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Cost Effectiveness of Energy Efficiency and On-site Photovoltaic Power for 2015 IECC Energy Rating Index (ERI) Compliance

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Background

The Natural Resources Defense Council (NRDC) contracted the Florida Solar Energy Center (FSEC) to conduct cost effectiveness analysis of new homes configured to comply with the Energy Rating Index (ERI) compliance provisions of Section R406 of the 2015 International Energy Conservation Code (IECC). Simulation analysis of homes configured to comply with the minimum envelope efficiency provisions and mandatory requirements of Section R406.2 of the 2015 IECC were used as the baseline for the analysis. These homes are compared against homes meeting the minimum prescriptive compliance requirements of Section R402 of the 2015 IECC and homes meeting the ERI thresholds of Section R406 of the 2015 IECC across representative U.S. climates. EnergyGauge® USA v.5.1, a RESNET-accredited HERS software tool, is used to conduct the simulation analysis.

This study builds on previous simulation and cost effectiveness analysis work used in the development of the ERI compliance values that were adopted by the 2015 IECC (Fairey 2013). This study extends the earlier work to include cost effectiveness analysis of homes using only energy efficiency to meet the ERI requirements, homes using only on-site photovoltaic power to meet the ERI requirements and homes using a combination of energy efficiency and on-site photovoltaic power to meet the ERI requirements.

Abstract

EnergyGauge® USA v.5.1 is used to simulate the energy use of one-story, three-bedroom, 2000 ft^2, single-family, frame homes in sixteen representative U.S. climates comprising all eight IECC climate zones. The energy use of the Section R406.2 minimum efficiency home (the Baseline Home) is compared against the energy use of homes complying with the prescriptive requirements of Section R402 of the 2015 IECC and against homes complying with the Section R406 Energy Rating Index (ERI) Compliance Alternative. The improvement cost and energy savings of the improved homes relative to the Baseline Home are then used to determine the cost effectiveness of the home improvements.

The Baseline Home is compared against four improved home scenarios, as follows.

1. 2015 IECC prescriptive compliance case
2. Baseline Home + PV case
3. 2015 IECC prescriptive compliance + PV case
4. Energy efficiency only case

Results from the analysis are useful in comparing the cost effectiveness of achieving compliance with Section R406 of the 2015 IECC using the Energy Rating Index (ERI)

and particularly for comparing the cost effectiveness of on-site photovoltaic power generation with the cost effectiveness of improved home efficiency measures.

Methodology

One-story, 2000 ft^2, 3-bedroom, frame homes are configured to represent the minimum envelope efficiencies and mandatory requirements specified by Section R406.2 of the 2015 IECC. These home configurations represent the baseline against which other home configurations are compared for improvement costs and energy cost savings in eleven representative TMY3 locations across six IECC climate regions of the United States. Best case window orientation is simulated such that 35% of the total window area is located on the front (north) and rear (south) faces of the home and 15% is located on the east and west faces. The front of the homes also had a 20-foot adjoining garage wall. The foundation for the homes was varied by IECC climate zone with slab-on-grade foundations in zones 1 - 2, vented crawlspaces in zones 3 - 4, and unconditioned basements in zones 5 - 6.

Baseline Homes

Tables 1 through 5 present the characteristics for the Baseline Home configurations used in the simulation analysis. This baseline represents the Section R406 efficiency "backstops" of the 2015 IECC Energy Rating Index Compliance Alternative. Envelope characteristics are limited to the provisions of the 2009 IECC with "mandatory" requirements of the 2015 IECC included. Thus, the Baseline Home represent the *maximum ERI* allowed under the energy efficiency provisions of the 2015 IECC.

Table 1: General Home Characteristics

Component	Units
Conditioned floor area (ft^2)	2,000
Conditioned volume (ft^3)	18,000
N-S wall length (ft)	50
E-W wall length (ft)	40
1st floor wall height (ft)	9
Door area (ft^2)	40
Window/floor area ratio (%)	15%
Total window area (ft^2)	300
N-S window fraction (%)	35%
E-W window fraction (%)	15%

Table 2: Baseline Component Insulation Values

LOCATION	**IECC CZ**	**Ceiling R-value**	**Wall R-value**	**Found. Type**	**Slab R-value**	**Floor R-value**	**Fen U-factor**	**Fen SHGC**
Miami, FL	1A	30	13	SOG	none	n/a	1.20	0.30
Orlando, FL	2A	30	13	SOG	none	n/a	0.65	0.30
Houston, TX	2A	30	13	SOG	none	n/a	0.65	0.30
Phoenix, AZ	2B	30	13	SOG	none	n/a	0.65	0.30
Charleston, SC	3A	30	13	Crawl	n/a	19	0.50	0.30
Las Vegas, NV	3B	30	13	Crawl	n/a	19	0.50	0.30
Baltimore, MD	4A	38	13	Crawl	n/a	19	0.35	0.40
Chicago, IL	5A	38	13+5	ucBsmt	n/a	30	0.35	0.40
Denver, CO	5B	38	13+5	ucBsmt	n/a	30	0.35	0.40
Minneapolis, MN	6A	49	13+5	ucBsmt	n/a	30	0.35	0.40

LOCATION	IECC CZ	Ceiling R-value	Wall R-value	Found. Type	Slab R-value	Floor R-value	Fen U-factor	Fen SHGC
Billings, MT	6B	49	13+5	ucBsmt	n/a	30	0.35	0.40

Notes for Tables 2:
Wall R-value: 1st value is cavity fill and 2nd value is continuous insulation
SOG = slab on grade
Crawl = crawlspace
ucBsmt = unconditioned basement

Table 3: Additional Baseline Home Characteristics

Item	Value
Envelope Leakage	7 ach50
Air Distribution System Efficiency	See Table 4
Programmable Thermostat	Yes
High Efficiency Lighting	75%
Hot Water Pipe Insulation (R-3)	Yes
Mechanical Ventilation (per ASHRAE 62.2-2013)	See Table 9
Sealed Air Handlers	No

Table 4: Baseline Home Air Distribution Systems (ADS)

Foundation Type	ADS location	Duct R-value	Duct leakage
Slab on grade	Attic/garage AHU	8	8 cfm25/100 ft^2
Crawlspace	Crawlspace	6	8 cfm25/100 ft^2
Basement	Basement	6	8 cfm25/100 ft^2

Base heating and cooling thermostat set point temperatures for all simulations were maintained at 78 °F for cooling and 68 °F for heating with programmable thermostat setup/setback of 2 °F for 6 hours per day in accordance with ANSI/RESNET/ICC Standard 301-2014.

Table 5: Baseline Home Equipment

LOCATION	IECC CZ	Heating System		Cooling System		Water Heater	
		Fuel	Eff	Fuel	SEER	Fuel	EF
Miami, FL	1A	elec	8.2	elec	14	elec (40)	0.95
Orlando, FL	2A	elec	8.2	elec	14	elec (40)	0.95
Houston, TX	2A	elec	8.2	elec	14	elec (40)	0.95
Phoenix, AZ	2B	elec	8.2	elec	14	elec (40)	0.95
Charleston, SC	3A	elec	8.2	elec	14	elec (40)	0.95
Las Vegas, NV	3B	gas	80%	elec	14	gas (40)	0.62
Baltimore, MD	4A	gas	80%	elec	14	gas (40)	0.62
Chicago, IL	5A	gas	80%	elec	13	gas (40)	0.62
Denver, CO	5B	gas	80%	elec	13	gas (40)	0.62
Minneapolis, MN	6A	gas	80%	elec	13	gas (40)	0.62
Billings, MT	6B	gas	80%	elec	13	gas (40)	0.62

Notes for Tables 5 and 7:
Eff = heating system efficiency where gas-fired furnace is given as AFUE (%) and electric heat pump is given as HSPF

The Baseline Home equipment shown in Table 5 is minimally compliant with the 2015 federal standards (U.S. Department of Energy, 10 CFR Part 430) for heating, cooling and water heating equipment.

Improved Homes

In addition to the baseline homes, four additional home configuration scenarios are simulated as follows:

1. 2015 IECC prescriptive compliance case
2. Baseline + PV case
3. 2015 IECC prescriptive compliance + PV case
4. Energy efficiency only case

<u>Scenario 1</u> is configured to be minimally compliant with the prescriptive requirements of Section 402 of the 2015 IECC. The configurations for these homes are given in Table 6 through Table 8. The values in ***bold italic*** font represent changes from the Baseline Home configurations.

Table 6: 2015 IECC Prescriptive Insulation Values used for Scenario 1

LOCATION	**IECC CZ**	**Ceiling R-value**	**Wall R-value**	**Found. Type**	**Slab R-value**	**Floor R-value**	**Fen U-factor**	**Fen SHGC**
Miami, FL	1A	30	13	SOG	none	n/a	***0.50***	***0.25***
Orlando, FL	2A	***38***	13	SOG	none	n/a	***0.40***	***0.25***
Houston, TX	2A	***38***	13	SOG	none	n/a	***0.40***	***0.25***
Phoenix, AZ	2B	***38***	13	SOG	none	n/a	***0.40***	***0.25***
Charleston, SC	3A	***38***	***20***	Crawl	n/a	19	***0.35***	***0.25***
Las Vegas, NV	3B	***38***	***20***	Crawl	n/a	19	***0.35***	***0.25***
Baltimore, MD	4A	***49***	***20***	Crawl	n/a	19	0.35	0.40
Chicago, IL	5A	49	13+5	ucBsmt	n/a	30	***0.32***	0.40
Denver, CO	5B	49	13+5	ucBsmt	n/a	30	***0.32***	0.40
Minneapolis, MN	6A	49	***20***+5	ucBsmt	n/a	30	***0.32***	0.40
Billings, MT	6B	49	***20***+5	ucBsmt	n/a	30	***0.32***	0.40

Notes for Tables 6:

Wall R-value: 1st value is cavity fill and 2nd value is continuous insulation

SOG = slab on grade

Crawl = crawlspace

ucBsmt = unconditioned basement

Table 7: Additional 2015 IECC Home Characteristics

Item	**Value**
Envelope Leakage	***CZ 1-2: 5 ach50*** ***CZ 3-8: 3 ach50***
Air Distribution System Efficiency	See Table 8
Programmable Thermostat	Yes
Hot Water Pipe Insulation (R-3)	Yes
Mechanical Ventilation (per ASHRAE 62.2-2013)	***See Table 9***
Sealed Air Handlers	***Yes***

Table 8: 2015 IECC Home Air Distribution Systems (ADS)

Foundation Type	ADS location	Duct R-value	Duct leakage
Slab on grade	Attic/garage AHU	8	***4*** cfm25/100 ft^2
Crawlspace	Crawlspace	6	***4*** cfm25/100 ft^2
Basement	Basement	6	***4*** cfm25/100 ft^2

The heating, cooling and hot water equipment in the 2015 IECC Homes is the same as the equipment in the Baseline Homes (see Table 5.)

Mechanical ventilation in both the Baseline Homes and the Improved Homes (IECC 2015 or better) is variable by climate location. Table 9 provides the ASHRAE 62.2-2013 weather and shielding factors (wsf) for each location and the resultant mechanical ventilation rates (cfm) used in the simulations for this study.

Table 9: Mechanical Ventilation Rates by Location

Location	**IECC Zone**	**62.2-2013 wsf**	**Mech vent rate (cfm)**	
			Baseline	**IECC 2015**
Miami, FL	1A	0.41	43	57
Orlando, FL	2A	0.39	42	56
Houston, TX	2A	0.42	42	56
Phoenix, AZ	2B	0.43	41	55
Charleston, SC	3A	0.43	41	69
Las Vegas, NV	3B	0.55	30	63
Baltimore, MD	4A	0.50	33	66
Chicago, IL	5A	0.60	30	61
Denver, CO	5B	0.59	30	61
Minneapolis, MN	6A	0.63	30	62
Billings, MT	6B	0.66	30	58

<u>Scenario 2</u> comprises the Baseline Home plus sufficient on-site photovoltaic power to achieve compliance with the ERI score requirements of Table R406.4 of the 2015 IECC. The ERI scores for both the Baseline Home and for 2015 IECC compliance are given in Table 10, showing the ERI point difference that must be compensated by on-site photovoltaic power to achieve 2015 IECC ERI compliance.

Table 10: 2015 IECC Criteria

Climate Zone	Baseline ERI	Compliance ERI
Zone 1	78	52
Zone 2	78	52
Zone 3	77	51
Zone 4	86	54
Zone 5	88	55
Zone 6	88	54

<u>Scenario 3</u> is similar to Scenario 2 except it comprises the 2015 IECC prescriptive compliance Home plus sufficient on-site photovoltaic power to achieve compliance with the ERI compliance score requirements.

<u>Scenario 4</u> comprises only energy efficiency options to achieve the ERI compliance score requirements. The most common efficiency improvements employed in Scenario 4 are 100% high-efficiency lighting; higher efficiency heating, cooling and water heating equipment; interior, leak-free air distribution systems; enhanced envelope efficiencies; and energy star refrigerators, dishwashers and clothes washers.

Appendix A provides the full economic analysis for each of these four scenarios along with a complete listing of the specific home improvements for each scenario and climate location.

Improvement Costs

Incremental improvement costs are determined using the methodology used by Fairey and Parker (2012). In most cases, improvement costs used in the investigation parallel those available from the National Renewable Energy Laboratory's (NREL) National Residential Efficiency Measure Database[1] and from the NAHB (2009) economic database.

For heating and air conditioning equipment costs, Fairey and Parker (2012) relied on a separate methodology whereby the costs are expressed as a function of the equipment capacity and efficiency along with an offset, derived using available retail data and estimated fixed costs. The data and analysis that underlie the heating and cooling equipment cost equations are presented in Appendix B. For certain other costs, the NREL cost data were reduced to equations based on component areas and incremental improvement changes. For example, examination of the NREL data on blown cellulose insulation reveals that the cost is approximately $0.034/ft^2 per R-value. For these types of improvements these costs are cast in such terms. For most other costs, the costs contained in the NREL database are adopted.

For ENERGY STAR appliance costs, representative pricing from the internet is used to determine incremental costs. However, this is difficult because most new appliances are now ENERGY STAR compliant and it is often difficult to find appliances with similar features that are not rated as ENERGY STAR.

Attic radiant barrier systems (RBS) are employed to enhance efficiency in a number of cooling dominated and mixed climate homes. The cost of the RBS is determined as $0.25 per square foot of roof area. For each of the improved homes, the forced air distribution systems is brought into the conditioned space and tested to be leak free. The cost of this improvement is taken as $0.50 per square foot of conditioned floor area.

For HVAC equipment, the following equations are used to calculate installed costs (see Appendix B for derivations).

- Heat pumps: –5539 + 604*SEER + 699*tons
- Air conditioners (with strip heat): –1409 + 292*SEER + 520*tons
- Gas furnace/air conditioner: –6067 + 568*SEER + 517*tons + 4.04*kBtu + 1468*AFUE
- Gas furnace only: –3936 + 14.95*kBtu + 5865*AFUE

where:

tons = air conditioning capacity, which is limited to a minimum value of 1.5 tons
kBtu = gas furnace capacity, which is limited to a minimum value of 40 kBtu

[1] www.nrel.gov/ap/retrofits/index.cfm

The estimating equations are valid for heat pump and cooling system sizes of 1.5–5 tons. Similarly, the costs of gas heating equipment are based on heating capacities of 40–120 kBtu/h.

For envelope measures, incremental costs are determined as the difference between the measure cost for the Baseline Home component and the measure cost for the Improved Home component. For example, if the ceiling insulation level requirement in the Baseline Home is R-30 and it is increased to R-38 in the Improved Home, the incremental cost would be the R-value difference (8) times $0.034 per square foot of ceiling area (for blown cellulose).

Wall R-value is increased in some Improved Homes. Wall R-value may be increased in two ways: 1) the sheathing insulation R-value may be increased and 2) the wall cavity insulation R-value may be increased. Where the sheathing insulation R-value is increased, it is increased from R-5 (base case) to R-10. The incremental cost for this increase is taken as the difference in cost between the R-5 XPS base case ($1.30/ft^2) and the R-10 XPS improved case ($1.70/ft^2), as given in the NREL cost database.[2] The cost for the R-5 XPS base case sheathing can also be cross checked by examining the NAHB (2009) economic database developed in support of 90.2 (ASHRAE 1481-RP). Matrix B.1 of this report provides the cost values shown in Table 11.

Table 11: Construction cost for wood frame walls with fiberglass insulation

Construction	$/ft^2	Δ $/ft^2	
2x4, 16” oc; R-13	$5.72	---	base wall
add R-5 XPS	$6.95	$1.23	increase for sheathing on 2x4 walls
2x6, 24” oc; R21	$6.58	$0.86	increase for 2X6 studs + R-21
add R-5 XPS	$7.69	$1.97	increase for 2x6 + R-21 + R-5 sheathing

Table 11 data show the added cost for R-5 XPS sheathing to be $1.23/ft^2 of wall, which is very similar to the NREL cost database value of $1.30/ft^2. The ASHRAE 1481-RP report does not report construction costs for R-10 XPS so the values given in the NREL cost database are used for sheathing insulation improvements in the economic cost effectiveness analysis conducted here.

For wall cavity insulation, R-value may be increased from R-13 for 2x4 frame walls to R-20 for 2x6 frame walls. Table 11 shows that this increase in cavity wall R-value, including the change from 2x4 studs on 16” centers to 2x6 studs on 24” centers, has an incremental cost of $0.86/ft^2. The wall construction costs shown in Table 8 are used for wall cavity insulation improvements for the economic cost effectiveness analysis conducted here.

Window thermal characteristics are also improved. Window improvement costs are given as a function of window U-factor by ASHRAE 1481-RP. Figure 1 of ASHRAE 1481-RP casts the incremental window cost above the cost of a standard, double pane window in terms of an exponential equation as a function of window U-factor, as follows:

$$\text{Incremental Window Cost} = 1851.9 * e^{(-19.29 * U)} \qquad \text{Eq. 1}$$

[2] http://www.nrel.gov/ap/retrofits/measures.cfm?gId=12&ctId=410

Equation 1 represents the incremental cost of improving the window U-Factor with respect to the cost of the standard, double pane window of the same frame type. Table 3 of ASHRAE 1481-RP provides 2009 construction costs for 5 standard, double pane, vinyl, frame windows with an average U-factor of 0.49 and an average cost of $15.09. Escalating this cost from 2009 to 2015 at a general inflation rate of 2.5% yields an average 2015 cost of $17.50. Thus, the total cost of vinyl frame windows in new construction can be represented by the equation 2.

$$\text{Window Cost} = \$17.50 + 1851.9 * e^{(-19.29 * U)} \qquad \text{Eq. 2}$$

Incremental window improvement costs as a function of U-factor can also be derived from data provided in the NREL cost database.[3] Figure 1 shows the results from such an analysis of the incremental costs in the NREL cost database. While the resulting exponential equation has somewhat different coefficient values, the results are quite close and provide an additional level of confidence in the ASHRAE 1481-RP data in that they can be effectively confirmed using a second, independent data source. Figure 2 shows the similarity between the resulting equations along with the three window U-factors specified by the 2015 IECC, where climate zone 1 = 0.40, zones 2-4 = 0.35 and zones 5-8 = 0.32.

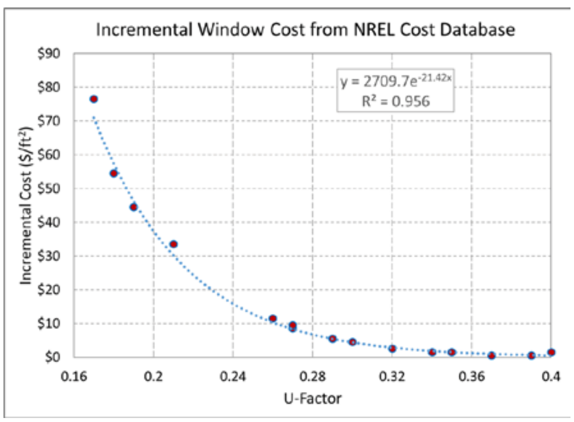

Figure 1: Incremental window cost versus window U-Factor derived from NREL cost database.

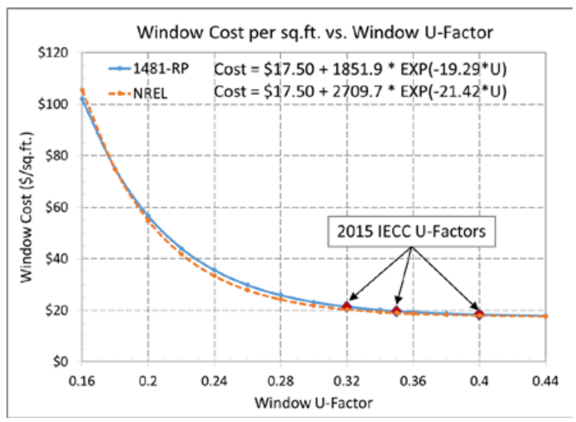

Figure 2: Comparison of ASHRAE 1481-RP window costs and NREL database window costs.

Equation 2 is used in this study to determine baseline and improved window costs where windows are improved.

Installed PV costs are taken at $4.00/Wp (watts at peak solar). This cost is somewhat greater than the costs reported by the Solar Market Research Report for the 3rd quarter of 2014, which shows residential turnkey Rooftop PV system costs steadily declining from $3.83/Wp during the 1st quarter of 2014 to $3.60/Wp in the 3rd quarter of the year.[4] A 30% income tax credit (ITC) is applied to the $4.00/Wp cost of PV systems. Net metering is assumed for the PV systems. PV power production is subtracted from the total electricity energy use of the home to arrive at the net electricity use for the homes given in Appendix A and in the tables contained in the findings of the study.

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[3] http://www.nrel.gov/ap/retrofits/measures.cfm?gId=16&ctId=190

[4] http://www.seia.org/research-resources/solar-market-insight-report-2014-q3

Economic Analysis

Economic analysis is based on a 30-year, present value, life-cycle-cost analysis using the methodology specified by Section 4.6, ANSI/RESNET 301-2014, which is based on the P1, P2 method of determining present worth values by Duffie and Beckman (1980). The equations used to determine P1 and P2 are given in Appendix C. The economic parameter values published on the RESNET web site for 2014[5] are used in the analysis. These economic parameter values are given in Table 12.

Table 12: Economic Parameter Values

General Inflation Rate (GR)	2.53%
Discount Rate (DR)	4.53%
Mortgage Interest Rate (MR)	5.42%
Down payment Rate (DnPmt)	10.00%
Energy Inflation Rate (ER)	4.18%

The life-cycle-cost analysis includes replacement costs (escalated at the general inflation rate) for measures lasting less than the full analysis period (standard residential mortgage period of 30 years in this case). For example, HVAC equipment, with an assumed service life of 15 years, would be replaced in year 16 and high efficiency CFL lighting, with an assumed service life of 5 years, would be replaced five times during the analysis period. Where incremental maintenance is required, a maintenance fraction is also included in the analysis.

Energy prices used in the economic analysis are the 2015 annual average U.S. prices for residential electricity and natural gas as provided by the U.S. Energy Information Administration.[6] The base prices used for the analysis are \$0.1267/kWh for residential electricity[7] and \$1.038/therm for residential natural gas.[8] Energy prices are not varied by location in this report.

Cost Effectiveness

For the purposes of this study 'cost effective' is defined as the case in which the present value of the life-cycle energy cost reductions (the savings) exceeds the present value of the life-cycle improvement costs (the investment). The ratio of these two present values (Savings / Investment) is referred to as the savings-to-investment ratio or SIR. If the SIR is greater than unity, there is a net financial benefit derived from the investment. The net present value (NPV) of the improvements is also calculated, where NPV equals the present value of the life-cycle energy cost savings minus the present value of the life-cycle improvement costs.

[5] http://www.resnet.us/professional/standards/mortgage
[6] http://www.eia.gov/
[7] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3
[8] http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm

Figure 3 illustrates life-cycle cost economic analysis theory with respect to residential energy efficiency. The Baseline Home has no improvement costs, no energy savings and 100% of the Baseline life-cycle total costs (the red dot on the plot). The Improvement Cost curve (dotted red line) represents the life-cycle costs of energy improvements that can be made to the baseline home. There are normally improvements that can be made to the baseline home that will reduce energy use at very low cost. However, as energy use continues to be reduced, the cost of the improvements per unit of energy savings increases, resulting in an Improvement Cost curve that is exponential in nature. The sum of the Improvement Cost curve and the Energy Cost line (dashed purple line) yield the Total Cost curve (solid green line).

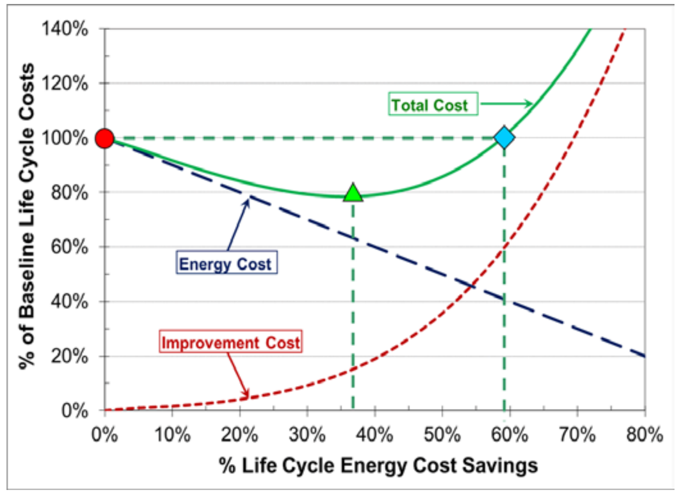

Figure 3: Generalized plot of life-cycle cost economic analysis theory.

There is a point on the Total Cost curve where the present value of the life-cycle cost of the residence is minimized. For Figure 3, this point occurs at about 37% life-cycle energy cost savings (light green tringle). There is another point on the Total Cost curve where the total life-cycle cost of the improved home is equal to the total life-cycle cost of the baseline home (light blue diamond at about 59% life-cycle energy cost savings). This point is often referred to as the neutral cost point. By definition it has an SIR of exactly 1.0 (i.e. life-cycle costs = life-cycle savings). While Figure 3 is only illustrative, it accurately represents the principles of life-cycle cost economics and cost effectiveness for home energy improvements.

Findings

The summary of findings in this study are presented in Tables 13 - 16 for each study scenario by IECC climate zone. Results are given as climate zone averages for the TMY3 sites in each climate zone. The column labels are as follows:

ERI = Energy Rating Index (per ANSI/RESNET/ICC Standard 301-2014)
1[st] Cost = initial cost of energy improvements with respect to the Baseline Home
LC Cost = present value of the life-cycle energy improvement costs
1stYr Save = initial year energy cost savings with respect to the Baseline Home
LC Save = present value of the life-cycle energy cost savings
NPV = Net Present Value of energy improvements = (LC Save) - (LC Cost)
SIR = Saving/Investment Ratio = (LC Save) / (LC Cost)

Table 13. Summary results for Scenario 1: 2015 IECC prescriptive compliance case

Climate Zone	ERI	1st Cost	LC Cost	1stYr Save	LC Save	NPV	SIR
Zone 1	70	$258	$243	$63	$1,717	$1,475	7.07
Zone 2	68	$800	$576	$94	$2,568	$1,992	4.46
Zone 3	64	$2,423	$2,168	$157	$4,281	$2,113	1.97
Zone 4	73	$2,080	$1,802	$164	$4,491	$2,689	2.49
Zone 5	77	$1,498	$1,474	$124	$3,395	$1,921	2.30
Zone 6	75	$1,974	$1,927	$183	$5,007	$3,080	2.60

Table 13 illustrates the fact that compliance with the prescriptive minimum efficiency requirements of the 2015 IECC is highly cost effective. Interestingly, the largest SIR occurs in the climate (zone 1) with the smallest stringency increase between the 2009 and 2015 IECC and the smallest SIR occurs in the climate (zone 3) with the largest stringency increase between the 2009 and 2015 IECC.

However, compliance with only these minimum prescriptive requirements does not achieve ERI scores that are compliant with Section R406 of the 2015 IECC.

Table 14. Summary results for Scenario 2: Baseline Home + PV case

Climate Zone	ERI	1st Cost	LC Cost	1stYr Save	LC Save	NPV	SIR
Zone 1	52	$7,140	$10,870	$467	$12,756	$1,886	1.17
Zone 2	52	$7,000	$10,657	$469	$12,818	$2,161	1.20
Zone 3	51	$7,245	$11,030	$519	$14,187	$3,158	1.29
Zone 4	54	$11,550	$17,584	$693	$18,947	$1,363	1.08
Zone 5	55	$11,340	$17,264	$702	$19,194	$1,930	1.11
Zone 6	54	$13,440	$20,461	$818	$22,353	$1,893	1.09

On the other hand, the ERI scores for Scenario 2 shown in Table 14 are fully compliant with Section R406 of the 2015 IECC. However, because these scores are achieved using only on-site photovoltaic power, the NPV and SIR for Scenario 2 are significantly smaller than for Scenario 1, with climate zones 4 and 6 showing only marginal cost effectiveness.

Table 15. Summary results for Scenario 3: 2015 IECC + PV case

Climate Zone	ERI	1st Cost	LC Cost	1stYr Save	LC Save	NPV	SIR
Zone 1	52	$6,348	$9,514	$461	$12,596	$3,082	1.32
Zone 2	52	$5,840	$8,249	$429	$11,730	$3,481	1.42
Zone 3	51	$6,565	$8,455	$444	$12,145	$3,690	1.44
Zone 4	54	$9,640	$13,311	$618	$16,890	$3,579	1.27
Zone 5	55	$9,793	$14,102	$640	$17,485	$3,383	1.24
Zone 6	54	$11,214	$15,994	$744	$20,339	$4,345	1.27

Scenario 3 combines the enhanced efficiency measures of the 2015 IECC prescriptive compliance case with sufficient on-site photovoltaic power to achieve Section R406 ERI compliance. This scenario requires smaller photovoltaic systems to reach this ERI compliance thresholds than does Scenario 2 and takes advantage of the improved energy efficiency cost effectiveness of the 2015 IECC prescriptive compliance to achieve larger NPV and SIR results than Scenario 2.

Table 16. Summary results for Scenario 4: Efficiency only case

Climate Zone	ERI	1st Cost	LC Cost	1stYr Save	LC Save	NPV	SIR
Zone 1	52	$3,086	$5,367	$410	$11,211	$5,844	2.09
Zone 2	52	$3,613	$5,673	$421	$11,515	$5,842	2.03
Zone 3	51	$3,846	$5,858	$427	$11,664	$5,805	1.99
Zone 4	54	$3,852	$5,246	$455	$12,432	$7,186	2.37
Zone 5	55	$3,361	$5,086	$425	$11,614	$6,528	2.28
Zone 6	54	$3,793	$5,457	$499	$13,632	$8,176	2.50

Scenario 4 comprises only energy efficiency upgrades to achieve R406 ERI compliance scores. This scenario achieves the larges NPV and SIR of the four scenarios. Thus, it is the most cost effective means of R406 ERI compliance of the scenarios studied. In all climate zones other than zone 3 the SIR exceeds a value of 2.0, meaning that the present value of life-cycle energy cost savings are at least two times greater than the present value of the life-cycle improvement costs.

Conclusions

Achieving compliance with the ERI provisions of the 2015 IECC can be cost effective in all cases studied. While cost effective compliance may be achieved using only on-site photovoltaic power generation, compliance using energy efficiency measures is shown to have greater economic cost effectiveness in all cases studied.

Energy Efficiency-Only Scenarios (Scenario 1 and Scenario 4)

Scenario 1 (2015 IECC Prescriptive Compliance Case) and Scenario 4 (complying with the ERI path using only energy efficiency measures) have the highest savings-to-investment ratios of the four scenarios. The present value of the savings from energy efficiency in both of these scenarios is at least double the costs: for every dollar invested in energy efficiency, a homeowner will receive $2 or more in energy savings.

Scenario 4 has the highest NPV of any of the scenarios, and still has a SIR greater than 2 for all climate zones except climate zone 3. Overall, this is the most cost-effective scenario over the life of the energy efficiency improvements: it is best, from a consumer economics perspective, to have a home that complies with the ERI pathway of the 2015 IECC using only energy efficiency.

In addition, the energy-efficiency-only Scenarios 1 and 4 have lower first costs for the consumer than Scenarios 2 or 3 (both of which involve the consumer purchasing a PV system). Complying with the ERI path of the code using only efficiency (Scenario 4) has a higher first cost than complying with the prescriptive path of the code (Scenario 1), but also has a much higher lifecycle cost savings and NPV in all climate zones. A home built under the ERI compliance method is significantly more efficient than a home built under the prescriptive compliance method, so the additional savings are expected.

PV Scenarios(Scenarios 2 and 3)

Scenarios 2 and 3 comply with the ERI path of the code, using various combinations of energy efficiency measures and purchased PV systems. Both scenarios are cost-effective for the consumer, though they both have a lower NPV and SIR than the efficiency-only scenarios due to the upfront cost of the PV system. Lifecycle savings are higher than in the efficiency-only scenarios but so are lifecycle costs. Therefore, the cost-effectiveness of both PV scenarios is highly sensitive to the cost of the PV system, including the impact of available tax credits. As PV prices continue to decline, there may be a tipping point when homes that include PV become more cost-effective for the consumer than homes that comply with the code using only efficiency. However, we are not yet at that price point. Under the assumptions made in this report, the cost of PV would need to be $2.00-$2.25 per peak Watt before this is the case.

Of the two PV scenarios, it is more economically beneficial from a consumer perspective to have an efficient home prior to "filling the gap" with PV. Scenario 3, where the home meets the 2015 IECC prescriptive requirements prior to installing a PV system, has lower first costs, lower lifecycle costs, and higher NPV and SIR than the home in Scenario 2 that meets only the minimum efficiency requirements.

There are many benefits of PV, including reduced utility bills and low carbon production. On-site PV helps jurisdictions meet net-zero energy consumption goals and producing energy is very desirable for both consumers and builders. However, from a consumer economics perspective, it is still most beneficial to ensure that the home is energy efficient prior to investing in on-site power generation.

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Miami Homes (Base attic ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	11,900	0	$1,508	75	11,404	0	$1,445	70	No
2: Max ERI + PV	11,900	0	$1,508	75	8,216	0	$1,041	52	Yes
3: 2015 Min + PV	11,900	0	$1,508	75	8,262	0	$1,047	52	Yes
4: High Eff	11,900	0	$1,508	75	8,662	0	$1,097	52	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	496	0	$63	4.2%	$258	$243	$1,717	$1,475	7.07
2: Max ERI + PV	3,684	0	$467	31.0%	$7,140	$10,870	$12,756	$1,886	1.17
3: 2015 Min + PV	3,638	0	$461	30.6%	$6,348	$9,514	$12,596	$3,082	1.32
4: High Eff	3,238	0	$410	27.2%	$3,086	$5,367	$11,211	$5,844	2.09

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	2,550	$0	$7,140	$7,140	30	1.94%	1.522	$10,870
			Totals	**$7,140**				**$10,870**

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14HP*	$4,665	$4,606	-$58	15		1.839	-$107
Capacity (kBtu)	30.0	29.0					
SEER	14	14					
HSPF	8.2	8.2					
Windows: 1.2/0.3→0.5/0.25	$5,250	$5,286	$36	30		1.096	$39
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
		Totals	**$258**				**$243**

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14HP*		$4,665	$4,606	-$58	15		1.839	-$107
Capacity (kBtu)		30.0	29.0					
SEER		14.0	14.0					
HSPF		8.2	8.2					
Windows: 1.2/0.3→0.5/0.25		$5,250	$5,286	$36	30		1.096	$39
Envelope: 7 ach50→5 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
PV System (Wdc):	2,175	$0	$6,090	$6,090	30	1.94%	1.522	$9,271
			Totals	**$6,348**				**$9,514**

Miami Homes (Base attic ADS; Qn=0.08)

High Efficiency Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER15.5HP*	$4,665	$4,988	$324	15		1.839	$595
Capacity (kBtu)	30.0	20.0					
SEER	14.0	15.5					
HSPF	8.2	8.8					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 1.2/0.3→0.5/0.25	$5,250	$5,286	$36	30		1.096	$39
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
RBS	$0	$542	$542	30		1.096	$594
HPWH	$300	$1,000	$700	15	2.22%	2.327	$1,629
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,086**				**$5,367**

* Heat Pump cost calculations based on capacity, SEER and HSPF

Orlando Homes (Base attic ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	10,743	0	$1,361	75	10,268	0	$1,301	69	No
2: Max ERI + PV	10,743	0	$1,361	75	7,457	0	$945	52	Yes
3: 2015 Min + PV	10,743	0	$1,361	75	7,701	0	$976	52	Yes
4: High Eff	10,743	0	$1,361	75	7,759	0	$983	52	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	475	0	$60	4.4%	$803	$583	$1,645	$1,061	2.82
2: Max ERI + PV	3,286	0	$416	30.6%	$6,720	$10,230	$11,378	$1,147	1.11
3: 2015 Min + PV	3,042	0	$385	28.3%	$6,053	$8,576	$10,533	$1,957	1.23
4: High Eff	2,984	0	$378	27.8%	$3,969	$6,329	$10,332	$4,003	1.63

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	2,400	$0	$6,720	$6,720	30	1.94%	1.522	$10,230
			Totals	**$6,720**				**$10,230**

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14HP*	$4,665	$4,391	-$274	15		1.839	-$503
Capacity (kBtu)	30.0	25.3					
SEER	14.0	14.0					
HSPF	8.2	8.2					
Windows: 0.65/0.3→0.40/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
		Totals	**$803**				**$583**

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14HP*		$4,665	$4,391	-$274	15		1.839	-$503
Capacity (kBtu)		30.0	25.3					
SEER		14.0	14.0					
HSPF		8.2	8.2					
Windows: 0.65/0.3→0.4/0.25		$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38		$2,068	$2,620	$552	50		0.919	$507
PV System (Wdc):	1,875	$0	$5,250	$5,250	30	1.94%	1.522	$7,993
			Totals	**$6,053**				**$8,576**

Orlando Homes (Base attic ADS; Qn=0.08)

High Efficiency Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER15.5HP*	$4,665	$5,110	$446	15		1.839	$820
Capacity (kBtu)	30.0	22.1					
SEER	14.0	15.5					
HSPF	8.2	8.6					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 0.65/0.3→0.40/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
RBS	$0	$542	$542	30		1.096	$593
HPWH	$300	$1,000	$700	15	2.22%	2.327	$1,629
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,969**				**$6,329**

* Heat Pump cost calculations based on capacity, SEER and HSPF

Houston Homes (Base attic ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				**Improved Homes**				
Scenario	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**Complies**
1: 2015 Min	11,990	0	$1,519	77	11,188	0	$1,418	70	No
2: Max ERI + PV	11,990	0	$1,519	77	8,033	0	$1,018	52	Yes
3: 2015 Min + PV	11,990	0	$1,519	77	8,347	0	$1,058	52	Yes
4: High Eff	11,990	0	$1,519	77	8,471	0	$1,073	52	Yes

	Savings over Max ERI Home				**Costs Effectiveness**			P1 =	27.328
Scenario	**Δ kWh/y**	**Δ Th/y**	**Δ $/yr**	**%save**	**1stCost**	**LC Cost**	**LC Save**	**NPV**	**SIR**
1: 2015 Min	802	0	$102	6.7%	$786	$551	$2,777	$2,226	5.04
2: Max ERI + PV	3,957	0	$501	33.0%	$8,190	$12,468	$13,701	$1,233	1.10
3: 2015 Min + PV	3,643	0	$462	30.4%	$6,666	$9,503	$12,614	$3,111	1.33
4: High Eff	3,519	0	$446	29.3%	$3,905	$6,211	$12,184	$5,974	1.96

Max ERI + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
PV System (Wdc):	2,925	$0	$8,190	$8,190	30	1.94%	1.522	$12,468
			Totals	**$8,190**				**$12,468**

2015 Min Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14HP*	$5,072	$4,781	-$291	15		1.839	-$536
Capacity (kBtu)	37.0	32.0					
SEER	14.0	14.0					
HSPF	8.2	8.2					
Windows: 0.65/0.3→0.4/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
		Totals	**$786**				**$551**

2015 Min + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14HP*		$5,072	$4,781	-$291	15		1.839	-$536
Capacity (kBtu)		37.0	32.0					
SEER		14.0	14.0					
HSPF		8.2	8.2					
Windows: 0.65/0.3→0.4/0.25		$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38		$2,068	$2,620	$552	50		0.919	$507
PV System (Wdc):	2,100	$0	$5,880	$5,880	30	1.94%	1.522	$8,952
			Totals	**$6,666**				**$9,503**

Houston Homes (Base attic ADS; Qn=0.08)

High Efficiency Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER15.5HP*	$5,072	$5,454	$382	15		1.839	$702
Capacity (kBtu)	37.0	28.0					
SEER	14.0	15.5					
HSPF	8.2	8.6					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 0.65/0.3→0.40/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
RBS	$0	$542	$542	30		1.096	$593
HPWH	$300	$1,000	$700	15	2.22%	2.327	$1,629
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,905**				**$6,211**

* Heat Pump cost calculations based on capacity, SEER and HSPF

Phoenix Homes (Base attic ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				**Improved Homes**				
Scenario	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**Complies**
1: 2015 Min	13,016	0	$1,649	74	12,068	0	$1,529	66	No
2: Max ERI + PV	13,016	0	$1,649	74	9,153	0	$1,160	52	Yes
3: 2015 Min + PV	13,016	0	$1,649	74	9,538	0	$1,208	52	Yes
4: High Eff	13,016	0	$1,649	74	9,542	0	$1,209	52	Yes

	Savings over Max ERI Home				**Costs Effectiveness**			P1 =	27.328
Scenario	**Δ kWh/y**	**Δ Th/y**	**Δ $/yr**	**%save**	**1stCost**	**LC Cost**	**LC Save**	**NPV**	**SIR**
1: 2015 Min	948	0	$120	7.3%	$809	$594	$3,282	$2,688	5.53
2: Max ERI + PV	3,863	0	$489	29.7%	$6,090	$9,271	$13,376	$4,104	1.44
3: 2015 Min + PV	3,478	0	$441	26.7%	$4,799	$6,668	$12,042	$5,374	1.81
4: High Eff	3,474	0	$440	26.7%	$2,964	$4,481	$12,029	$7,548	2.68

Max ERI + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
PV System (Wdc):	2,175	$0	$6,090	$6,090	30	1.94%	1.522	$9,271
			Totals	**$6,090**				**$9,271**

2015 Min Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14HP*	$4,665	$4,397	-$268	15		1.839	-$493
Capacity (kBtu)	30.0	25.4					
SEER	14.0	14.0					
HSPF	8.2	8.2					
Windows: 0.65/0.3→0.40/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
		Totals	**$809**				**$594**

2015 Min + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14HP*		$4,665	$4,397	-$268	15		1.839	-$493
Capacity (kBtu)		30.0	25.4					
SEER		14.0	14.0					
HSPF		8.2	8.2					
Windows: 0.65/0.3→0.4/0.25		$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38		$2,068	$2,620	$552	50		0.919	$507
PV System (Wdc):	1,425	$0	$3,990	$3,990	30	1.94%	1.522	$6,074
			Totals	**$4,799**				**$6,668**

Phoenix Homes (Base attic ADS; Qn=0.08)

High Efficiency Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER14HP*	$4,665	$4,105	-$559	15		1.839	-$1,028
Capacity (kBtu)	30.0	20.4					
SEER	14.0	14.0					
HSPF	8.2	8.2					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 0.65/0.3→0.40/0.25	$5,252	$5,498	$246	30		1.096	$269
Envelope: 7 ach50→5 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
RBS	$0	$542	$542	30		1.096	$593
HPWH	$300	$1,000	$700	15	2.22%	2.327	$1,629
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$2,964**				**$4,481**

* Heat Pump cost calculations based on capacity, SEER and HSPF

Charleston Homes (Base crawl ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	12,846	0	$1,628	76	11,513	0	$1,459	65	No
2: Max ERI + PV	12,846	0	$1,628	76	8,550	0	$1,083	51	Yes
3: 2015 Min + PV	12,846	0	$1,628	76	8,935	0	$1,132	51	Yes
4: High Eff	12,846	0	$1,628	76	8,872	0	$1,124	51	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	1,333	0	$169	10.4%	$2,402	$2,129	$4,615	$2,487	2.17
2: Max ERI + PV	4,296	0	$544	33.4%	$8,400	$12,788	$14,875	$2,087	1.16
3: 2015 Min + PV	3,911	0	$496	30.4%	$7,326	$9,587	$13,542	$3,955	1.41
4: High Eff	3,974	0	$504	30.9%	$3,913	$5,952	$13,760	$7,808	2.31

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	3,000	$0	$8,400	$8,400	30	1.94%	1.522	$12,788
			Totals	$8,400				$12,788

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14HP*	$4,548	$4,286	-$262	15		1.839	-$482
Capacity (kBtu)	28.0	23.5					
SEER	14.0	14.0					
HSPF	8.2	8.2					
Windows: 0.5/0.3→0.35/0.25	$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
		Totals	$2,402				$2,129

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14HP*		$4,665	$4,286	-$379	15		1.839	-$696
Capacity (kBtu)		30.0	23.5					
SEER		14.0	14.0					
HSPF		8.2	8.2					
Windows: 0.5/0.3→0.35/0.25		$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38		$2,068	$2,620	$552	50		0.919	$507
Wall cavity: R-13→R-20		$2,264	$3,483	$1,219	50		0.919	$1,121
PV System (Wdc):	1,800	$0	$5,040	$5,040	30	1.94%	1.522	$7,673
			Totals	$7,326				$9,587

Charleston Homes (Base crawl ADS; Qn=0.08)							
High Efficiency Home							
Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER15HP*	$4,665	$4,686	$22	15		1.839	$40
Capacity (kBtu)	30.0	20.0					
SEER	14.0	15.0					
HSPF	8.2	8.8					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 0.5/0.3→0.35/0.25	$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
RBS	$0	$542	$542	30		1.096	$593
HPWH	$300	$1,000	$700	15	2.22%	2.327	$1,629
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,913**				**$5,952**

* Heat Pump cost calculations based on capacity, SEER and HSPF

Las Vegas Homes (Base crawl ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				**Improved Homes**				
Scenario	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**Complies**
1: 2015 Min	9,372	330	$1,530	72	8,781	263	$1,386	62	No
2: Max ERI + PV	9,372	330	$1,530	72	5,514	325	$1,036	51	Yes
3: 2015 Min + PV	9,372	330	$1,530	72	6,653	283	$1,137	51	Yes
4: High Eff	9,372	330	$1,530	72	7,559	214	$1,180	51	Yes

	Savings over Max ERI Home				**Costs Effectiveness**			P1 =	27.328
Scenario	**Δ kWh/y**	**Δ Th/y**	**Δ $/yr**	**%save**	**1stCost**	**LC Cost**	**LC Save**	**NPV**	**SIR**
1: 2015 Min	591	67	$144	9.4%	$2,445	$2,207	$3,947	$1,740	1.79
2: Max ERI + PV	3,858	5	$494	32.3%	$6,090	$9,271	$13,500	$4,229	1.46
3: 2015 Min + PV	2,719	47	$393	25.7%	$5,805	$7,322	$10,748	$3,425	1.47
4: High Eff	1,813	116	$350	22.9%	$3,779	$5,765	$9,568	$3,803	1.66

Max ERI + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
PV System (Wdc):	2,175	$0	$6,090	$6,090	30	1.94%	1.522	$9,271
			Totals	**$6,090**				**$9,271**

2015 Min Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14GF80*	$4,332	$4,112	-$219	15		1.839	-$403
Cooling Capacity (kBtu)	27.0	22.5					
SEER	14.0	14.0					
Heating Cap (kBtu)	27.0	20.7					
AFUE	0.80	0.80					
Windows: 0.5/0.3→0.35/0.25	$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
		Totals	**$2,445**				**$2,207**

2015 Min + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14GF80*		$4,332	$4,112	-$219	15		1.839	-$403
Capacity (kBtu)		27.0	22.5					
SEER		14.0	14.0					
Heating Cap (kBtu)		27.0	20.7					
AFUE		0.80	0.80					
Windows: 0.5/0.3→0.35/0.25		$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38		$2,068	$2,620	$552	50		0.919	$507
Wall cavity: R-13→R-20		$2,264	$3,483	$1,219	50		0.919	$1,121
PV System (Wdc):	1,200	$0	$3,360	$3,360	30	1.94%	1.522	$5,115
			Totals	**$5,805**				**$7,322**

Las Vegas Homes (Base crawl ADS; Qn=0.08)							
High Efficiency Home							
Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER16GF92*	$4,332	$5,360	$1,029	15		1.839	$1,892
Capacity (kBtu)	27.0	21.2					
SEER	14.0	16.0					
Heating Cap (kBtu)	27.0	18.7					
AFUE	0.80	0.92					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Windows: 0.5/0.3→0.35/0.25	$5,286	$5,900	$614	30		1.096	$672
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-30→R-38	$2,068	$2,620	$552	50		0.919	$507
gasWH (EF=0.67)	$600	$700	$100	15		1.839	$184
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,779**				**$5,765**

*Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Baltimore Homes (Base crawl ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				**Improved Homes**				
Scenario	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**Complies**
1: 2015 Min	7,443	684	$1,653	84	7,252	549	$1,489	73	No
2: Max ERI + PV	7,443	684	$1,653	84	1,971	684	$960	54	Yes
3: 2015 Min + PV	7,443	684	$1,653	84	3,671	549	$1,035	54	Yes
4: High Eff	7,443	684	$1,653	84	6,384	375	$1,198	54	Yes

	Savings over Max ERI Home				**Costs Effectiveness**			P1 =	27.328
Scenario	**Δ kWh/y**	**Δ Th/y**	**Δ $/yr**	**%save**	**1stCost**	**LC Cost**	**LC Save**	**NPV**	**SIR**
1: 2015 Min	191	135	$164	9.9%	$2,080	$1,802	$4,491	$2,689	2.49
2: Max ERI + PV	5,472	0	$693	41.9%	$11,550	$17,584	$18,947	$1,363	1.08
3: 2015 Min + PV	3,772	135	$618	37.4%	$9,640	$13,311	$16,890	$3,579	1.27
4: High Eff	1,059	309	$455	27.5%	$3,852	$5,246	$12,432	$7,186	2.37

Max ERI + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
PV System (Wdc):	4,125	$0	$11,550	$11,550	30	1.94%	1.522	$17,584
			Totals	**$11,550**				**$17,584**

2015 Min Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER14GF80*	$4,127	$3,950	-$177	15		1.839	-$326
Cooling Capacity (kBtu)	21.5	18.0					
SEER	14.0	14.0					
Heating Cap (kBtu)	35.0	28.4					
AFUE	0.80	0.80					
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
		Totals	**$2,080**				**$1,802**

2015 Min + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER14GF80*		$4,127	$3,950	-$177	15		1.839	-$326
Capacity (kBtu)		21.5	18.0					
SEER		14.0	14.0					
Heating Cap (kBtu)		35.0	28.4					
AFUE		0.80	0.80					
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49		$2,620	$3,378	$758	50		0.919	$697
Wall cavity: R-13→R-20		$2,264	$3,483	$1,219	50		0.919	$1,121
PV System (Wdc):	2,700	$0	$7,560	$7,560	30	1.94%	1.522	$11,509
			Totals	**$9,640**				**$13,311**

Baltimore Homes (Base crawl ADS; Qn=0.08)							
High Efficiency Home							
Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER14GF92*	$4,127	$4,117	-$11	15		1.839	-$19
Capacity (kBtu)	21.5	18.0					
SEER	14.0	14.0					
Heating Cap (kBtu)	35.0	26.1					
AFUE	0.80	0.92					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
Tnkless gasWH (EF=0.83)	$600	$1,000	$400	15	2.29%	2.342	$937
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,852**				**$5,246**

* Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Chicago Homes (Base ucBsmt ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	6,843	864	$1,764	86	6,740	734	$1,616	76	No
2: Max ERI + PV	6,843	864	$1,764	86	809	864	$999	55	Yes
3: 2015 Min + PV	6,843	864	$1,764	86	2,497	735	$1,079	55	Yes
4: High Eff	6,843	864	$1,764	86	5,991	528	$1,307	55	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	103	130	$148	8.4%	$1,472	$1,426	$4,044	$2,618	2.84
2: Max ERI + PV	6,034	0	$765	43.3%	$13,440	$20,461	$20,893	$432	1.02
3: 2015 Min + PV	4,346	129	$685	38.8%	$10,922	$15,813	$18,707	$2,895	1.18
4: High Eff	852	336	$457	25.9%	$3,300	$4,974	$12,481	$7,507	2.51

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	4,800	$0	$13,440	$13,440	30	1.94%	1.522	$20,461
			Totals	**$13,440**				**$20,461**

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER13GF80*	$3,484	$3,408	-$76	15		1.839	-$139
Cooling Capacity (kBtu)	19.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	43.1	35.0					
AFUE	0.80	0.80					
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
		Totals	**$1,472**				**$1,426**

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER13GF80*		$3,484	$3,408	-$76	15		1.839	-$139
Capacity (kBtu)		19.0	18.0					
SEER		13.0	13.0					
Heating Cap (kBtu)		43.1	35.0					
AFUE		0.80	0.80					
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49		$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4		$5,900	$6,409	$509	30		1.096	$558
PV System (Wdc):	3,375	$0	$9,450	$9,450	30	1.94%	1.522	$14,387
			Totals	**$10,922**				**$15,813**

Chicago Homes (Base ucBsmt ADS; Qn=0.08)

High Efficiency Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER13GF96*	$3,484	$3,632	$148	15		1.839	$272
Capacity (kBtu)	19.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	43.1	32.2					
AFUE	0.80	0.96					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
Tnkless gasWH (EF=0.83)	$600	$1,000	$400	15	2.29%	2.342	$937
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,300**				**$4,974**

* Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Denver Homes (Base ucBsmt ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				**Improved Homes**				
Scenario	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**kWh/y**	**Th/y**	**$/yr**	**ERI**	**Complies**
1: 2015 Min	6,609	681	$1,544	85	6,537	593	$1,444	77	No
2: Max ERI + PV	6,609	681	$1,544	85	1,556	681	$904	55	Yes
3: 2015 Min + PV	6,609	681	$1,544	85	2,633	593	$949	55	Yes
4: High Eff	6,609	681	$1,544	85	5,676	416	$1,151	55	Yes

	Savings over Max ERI Home				**Costs Effectiveness**			P1 =	27.328
Scenario	**Δ kWh/y**	**Δ Th/y**	**Δ $/yr**	**%save**	**1stCost**	**LC Cost**	**LC Save**	**NPV**	**SIR**
1: 2015 Min	72	88	$100	6.5%	$1,524	$1,522	$2,746	$1,223	1.80
2: Max ERI + PV	5,053	0	$640	41.5%	$9,240	$14,067	$17,496	$3,429	1.24
3: 2015 Min + PV	3,976	88	$595	38.5%	$8,664	$12,392	$16,263	$3,871	1.31
4: High Eff	933	265	$393	25.5%	$3,422	$5,198	$10,748	$5,550	2.07

Max ERI + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
PV System (Wdc):	3,300	$0	$9,240	$9,240	30	1.94%	1.522	$14,067
			Totals	**$9,240**				**$14,067**

2015 Min Home

Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER13GF80*	$3,403	$3,380	-$23	15		1.839	-$43
Cooling Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	33.8	28.0					
AFUE	0.80	0.80					
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
		Totals	**$1,524**				**$1,522**

2015 Min + PV Home

Measure		**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER13GF80*		$3,403	$3,380	-$23	15		1.839	-$43
Capacity (kBtu)		18.0	18.0					
SEER		13.0	13.0					
Heating Cap (kBtu)		33.8	28.0					
AFUE		0.80	0.80					
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49		$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4		$5,900	$6,409	$509	30		1.096	$558
PV System (Wdc):	2,550	$0	$7,140	$7,140	30	1.94%	1.522	$10,870
			Totals	**$8,664**				**$12,392**

Denver Homes (Base ucBsmt ADS; Qn=0.08)

High Efficiency Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER13GF96*	$3,403	$3,623	$220	15		1.839	$404
Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	33.8	30.0					
AFUE	0.80	0.96					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Ceiling: R-38→R-49	$2,620	$3,378	$758	50		0.919	$697
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
Tnkless gasWH (EF=0.83)	$600	$1,000	$400	15	2.29%	2.342	$937
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
Low-flow fixtures (Nbr+2)	$250	$300	$50	15		1.839	$92
		Totals	**$3,422**				**$5,198**

* Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Minneapolis Homes (Base ucBsmt ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	6,803	1,015	$1,916	86	6,701	839	$1,720	75	No
2: Max ERI + PV	6,803	1,015	1,916	86	9	1,011	$1,051	54	Yes
3: 2015 Min + PV	6,803	1,015	1,916	86	2,042	839	$1,130	54	Yes
4: High Eff	6,803	1,015	1,916	86	5,959	610	$1,388	54	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	102	176	$196	10.2%	$1,969	$1,917	$5,346	$3,429	2.79
2: Max ERI + PV	6,794	4	$865	45.2%	$14,700	$22,379	$23,637	$1,258	1.06
3: 2015 Min + PV	4,761	176	$786	41.0%	$12,049	$17,263	$21,477	$4,215	1.24
4: High Eff	844	405	$527	27.5%	$3,778	$5,429	$14,411	$8,982	2.65

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	5,250	$0	$14,700	$14,700	30	1.94%	1.522	$22,379
			Totals	**$14,700**				**$22,379**

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER13GF80*	$3,458	$3,419	-$39	15		1.839	-$72
Cooling Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	47.3	37.6					
AFUE	0.80	0.80					
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
		Totals	**$1,969**				**$1,917**

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER13GF80*		$3,458	$3,419	-$39	15		1.839	-$72
Capacity (kBtu)		18.0	18.0					
SEER		13.0	13.0					
Heating Cap (kBtu)		47.3	37.6					
AFUE		0.80	0.80					
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20		$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4		$5,900	$6,409	$509	30		1.096	$558
PV System (Wdc):	3,600	$0	$10,080	$10,080	30	1.94%	1.522	$15,346
			Totals	**$12,049**				**$17,263**

Minneapolis Homes (Base ucBsmt ADS; Qn=0.08)

High Efficiency Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER13GF96*	$3,458	$3,623	$165	15		1.839	$303
Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	47.3	30.0					
AFUE	0.80	0.96					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
Tnkless gasWH (EF=0.83)	$600	$1,000	$400	15	2.29%	2.342	$937
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,778**				**$5,429**

* Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Billings Homes (Base ucBsmt ADS; Qn=0.08)									
	Maximum ERI Home (Scenario 0)				Improved Homes				
Scenario	kWh/y	Th/y	$/yr	ERI	kWh/y	Th/y	$/yr	ERI	Complies
1: 2015 Min	6,608	856	$1,726	86	6,505	704	$1,555	75	No
2: Max ERI + PV	6,608	856	$1,726	86	523	856	$955	54	Yes
3: 2015 Min + PV	6,608	856	$1,726	86	2,308	704	$1,023	54	Yes
4: High Eff	6,608	856	$1,726	86	5,763	506	$1,255	54	Yes

	Savings over Max ERI Home				Costs Effectiveness			P1 =	27.328
Scenario	Δ kWh/y	Δ Th/y	Δ $/yr	%save	1stCost	LC Cost	LC Save	NPV	SIR
1: 2015 Min	103	152	$171	9.9%	$1,980	$1,937	$4,668	$2,732	2.41
2: Max ERI + PV	6,085	0	$771	44.7%	$12,180	$18,543	$21,069	$2,527	1.14
3: 2015 Min + PV	4,300	152	$703	40.7%	$10,380	$14,725	$19,200	$4,476	1.30
4: High Eff	845	350	$470	27.3%	$3,808	$5,484	$12,854	$7,370	2.34

Max ERI + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
PV System (Wdc):	4,350	$0	$12,180	$12,180	30	1.94%	1.522	$18,543
			Totals	$12,180				$18,543

2015 Min Home

Measure	Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04	$0	$250	$250	30		1.096	$274
SEER13GF80*	$3,429	$3,400	-$28	15		1.839	-$52
Cooling Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	40.0	33.0					
AFUE	0.80	0.80					
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
		Totals	$1,980				$1,937

2015 Min + PV Home

Measure		Base$	Improv$	Incr$	svc life	Maint	P2	LC Cost
Duct Qn 0.08→0.04		$0	$250	$250	30		1.096	$274
SEER13GF80*		$3,429	$3,400	-$28	15		1.839	-$52
Capacity (kBtu)		18.0	18.0					
SEER		13.0	13.0					
Heating Cap (kBtu)		40.0	33.0					
AFUE		0.80	0.80					
Envelope: 7 ach50→3 ach50		$100	$125	$25	30		1.096	$27
Factory Sealed AHU		$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20		$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4		$5,900	$6,409	$509	30		1.096	$558
PV System (Wdc):	3,000	$0	$8,400	$8,400	30	1.94%	1.522	$12,788
			Totals	$10,380				$14,725

Billings Homes (Base ucBsmt ADS; Qn=0.08)							
High Efficiency Home							
Measure	**Base$**	**Improv$**	**Incr$**	**svc life**	**Maint**	**P2**	**LC Cost**
In Duct Qn 0.08→0.01	$0	$1,000	$1,000	30		1.096	$1,096
SEER13GF96*	$3,429	$3,623	$195	15		1.839	$358
Capacity (kBtu)	18.0	18.0					
SEER	13.0	13.0					
Heating Cap (kBtu)	40.0	30.1					
AFUE	0.80	0.96					
Lighting: 75%FL→100%FL	$360	$540	$180	5		4.847	$873
Envelope: 7 ach50→3 ach50	$100	$125	$25	30		1.096	$27
Factory Sealed AHU	$0	$5	$5	15		1.839	$9
Wall cavity: R-13→R-20	$2,264	$3,483	$1,219	50		0.919	$1,121
Windows: 0.35/0.4→0.32/0.4	$5,900	$6,409	$509	30		1.096	$558
Tnkless gasWH (EF=0.83)	$600	$1,000	$400	15	2.29%	2.342	$937
eStar refrigerator	$1,200	$1,275	$75	15		1.839	$138
eStar clothes wash/dry	$1,200	$1,350	$150	15		1.839	$276
eStar dishwasher	$450	$500	$50	15		1.839	$92
		Totals	**$3,808**				**$5,484**

* Air conditioner / gas furnace cost calculations based on capacity, SEER and AFUE

Appendix B
Determination of HVAC Equipment Costs

NREL maintains a very useful online National Residential Efficiency Measure Database (http://www.nrel.gov/ap/retrofits/index.cfm) containing estimated retrofit costs for HVAC equipment.

The HVAC cost data are cast in terms of only the equipment capacity as Cost = a*CAP. The database provides the value of 'a' for each listed efficiency. Although it would likely be possible to use the listed efficiencies to develop a formulation cast in terms of both efficiency and capacity (e.g. Cost = a*CAP + b*EFF), this likely does not adequately characterize costs. Conventional pricing logic implies that fixed and variable costs are associated with HVAC installation. This can be empirically verified by regressing on collected cost data where fixed and variable cost components are clearly revealed. For example, fixed costs are associated with selling the new equipment, dispatching a vehicle and service personnel to the installation site, removing the old equipment, and hooking up the new equipment that are not tied directly to the efficiency or the size of the new equipment. Thus, the characterization of HVAC costs as stemming solely from equipment efficiency and capacity tends to underestimate costs for small capacity equipment (which will incur a larger percentage of fixed costs relative to total cost) and overstate costs for large capacity equipment (which will incur a smaller percentage of fixed costs relative to total cost).

BA-PIRC attempted to characterize the fixed costs associated with HVAC replacements using an empirical approach. Available online retail costs from available manufacturers were used to determine the, uninstalled retail cost of a variety of HVAC equipment. One clear advantage of this method is that the cost data, unlike those collected from installers are very consistent in their origin with less statistical variation. To these online values were added fixed costs that make up the total price similar to those observed in the NREL database. The resulting total cost data are then regressed in terms of equipment efficiency and capacity for four categories of commonly available HVAC equipment. The four categories are:

- Heat pumps
- Air conditioners (with strip resistance heating)
- Gas furnaces (with no air conditioning)
- Gas furnace-air conditioner combinations

For each equipment category, an 8% tax was applied to the online retail cost plus a fixed "service" cost plus 35% overhead and profit, such that

Total Cost = Retail*1.08 + $750 + Retail*0.35

The fixed "service" cost is calculated based on 4 man-hours of sales time at $28.00 per hour and 16 hours of installation time at $22.50 per hour with a 10% fringe and 30% overhead added to these salary rates. In addition, a daily average truck charge of $100 is added to this total salary charge to arrive at the fixed service charge.

The resulting total cost estimates are then regressed against the equipment capacity and efficiency from online data sources to arrive at generalized equations that can be used to calculate the HVAC costs used in economic cost effectiveness calculations. The resulting equations are as follows.

Heat Pumps: -5539 + 604*SEER + 699*tons
Air Conditioners (with strip heat): –1409 + 292*SEER + 520*tons
Gas Furnace/air conditioner: –6067 + 568*SEER + 517*tons + 4.04*kBtu + 1468*AFUE
Gas Furnace only: –3936 + 14.95*kBtu + 5865*AFUE

Results from the regressions showing the sample size (n) and correlation coefficient (R^2) for each equipment category are shown in Figure B-1.

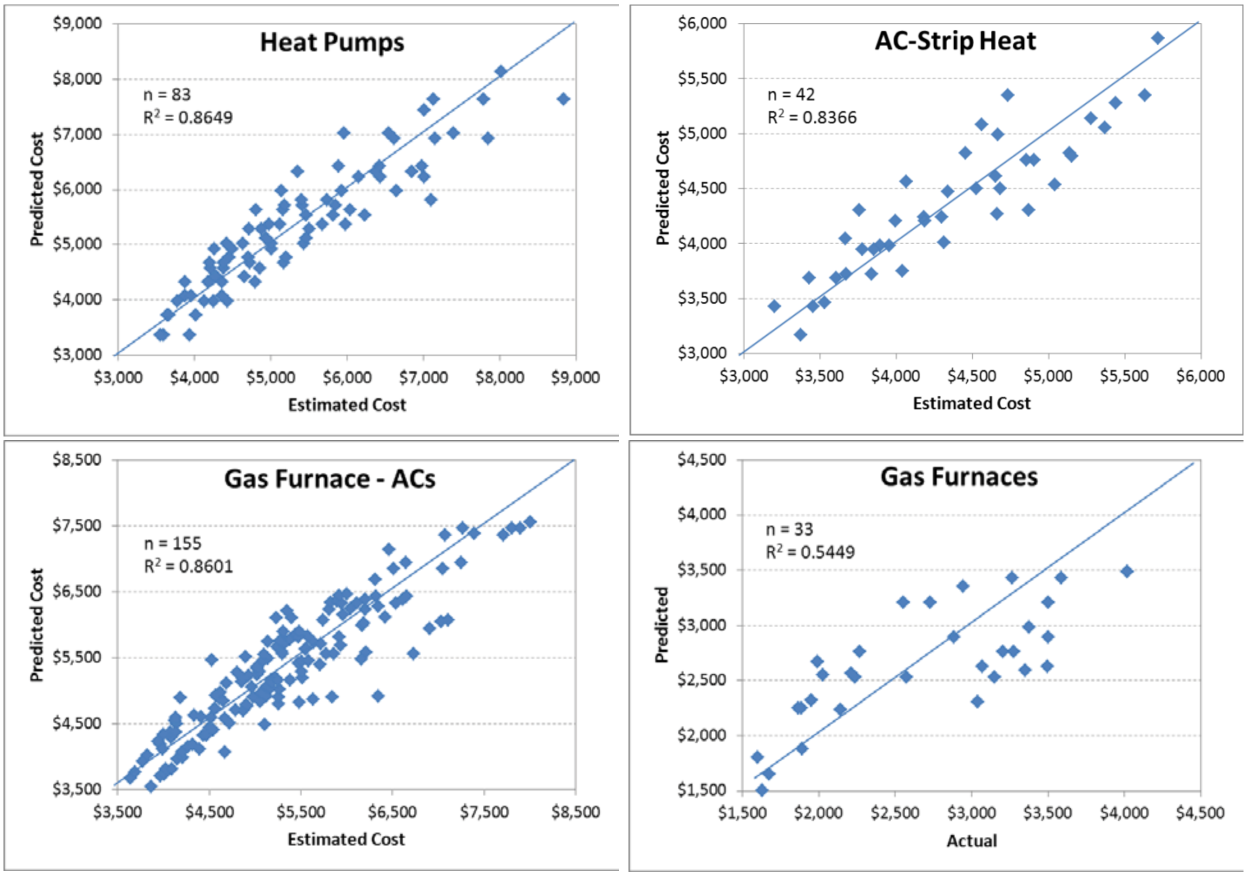

Figure B-1. Results from regression analysis of CostOpt HVAC cost estimates

Considering the variability of the marketplace, the correlation coefficients are reasonable for these regressions. For comparison, Tables B-1 through Table B-3 show the range of costs provided by the NREL database for replacement heat pumps, air conditioners, and gas furnaces.

Table B-1. NREL Cost Estimates for Heat Pumps

NREL Heat Pump Replacement Costs				
SEER	Low $/kBtu	High $/kBtu	Average $/kBtu	± %
13	97	170	140	26%
14	110	180	140	25%
15	110	190	150	27%
16	120	200	160	25%
17	130	210	170	24%
18	140	220	180	22%
19	140	230	180	25%
20	150	230	190	21%
21	160	240	200	20%

Table B-2. NREL Cost Estimates for Air Conditioners

NREL Air Conditioner Replacement Costs				
SEER	Low $/kBtu	High $/kBtu	Average $/kBtu	± %
13	59	190	130	50%
14	66	200	130	52%
15	73	210	140	49%
16	80	210	150	43%
17	87	220	150	44%
18	94	230	160	43%
19	100	230	170	38%
20	110	240	170	38%
21	110	250	180	39%

Table B-3. NREL Cost Estimates for Gas Furnaces

NREL Gas Furnace Replacement Costs				
AFUE	Low $/kBtu	High $/kBtu	Average $/kBtu	± %
78%	8.7	33.3	15	82%
80%	8.7	35.3	18	74%
82%	8.7	38.3	21	70%
90%	14.7	49.3	32	54%
92%	17.7	52.3	35	49%
94%	20.7	55.3	38	46%
96%	23.7	58.3	41	42%

These estimates indicate significant variations in the marketplace with respect to HVAC costs and to a certain degree mirror the variations in costs represented in Figure B-1, with gas furnaces showing the largest variance.

BA-PIRC evaluated the economic cost effectiveness estimates against those provided by the NREL database average cost estimates for heat pumps and gas furnaces. Figure B-2 presents the results of this comparison.

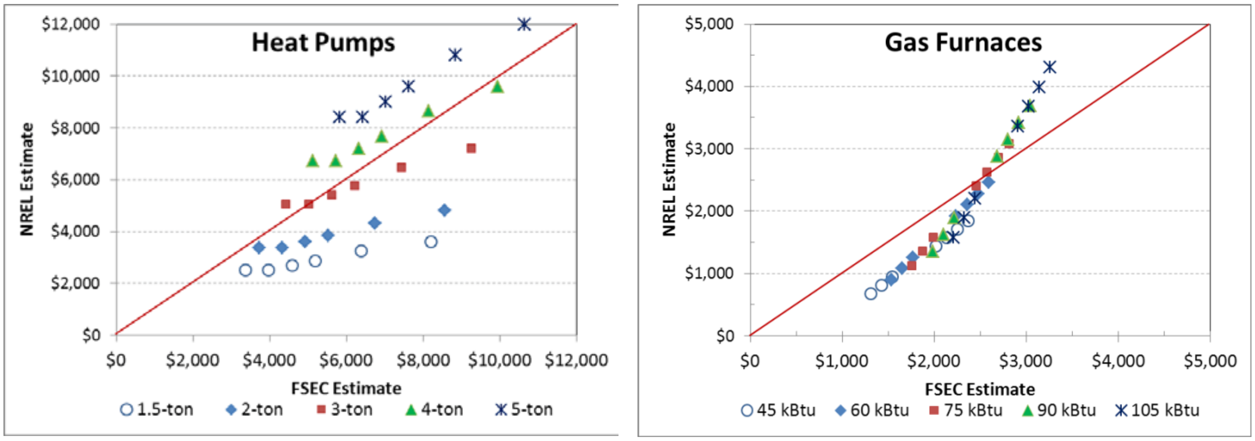

Figure B-2. Comparison of BA-PIRC HVAC cost estimates and NREL HVAC cost estimates

In Figure B-2 the individual plot points represent different efficiencies, with SEERs of 13, 14, 15, 16, 18, and 21 represented on the heat pump chart. The right-hand panel shows data for furnaces: with representative AFUEs of 78%, 80%, 82%, 90%, 92%, 94%, and 96%. Each chart also distinguishes between different capacities, with 1.5-, 2-, 3-, 4-, and 5-ton equipment on the heat pump chart and 45, 60, 75, 90, and 105 kBtu/h equipment on the gas furnace chart.

Both charts show that the BA-PIRC estimates are larger for the lower capacity and smaller for the larger capacity equipment. The charts also show that, on average, the BA-PIRC estimates are consistent with the NREL estimates. However, the fact that the BA-PIRC estimates treat fixed costs more explicitly is evident on both charts. In a practical sense, the BA-PIRC estimates generally show that monetary savings in the capacity of installed equipment coming from more efficient envelope measures are slightly less important than the original values in the NREL database.

Appendix C
Economic Cost Effectiveness

If analyses are conducted to evaluate energy saving improvements to the home, indicators of economic cost effectiveness shall use present value life-cycle costs and benefits, which shall be calculated as follows:

LCC_E = P1 * (1st Year Energy Costs) **Eq. [1]**

LCC_I = P2 * (1st Cost of Improvements) **Eq. [2]**

where:
LCC_E = Present Value Life-Cycle Cost of Energy
LCC_I = Present Value Life-Cycle Cost of Improvements
P1 = Ratio of Life-Cycle energy costs to the 1st year energy costs
P2 = Ratio of Life-Cycle Improvement costs to the first cost of improvements

Present value life-cycle energy cost savings shall be calculated as follows:

$LCC_S = LCC_{E,b} – LCC_{E,i}$ **Eq. [3]**
where:
LCC_S = Present Value Life Cycle Energy Cost Savings
$LCC_{E,b}$ = Present Value LCC of energy for **baseline** home configuration
$LCC_{E,i}$ = Present Value LCC of energy for **improved** home configuration

Standard economic cost effectiveness indicators shall be calculated as follows:

$SIR = LCC_S / LCC_I$ **Eq. [4]**

$NPV = LCC_S - LCC_I$ **Eq. [5]**
where:
SIR = Present Value Savings to Investment Ratio
NPV = Net Present Value of Improvements

Calculation of P1 and P2. The ratios represented by P1 and P2 shall be calculated in accordance with the following methodology[9]:

P1 = 1 / (DR - ER) * (1 - ((1 + ER) / (1 + DR))^nAP) **Eq. [6a]**

or if DR = ER then

P1 = nAP / (1+DR) **Eq. [6b]**
where:
P1 = Ratio of Present Value Life Cycle Energy Costs to the 1st year Energy Costs
DR = Discount Rate
ER = Energy Inflation Rate
nAP = number of years in Analysis Period

$P2 = DnPmt + P2_A - P2_B + P2_C + P2_D - P2_E + P2_F$ **Eq. [7]**
where:

[9] Duffie, J.A. and W.A. Beckman, 1980. *Solar Engineering of Thermal Processes*, pp. 398-406, John Wylie & Sons, Inc., New York, NY.

$P2$ = Ratio of Life Cycle Improvement costs to the first cost of improvements
DnPmt = Mortgage down payment rate
$P2_A$ = Mortgage cost parameter
$P2_B$ = Income Tax cost parameter
$P2_C$ = Operation & Maintenance cost parameter
$P2_D$ = Property tax cost parameter
$P2_E$ = Salvage value cost parameter
$P2_F$ = Replacement cost parameter

$P2_A$ = (1 - DnPmt) * (PWFd / PWFi) **Eq. [8a]**

where:
PWFd = Present Worth Factor for the discount rate = 1/DR*(1-(1/(1+DR)^nAP))
PWFi = Present Worth Factor for the mortgage rate = 1/MR*(1-(1/(1+MR)^nMP))
DR = Discount Rate
MR = Mortgage interest Rate
nAP = number of years of the Analysis Period
nMP = number of years of the Mortgage Period

$P2_B$ = (1 - DnPmt) * iTR * (PWdiff *(MR – 1 / PWFi) + PWFd / PWFi) **Eq. [8b]**

where:
iTR = effective income Tax Rate
PWdiff = ratio of the present worth discount rate to present worth mortgage rate
= 1 / (DR - MR) * (1- (((1 + MR) / (1 + DR))^nMP))

or if DR = MR then
= nMP/(1+MR)

$P2_C$ = MFrac*PWinf **Eq. [8c]**

where:
MFrac = annual O&M costs as a fraction of first cost of improvements
PWinf = ratio of present worth discount rate to present worth general inflation rate
= 1/(DR-GR)*(1-(((1+GR)/(1+DR))^nAP))

or if DR = GR then
= nAP/(1+DR)

GR = General Inflation Rate

$P2_D$ = pTR*AssessRatio*PWinf **Eq. [8d]**

where:
pTR = effective property Tax Rate
AssessRatio = Fraction of assessed property value against which pTR is applied
(typically 0.80)

$P2_E$ = RLF / ((1 + DR)^nAP) **Eq. [8e]**

where:
RLF = Remaining Life Fraction following the end of the analysis period
and
RLF = (nAP/Life) – (Integer (nAP/Life))

or if Life > nAP
RLF = (Life-nAP) / nAP
where:
Life = useful service life of the improvement(s)

$P2_F$ = Sum {1 / ((1 + (DR - GR))^(Life*i))} for i=1, n **Eq. [8f]**
where:
i = the i^{th} replacement of the improvement
Life = the expected service life of the improvement

Determination of Economic Parameters. Economic parameter values used in the cost effectiveness calculations shall be determined as follows:

General Inflation Rate (GR) shall be the greater of the 5-year and the 10-year Annual Compound Rate (ACR) of change in the Consumer Price Index for Urban Dwellers (CPI-U) as reported by the U.S. Bureau of Labor Statistics, where ACR shall be calculated in accordance with equation [9].

ACR = ((endVal)/(startVal))^(1.0/((endYr)-(startYr)))-1.0 **Eq. [9]**
where:
ACR = Annual Compound Rate of change
endVal = Value of parameter at end of period
startVal = Value of parameter at start of period
endYr = Year number at end of period
startYr = Year number at start of period

Discount Rate (DR) shall be equal to the General Inflation Rate plus 2%.

Mortgage Interest Rate (MR) shall be the greater of the 5-year and the 10-year average of simple interest rate for fixed rate, 30-year mortgages computed from the Primary Mortgage Market Survey (PMMS) as reported by Freddie Mac.

Down Payment Rate (DnPmt) shall be 10% of 1st cost of improvements.

Energy Inflation Rate (ER) shall be the greater of the 5-year and the 10-year Annual Compound Rate (ACR) of change in the Bureau of Labor Statistics, Table 3A, Housing, Fuels and Utilities, Household Energy Index[10] as calculated using Equation [9].

Mortgage Period (nMP) shall be defaulted to 30 years unless a mortgage finance period is specified by a program or mortgage lender, in which case the specified mortgage period shall be used. The mortgage period used in the cost effectiveness calculation shall be disclosed in reporting results.

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[10] Table 3A from detailed reports listed at http://www.bls.gov/cpi/cpi_dr.htm