An Economic Feasibility Test for Residential Energy Efficiency Measures When First Costs Are Uncertain

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ABSTRACT

Recent advances in building energy codes have resulted in energy savings of more than 30% compared to codes from just a decade ago. These advances have resulted in an increasing emphasis on cost-effectiveness of efficiency measures proposed for future code revisions. Cost-effectiveness calculations are typically conducted using Life Cycle Cost (LCC) analysis, which depends heavily on a measure's estimated first cost. Such costs are often challenging to establish or uncertain for new or emerging technologies, and can be controversial even for well-established technologies. Sensitivity analyses or other methods that evaluate a range of input values are often helpful, but those approaches may actually increase the number of uncertain inputs that must be estimated.

This paper discusses an approach that rearranges the LCC calculation to derive a justified first cost rather than require a first cost as input. The justified first cost is that cost which would exactly balance an efficiency measure's benefits—i.e., give a net LCC of zero. This technique establishes a threshold cost at which a measure becomes cost-effective. This paper describes the justified first cost methodology and shows how it was successfully used with DOE's cost-effectiveness methodology to identify candidate efficiency measures for future generations of residential energy codes. The cost thresholds can also inform DOE's near-term planning for residential efficiency research by showing the market prices new technologies must meet before they can be considered for incorporation into mainstream building energy codes.

Introduction

Building energy efficiency is just one expenditure among many for which cost-effectiveness is a key consideration. The authors have been involved in development of building energy efficiency codes for several decades and have watched the overall efficiency of residential buildings improve substantially. Over the last three development cycles of the International Energy Conservation Code (ICC 2016), for example, the annual energy cost of a code-compliant home has been reduced by about 30%.[1] As the code gets more efficient, it increasingly pushes the bounds of cost-effectiveness, highlighting the importance of the assumptions, data, and calculations behind whatever metrics are deemed appropriate definitions of "cost-effective." This paper looks at one little used metric that may be helpful in assessing the appropriateness of an investment in new efficiency measures—the *justified first cost*.

[1] When an IECC revision becomes available, the U.S. DOE issues a formal "determination" as to whether it will reduce energy consumption in residences. Information on the determination process as well as the formal determinations and supporting analysis can be found at http://www.iccsafe.org/codes-tech-support/code-development-process/ .

Various economic metrics are favored by energy code stakeholders depending on their points of view and economic perspectives. Some prefer the simplicity of a *simple payback period*, which gives an estimate of the number of years required for energy savings to "pay for" the initial investment. Others prefer the long-term perspective of *life-cycle cost* (LCC) analysis, which evaluates all costs and benefits over the life of an efficiency measure, converts each cash flow to a present value based on an appropriate discount rate, and calculates the net present value of those cash flows. Others gain insight by calculating an *internal rate of return* (IRR), which attempts to quantify an efficiency investment's economic performance as a return on investment, making it easy to compare against alternative investments available to the homebuyer. These and other metrics require a broad range of input assumptions. Simple payback period requires the initial cost of the efficiency measure and the estimated annual energy savings, while LCC and IRR also require knowledge of mortgage financing parameters, fuel price escalation rates, tax parameters, expected maintenance costs, assumptions regarding replacement costs and residual values, and any other parameters that may impact a consumer's cash flow at any time during the period of analysis. One consistent requirement across all these cost-effectiveness metrics is first cost—the initial cost of the efficiency measure in question.

It might seem obvious that the first cost of a measure is necessary for determining cost-effectiveness—and that is perhaps why justified first cost is seldom encountered—but for a number of reasons, first cost can be a difficult and even controversial parameter to establish, at least for analyses of building codes and other efficiency programs that affect large numbers of buildings across a broad geography. When first costs are difficult to establish or agree on, inverting the economic test such that first cost is an output rather than an input can be an effective approach to evaluating efficiency measures. This idea is neither new nor particularly novel, but the authors believe it could be a useful tool for stakeholders in the building energy code development process.

The First Cost Controversy

Although nearly every economic parameter used in a cost-effectiveness analysis can be controversial when the context is an energy code that may bear the force of law when adopted by a state or local jurisdiction, first cost is perhaps unique in its propensity to attract debate. There are several reasons for this. First, unlike discount and escalation rates, tax effects, and other arcana, first cost is well understood by virtually all stakeholders, regardless of their comfort with the vagaries of financial analysis, making it a parameter that is carefully considered by all involved.

Second, first costs can vary substantially with geography, builder (e.g., due to purchase volumes), season, economic climate, weather singularity, natural disaster, etc. Material costs can make drastic cost jumps in the wake of large-scale hurricane damage, pine beetle infestations, or forest fires, for example. Costs also change with time as general inflation and/or fuel costs escalate manufacturing and transportation costs.

Third, the nature of energy efficiency codes often results in a call for efficiency measures that rely on relatively new technologies or techniques. Consequently, there may be a minimal history of price information on which to draw, and current costs are often a poor reflection of future costs when the code is actually implemented. Prices of new technologies tend to fall with time, but the projections are subject to uncertainty and controversy.

Stakeholders directly involved in the building industry often have deep experience with the costs of constructing buildings and are understandably loath to accept others' cost estimates that depart substantially from that experience. Others such as state officials or energy efficiency advocates may have an overview experience covering a broad range of buildings, builders, climates, and local economic situations, and consequently prefer average or aggregate costs. The upshot of all these factors is that legitimate estimates of first costs can vary tremendously.

Justified First Cost Defined

The justified first cost is very simple in concept and can be calculated for many different economic test metrics. In the context of a simple payback period, for example, the justified first cost would simply be the annual (i.e., first-year) energy cost savings multiplied by the payback threshold (number of years) deemed appropriate by the person or entity doing the analysis. For LCC analysis, our focus here, justified first cost is the first cost of an efficiency measure that results in a net LCC of exactly zero. That is, it's the first cost that exactly balances costs and benefits. Or, in consumer terms, it's the highest price one would be economically justified in paying for the measure. This price is actually the differential cost between the efficiency measure being considered and whatever alternative building element would be purchased in the absence of the measure. For an IRR analysis, the justified first cost is the first cost that results in an IRR exactly equal to the lowest rate of return deemed acceptable.

Calculating justified first cost for an LCC analysis requires an iterative process but is otherwise straightforward. Conceptually, an initial guess at the justified first cost is increased or decreased by sequentially smaller amounts until the LCC result is acceptably close to zero. Such procedures are generally available in statistical analysis, mathematical, or spreadsheet software under such labels as "optimization," "non-linear minimization," etc., and manual (by hand) trial and error can work for simple problems. The specific routines used for the examples in this paper are not discussed in detail.

The justified first cost of an efficiency measure obviously depends on the numerous other economic parameters used in an LCC analysis. Typically included in such analyses, and specifically in the examples that follow here, are a financial discount rate that adjusts future cash flows to present values; fuel prices; fuel price escalation rates (or year-by-year estimates of future prices); and mortgage parameters including down payment percentage, loan fee, loan term, and interest rate. The values assigned to these parameters set forth the relevant economic perspective.

For individual efficiency measures, in addition to the crucial first cost, there typically must be a known useful life, any ongoing associated maintenance costs, the annual energy savings associated with the measure, and assumptions regarding future replacement at the end of the measure's useful life and regarding the resale or residual value of the measure at the end of the analysis period.

The specific values assigned to these parameters in the examples that follow are incidental to the discussion of justified first cost and are not further discussed here. Where not shown in our examples, the values established by the United States Department of Energy (DOE) were used (Taylor et al. 2012). The DOE values are intended to represent a blended economic perspective of the initial and all future owners of a new home. Having established this primary economic perspective and the associated financial parameters, the justified first cost depends only on measure-specific parameters (energy savings, measure life, replacement cost fraction, residual value).

Figure 1 shows the justified first cost of a measure with annual energy cost savings of one dollar. The curve shows how justified first cost varies with the useful life of the measure. All economic parameters are set as outlined in DOE's established methodology (Taylor et al. 2012) except that the fuel price escalation rate is set to a real value of zero (i.e., fuel prices exactly track inflation). Solid gray vertical lines are drawn at 30 years, 60 years, and 100 years, to show a typical mortgage term, typical maximum envelope measure life, and typical maximum home life, respectively. These are for illustration purposes only.

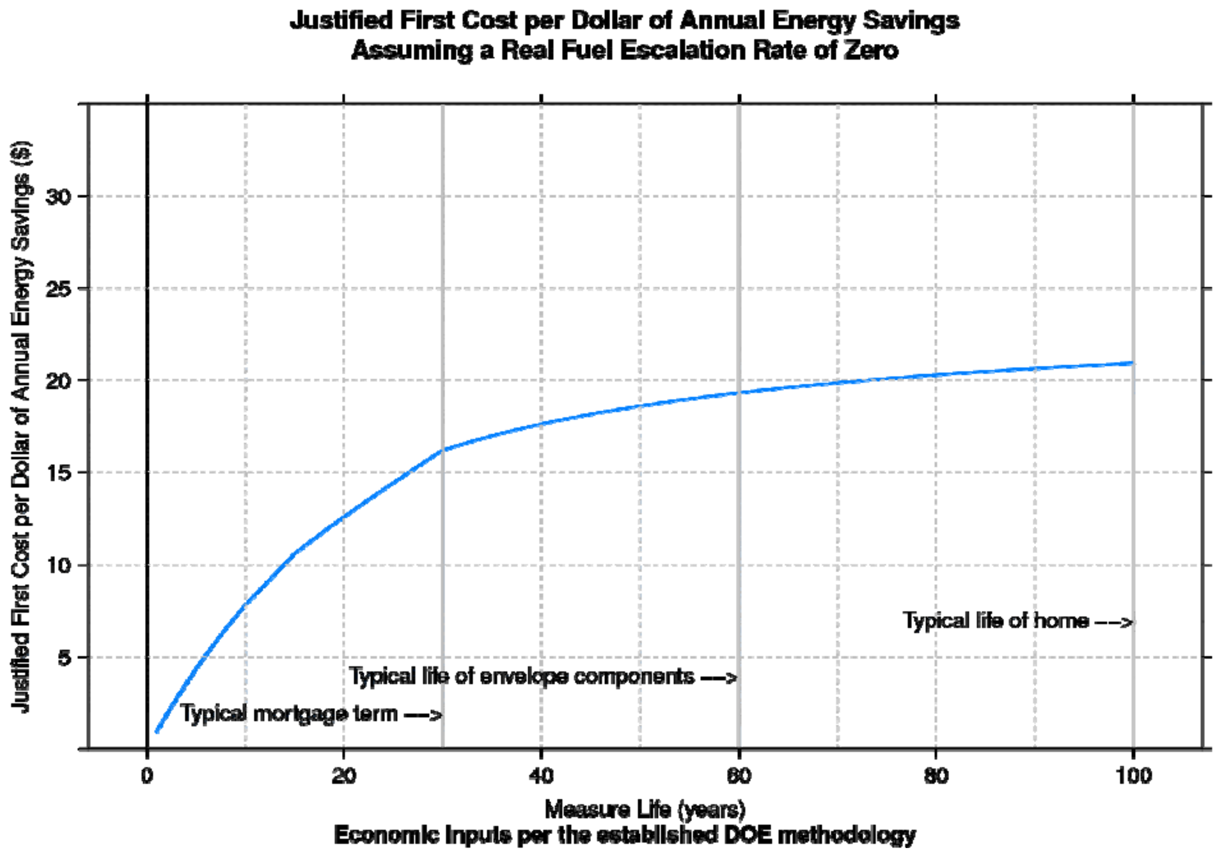

Figure 1: Justified first cost as a function of measure life assuming zero real fuel escalation rates

Several observations can be drawn from the figure. First, the justified first cost depends strongly on the useful life of the measure in question. For example, a measure with a ten-year life (meaning it would have to be replaced three times during a 30-year analysis period) justifies a first cost between seven and eight dollars per dollar of annual energy savings. Put another way, a measure that saves one dollar per year for ten years–10 dollars total–should cost no more than seven to eight dollars upfront. In contrast, a measure with a 30-year life justifies a first cost of about 16 dollars per dollar of annual savings. Second, the rate of increase in justified first cost as a function of measure life slows with increasing measure life. This is primarily a result of discounting in the LCC calculations. Cash flows in the distant future are valued less in present-value terms, so the benefits of not having to replace the measure as often are attenuated. Finally, there is a discontinuity in the justified first cost curve at a measure life of 30 years, corresponding to the end of the mortgage period. Prior to that, the mortgage costs and tax effects have an influence, whereas after that, the measure life merely affects the residual value assigned to the measure at the end of the 30-year analysis period. Were the graph drawn for a different set of economic assumptions, the discontinuities would differ.

Figure 2 illustrates the exact same scenario but with future fuel prices set to the year-by-year estimates available from EIA as of late 2015.[2] The graph is in all respects similar to the prior one but the justified first costs are somewhat higher because fuel prices are expected to rise somewhat faster than inflation. The justified first cost for a measure with a ten-year life, for example, has increased to about nine dollars per dollar of annual energy savings.

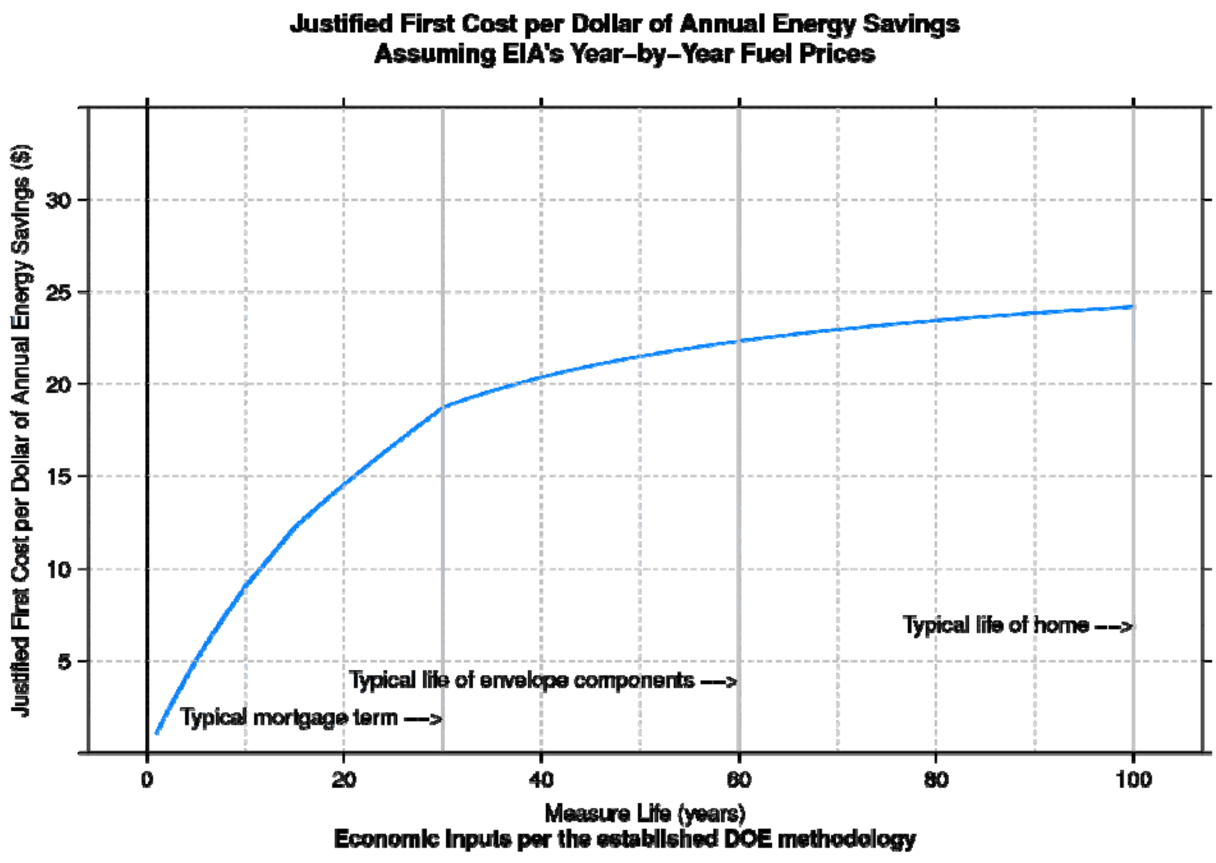

Figure 2: Justified first cost as a function of measure life based on EIA fuel price projections

[2] EIA, Annual Energy Outlook 2015, table accessed 2 Dec 2015 from http://www.eia.gov/beta/aeo/#/?id=3-AEO2015&cases=ref2015 .

The effect of various future fuel-price scenarios is further illustrated in Figure 3, which shows a family of curves for various fixed price escalation rates. A graphic such as this is valuable because it embodies in a single page the justified first cost for virtually any efficiency measure under a variety of future fuel price scenarios. One of the key advantages of justified first cost analysis is that virtually all other input parameters reflecting a desired economic perspective can be fixed so that any first-cost situation can be quickly evaluated without doing further calculations. If all available first cost estimates exceed the justified first cost, for example, the measure in question is clearly not economically viable. If, on the other hand, all estimates are below the justified first cost, cost-effectiveness can be reasonably concluded. If some first cost estimates exceed the justified first cost while others do not, cost-effectiveness is uncertain.

One natural use for this kind of analysis is planning for research and development. The observation, for example, that the justified first cost of a new technology is too low for current products to be used cost-effectively, might allow government agencies to establish first-cost targets to be pursued by research and development programs. One such application of the methodology by the U.S. Department of Energy is discussed in the following section.

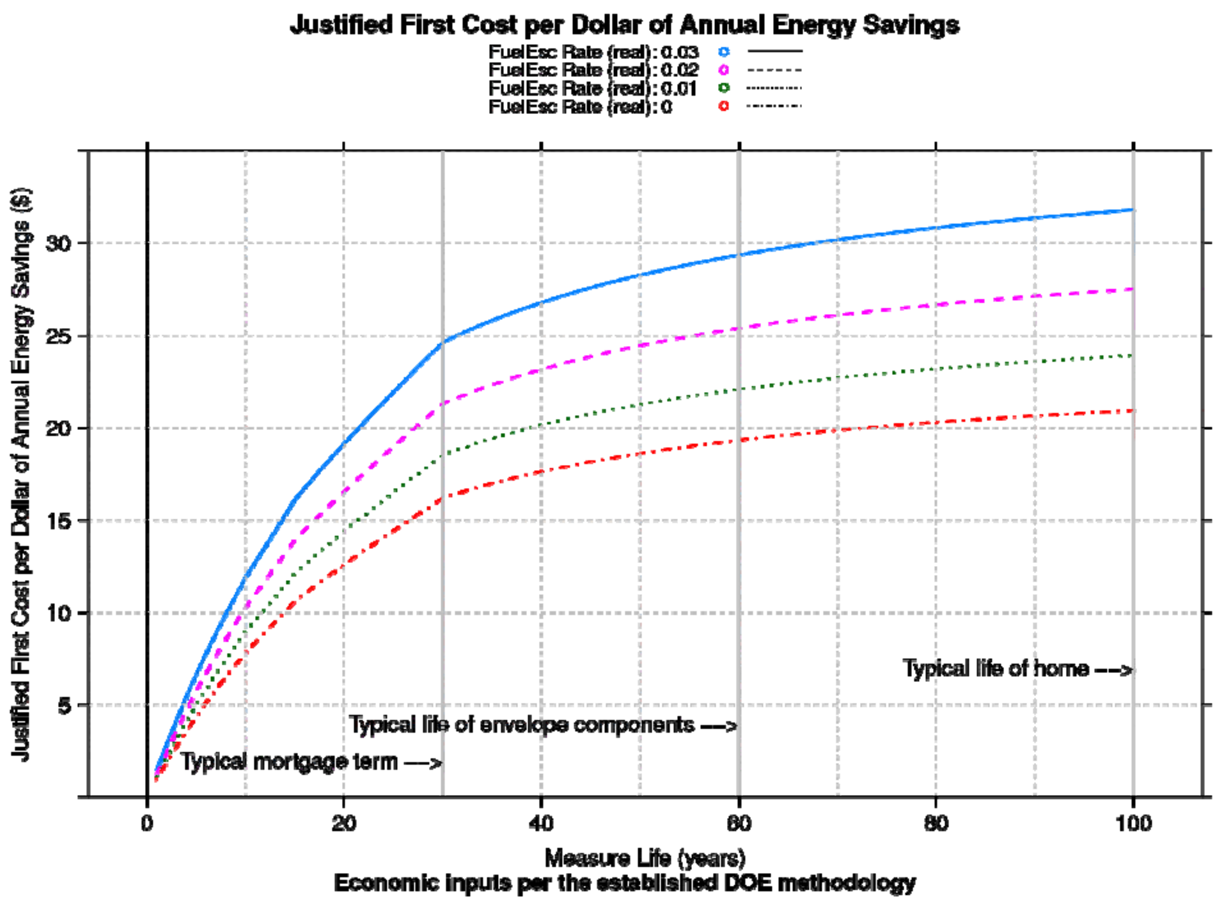

Figure 3: Justified first cost as a function of measure life for a variety of fuel escalation rates

Justified First Cost Illustrated

The United States Department of Energy (DOE) supports the development of energy-efficient cost-effective building energy codes through its Building Energy Codes Program (BECP). With the recent surges in the efficiency levels dictated by the residential provisions of the International Energy Conservation Code (IECC), cost-effectiveness has a renewed focus. At the same time, the development of building energy codes leads the adoption of the codes by several years due to the nature of the code development process. Revision of the code typically takes three years to complete for each edition of the IECC (ICC 2016). The time period between when a code provision is revised or a new one is proposed and when the code actually takes effect is often five years or more—long enough that fluctuations in construction and technology costs are likely.[3] For emerging or new technologies, these fluctuations are more likely to be reductions due to market transformation effects. This means that a provision that is not cost-effective under today's first costs may become cost-effective in a few years, as material and implementation costs decrease. It is beneficial, therefore, to know the justified first cost of a measure, to allow assessment of the probability that it may become cost-effective per DOE's cost-effectiveness methodology. The added benefit of knowing the justified first cost is that other programs and entities working on making new technologies or building practices more commonly accessible can use this information to target the necessary cost premium.

The authors conducted a feasibility analysis of select residential energy efficiency measures to identify building technologies or construction practices with the potential to be included in residential building energy codes in future cycles and to calculate the price point that the technologies must meet in order to be cost-effective per DOE's established residential codes cost-effectiveness methodology (Taylor et al. 2012). Table 1 summarizes the economic parameters used in this analysis to calculate the justified first costs.

Table 1: Summary of Economic Parameters Used in Analysis

Parameter	**Value**
Mortgage Interest Rate	5%
Loan Term	30 years
Down Payment Rate	10% of home price
Loan Fees	0.7% (non-deductible)
Discount Rate (nominal)	5% (equal to mortgage interest rate)
Period of Analysis	30 years
Property Tax Rate	0.9% of home price
Income Tax Rate	25% federal
Home Price Escalation Rate (nominal)	Equal to inflation rate
Inflation Rate	1.6% annual
Energy Prices and Fuel Price Escalation Rates	\$0.1226/kWh (electricity), \$1.033/therm (gas) Escalation of both at 1.6%/year

[3] For example, according to a report published by McKinsey& Company in 2015, the prices of LED lamps have fallen 80% since 2010. http://www.mckinsey.com/industries/oil-and-gas/our-insights/peering-into-energys-crystal-ball

The authors conducted a literature review of residential building technologies commonly used by beyond-code programs like Building America[4] and ENERGYSTAR[5] to identify potential items for consideration. The cost-effectiveness of the resulting candidate efficiency measures was analyzed using DOE's established residential codes cost-effectiveness methodology seeded with the parameters of Table 1 and compared against the residential provisions of the 2015 IECC as the baseline (ICC 2014). The feasibility analysis was conducted using DOE's single- and multifamily prototype buildings with *EnergyPlus*™ (DOE 2013). Each measure along with the efficiency level considered in the feasibility analysis is summarized below.

Ducts in Conditioned Space

Placing ducts in conditioned space has huge advantages in terms of the reduction of conduction and air leakage losses. This can be achieved by several methods including constructing chases through which to run the ducts, converting vented attics and crawlspaces to conditioned spaces, or burying or encapsulating ducts in the surrounding attic insulation. The duct location assumptions for the DOE residential building prototypes are based on the Building America House Simulation Protocols (Wilson et al. 2015). Energy models designed to minimally comply with the requirements of the 2015 IECC were compared with a similar set of models with all ducts placed within the conditioned zone, to evaluate the energy savings for this measure.

Heat Recovery Ventilation (HRV)

New houses are being built tighter than ever before and necessitating whole house ventilation systems. Outside fresh air brought in by ventilation can impose a significant load on the HVAC system of the house, especially in colder climate zones. HRV works on the principle of recovering a portion of energy that would otherwise be exhausted from the house to heat or preheat the incoming stream of fresh air. HRV systems can result in better pressure balancing compared to traditional exhaust-based systems, which can induce negative pressures in the home resulting in undesired air infiltration, indoor air contamination, backdrafting through chimneys, and moisture problems. HRV systems have been used in every Building America project since 2010 and are gaining wide acceptance in the energy conscious building community. The energy savings from a heat recovery system were estimated assuming a conservative 70% sensible heat recovery effectiveness at 100% airflow rate and 75% sensible heat recovery effectiveness at 75% airflow rate, at operating conditions consistent with industry standards for performance testing and reporting. The savings were estimated compared to an equivalent ventilation rate without heat recovery.

[4] See http://energy.gov/eere/buildings/building-america-bringing-building-innovations-market .
[5] See https://www.energystar.gov/campaign/home .

Improved Envelope Air Tightness

Infiltration is the biggest contributor of heat loss in modern homes, and lower air leakage limits have been a significant source of energy savings in recent residential energy codes. The 2012 and 2015 editions of the IECC require all new homes in climate zones 3-8 (roughly the whole country except the Gulf Coast and parts of the desert southwest) to test at or below a three-air changes per hour (ACH) threshold when tested at a 50-Pascal pressure differential (ICC 2011, ICC 2014). Nearly every Building America Project built after 2010 uses building techniques and materials to control air leakage to 1.0 ACH50 or less. The energy savings from this measure were calculated by comparing energy consumption of models with 1.0 ACH50 to those that minimally comply with the requirements of the 2015 IECC.

Better Windows

Windows are one of the biggest contributors of heat loss in homes after infiltration. DOE's Emerging Technologies Program has set a goal of making R-10 (U-0.10) windows available at a projected installed cost premium of less than $\$6/ft^2$ by the year 2025 (DOE 2014). While R-10(U-0.10) windows and DOE's goal are more forward-looking, this analysis evaluated an intermediate level of R-5(U-0.20) windows in the colder IECC climate zones 4-8. The baseline was maintained at the window U-factors prescribed by the 2015 IECC.

Advanced Wall Framing

Advanced wall framing has been practiced by beyond-code programs like Building America for many years. There are many elements to advanced framing; however, this analysis evaluates only one key feature of advanced framing: spacing 2"x6" studs 24" on-center rather than at 16" on-center as is standard practice. Increasing the stud spacing reduces the overall U-factor of the walls, thereby reducing heat lost through the walls, and also saves on material costs because fewer framing members are needed. This measure was evaluated only in IECC climate zones 4-8, where exterior above-grade wall insulation must be R-20 or greater per the provisions of the 2015 IECC, and studs are thus typically 2"x6".

Thicker Exterior Insulating Sheathing

Insulating sheathing on exterior above-grade walls has been required by the IECC in the colder climate zones since 2012 (ICC 2011). Insulating sheathing is effective at reducing the overall U-factor of walls and as a result, the heat loss through them. In this analysis, the justified first cost for an R-26 layer of insulating sheathing was calculated compared to the wall insulation levels prescribed by the 2015 IECC. The analysis was conducted only for climate zones 3-8, in which the 2015 IECC prescribes the use of insulating sheathing or a 2"x6" wall or both. The insulating sheathing was assumed to be a 6.5" thick layer of extruded polystyrene (EPS).

Table 2 summarizes the energy cost savings for the measures evaluated for the residential feasibility study compared to the 2015 IECC baseline, while Table 3 summarizes the justified first cost for each measure.

Table 2: Energy Cost Savings for Analyzed Measures Compared to the 2015 IECC

Measure	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
Ducts inside conditioned space	2.17%	3.42%	2.08%	2.93%	3.13%	3.28%	4.00%	4.97%
Heat recovery ventilation	1.62%	4.22%	4.39%	6.16%	7.93%	10.13%	10.86%	11.71%
Better envelope tightness	6.97%	9.68%	4.35%	7.23%	9.48%	11.83%	15.45%	14.85%
R-5 windows	NA	NA	NA	1.05%	4.40%	6.07%	6.73%	6.81%
Advanced wall framing	NA	NA	NA	0.16%	0.33%	0.22%	0.31%	0.37%
Thicker exterior wall insulating sheathing	NA	NA	7.49%	7.90%	9.21%	7.03%	7.29%	7.56%

Table 3: Justified First Costs for Analyzed Measures Compared to the 2015 IECC

Measure	CZ 1	CZ 2	CZ 3	CZ 4	CZ 5	CZ 6	CZ 7	CZ 8
Ducts inside conditioned space	$0.38/ft^2 duct area	$0.83/ ft^2 duct area	$0.36/ ft^2 duct area	$0.71/ ft^2 duct area	$0.75/ ft^2 duct area	$0.85/ ft^2 duct area	$1.61/ ft^2 duct area	$2.89/ ft^2 duct area
Heat recovery ventilation	$192/ Unit	$674/ unit	$483/ unit	$936/ unit	$1,220/ unit	$1,690/ unit	$2,654/ unit	$3,921/ unit
Better envelope tightness	$0.49/ ft^2 cond. floor area	$0.92/ ft^2 cond. floor area	$0.29/ ft^2 cond. floor area	$0.65/ ft^2 cond. floor area	$0.87/ ft^2 cond. floor area	$1.17/ ft^2 cond. floor area	$2.25/ ft^2 cond. floor area	$2.96/ ft^2 cond. floor area
R-5 windows	NA	NA	NA	$0.71/ ft^2 window area	$3.10/ ft^2 window area	$4.34/ ft^2 window area	$7.05/ ft^2 window area	$9.76/ ft^2 window area
Advanced wall framing	NA	NA	NA	$0.02/ ft^2 wall area	$0.03/ ft^2 wall area	$0.02/ ft^2 wall area	$0.05/ ft^2 wall area	$0.08/ ft^2 wall area
Thicker exterior wall insulating sheathing	NA	NA	$0.53/ ft^2 wall area	$0.77/ ft^2 wall area	$0.91/ ft^2 wall area	$0.75/ ft^2 wall area	$1.14/ ft^2 wall area	$1.63/ ft^2 wall area

Justified First Cost's Limitations

As discussed earlier, justified first cost analysis addresses a number of difficulties that arise in evaluating cost-effectiveness in a code-development context. Perhaps its biggest advantage is that it shifts the focus away from singular cost assumptions, and allows cost-effectiveness calculations to be useful to a much wider audience. However, justified first cost analysis is not a panacea. Its applicability is limited to evaluation of individual efficiency measures. Packages of measures, at least those mixing measures with different lifetimes, cannot be evaluated because there is no way to divvy the justified cost among the multiple measures. The resulting system of LCC equations is in effect underdetermined, having a multitude of potential solutions. For similar reasons, justified first cost is not useful in comparing two mutually exclusive measures unless they share the same useful life or additional constraints are imposed such as preferring the measure with greater energy savings. In this respect, it is similar to an IRR analysis.

Conclusions and Recommendations

The justified first cost method is a simple but useful economic parameter for evaluating energy efficiency measures in buildings, especially in the context of establishing new energy code requirements. The authors have demonstrated its usefulness in R&D planning and suggest that when used within its limitations, it adds useful information to the code development process and has the potential to simplify reasoning and decision making by energy code stakeholders.

Acknowledgments

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