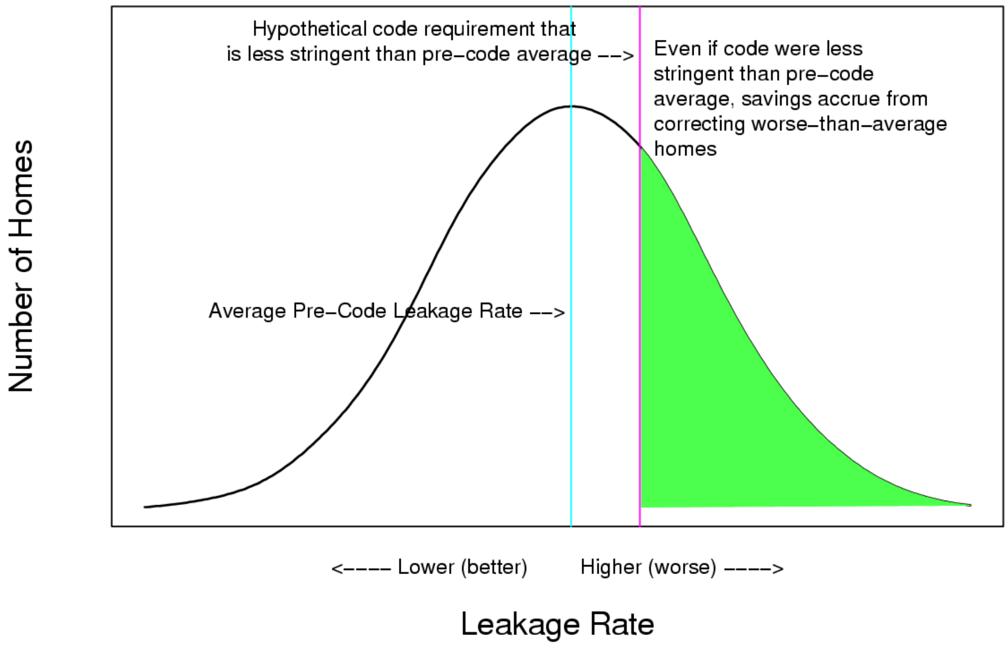

Figure A- 1. Illustration of Energy Savings from a Code Change that Improves the Worst-Performing Homes

The figure shows a hypothetical distribution of duct leakage rates among homes built prior to the addition of a code's required pressure test to verify acceptably low leakage rates. Because the pre-2009 code allowed duct sealing to be verified visually—a method that has proven to be unreliable—there was no objective maximum leakage rate requirement. Note that even if the 2009 IECC requirement for a maximum leakage rate were set at a level higher (less efficient) than the average pre-2009 house, there would still be substantial savings from the code change, because of the improvement of worse-than-average homes. This clearly illustrates the problem with using simple pre- and post-change simulation to directly estimate the savings of the new code when the pre-change code had no objective requirement or, more generally, when the primary effect of the code change is to enhance compliance rather than increase stringency.

For such energy conservation measures, DOE reserves the prerogative to estimate energy savings on a case-by-case basis, using a methodology appropriate to the measure and reasonable given the uncertainties involved.

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov