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Cost Effectiveness of Home Energy Retrofits in Pre-Code Vintage Homes in the United States

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Definitions

ACH50	Air changes per hour
AEU	Average source energy use
AFUE	Annual fuel utilization efficiency
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEopt	Building Energy Optimization
CF	Cubic feet
cfm	Cubic feet per minute
CFL	Compact fluorescent lamp
CMU	Concrete masonry wall system
Crwl	Crawlspace foundation
CZ	Climate zone
DnPmt	Down payment rate
DR	Discount rate
EA	Number of each
EAC	Equivalent annual cost
EF	Energy factor
EIA	Energy Information Administration
ER	Energy inflation rate
FMC	Fixed measure cost
Frm	Frame wall system
GF	Gas furnace archetype (natural gas space and water heating)
GR	General inflation rate
GSF	Gross square feet
HEM	Home energy management
HP	Heat pump archetype (electric space and water heating)
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilation, and air conditioning
HW	Hot water
IECC	International Energy Conservation Code

kBtu	One thousand British thermal units
kWh	Kilowatts per hour
LED	Light-emitting diode
LF	Linear feet
MBtu	One million British thermal units
MMC	Minimum measure cost
MR	Mortgage interest rate
MURS	Minimum upgrade reference ratio
NPV	Net present value
NSF	Net square feet
pEA	Unit cost per each item (normally appliances, etc)
pCF	Unit cost per cubic foot (normally the house volume)
pGSF	Unit cost per gross square foot (normally for skin finish cost)
pLF	Unit cost per linear foot (normally the perimeter)
pNSF	Unit cost per net square foot (normally applied to walls only)
pSFpR	Unit cost per square foot per ΔR (normally blown insulation applied to GSF)
PV	Photovoltaics
ΔR	R-value difference between existing home and improvement measure
RECS	Residential Energy Consumption Survey
ReFi	Refinance
RESNET	Residential Energy Services Network
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
SIR	Savings-to-investment ratio
SOG	Slab-on-grade
StDev	Standard deviation
Sty	Story
TMC	Total measure cost
UC Bsmt	Unconditioned, unfinished basement foundation

Executive Summary

This analytical study examined the opportunities for cost-effective energy efficiency and renewable energy retrofits in residential archetypes constructed before 1980 (Pre-Code) in 14 U.S. cities. These cities represent each International Energy Conservation Code climate zone in the contiguous United States.

The analysis was conducted using an in-house version of EnergyGauge USA v.2.8.05 named CostOpt that was programmed to perform iterative, incremental economic optimization on a long list of residential energy efficiency and renewable energy retrofit measures. The principal objectives were to:

- Determine the opportunities for cost-effective source energy reductions in this large cohort of existing residential building stock as a function of local climate and energy costs.
- Examine how retrofit financing alternatives impact the source energy reductions that are cost-effectively achievable.

A key finding was that the energy efficiency of even older, poorly insulated homes across U.S. climates can be dramatically improved. Moreover, with favorable economics, they can reach performance levels close to zero energy when evaluated on an annual source energy basis.

Findings indicated that retrofit financing alternatives and whether equipment requires replacement had considerable impact on the achievable source energy reduction in this cohort of residential building archetypes.

Figure 1 shows the study results. The four optimization scenarios examined are:

1. **Default 30-yr.** 30-year mortgage at 6.15% interest using full replacement cost
2. **Home Improve 7-yr.** 7-year mortgage at 6.15% interest using full replacement cost
3. **incHVAC 7-yr.** 7-year mortgage at 6.15% interest using incremental HVAC costs
4. **ReFi 30-yr.** 30-year refinance mortgage at 4.0% interest using full replacement costs.

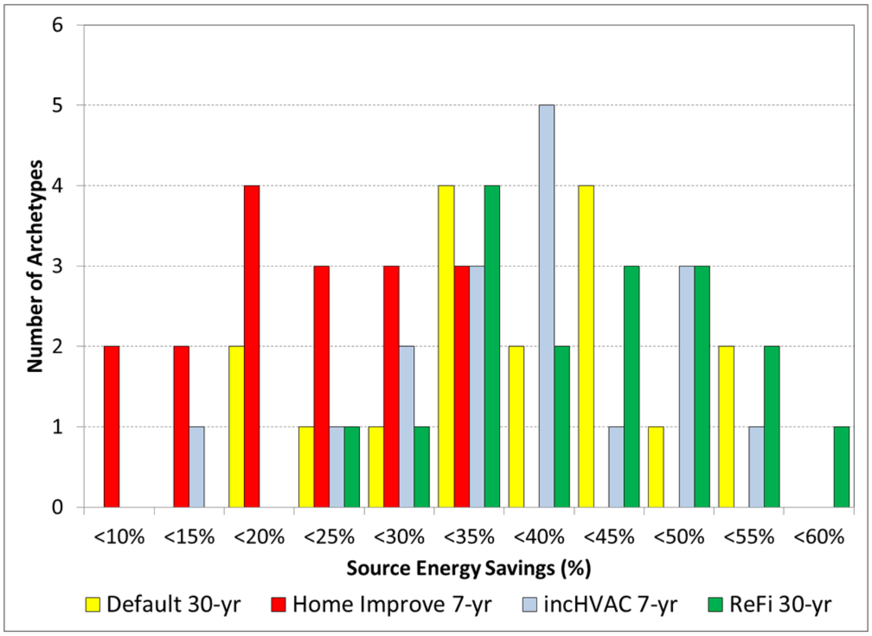


Figure 1. Histogram of achievable source energy reductions in 14 climates using four different financing alternatives

The figure shows that the standard short-term home improvement mortgage option seriously restricts cost effectiveness. However, at the same time, if only the incremental costs of replacement for heating, ventilation, and air-conditioning (HVAC) equipment are used in the analysis (the HVAC equipment is no longer operational), a short term mortgage can result in significant energy reductions. And, as expected, the home refinance option results in the largest potential for source energy savings in this residential cohort.

If home energy retrofits and their attendant energy cost and environmental emission reductions are considered advantageous to society as a whole, these results also have general policy implications:

- HVAC contractors should be encouraged to take advantage of low incremental replacement costs to substantially improve homes using short-term financing.
- Home refinance and resale opportunities offer a significant advantage to dramatically improve home energy efficiency.
- The foreclosure marketplace and 30-yr mortgages should be a focus for home improvement opportunities.

The findings relative to specific measures and how they perform across climates, utility costs, and financing scenarios are:

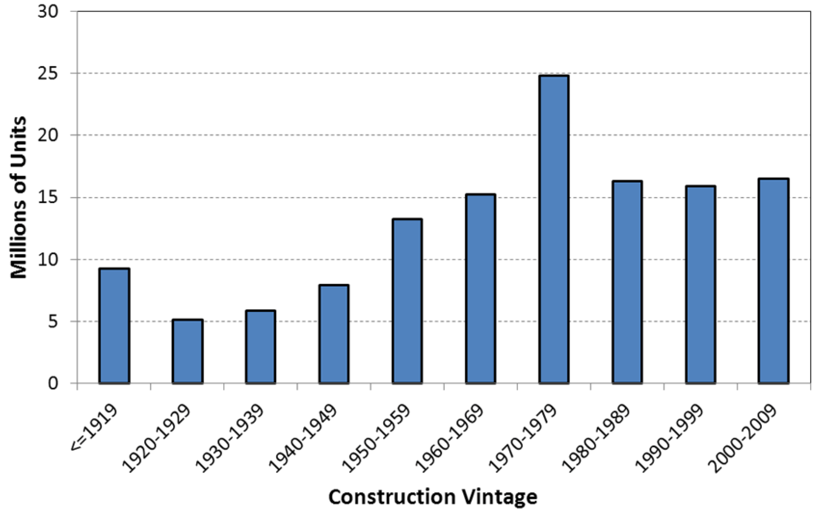
- **What works everywhere.** Compact fluorescent lamps, duct sealing, ceiling insulation, hot water tank wraps, low-flow fixtures.

- **What works in some places.** Frame wall insulation, crawlspace wall insulation, solar water heating, heat pump water heaters, photovoltaic systems, appliances that need replacement and have low incremental costs.
- **What does not work anywhere.** Outright replacement of windows; most expensive HVAC systems, and roof replacement.

1 Introduction

Many U.S. homes were constructed before the advent of building energy codes. In 1975, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) promulgated Standard 90-75, which is widely regarded as the first U.S. residential energy code. Since that time, housing energy efficiency has significantly improved in many states. However, pre-code housing remains a significant fraction of the nation's housing stock.

According to the U.S. Census Bureau, almost 25 million of the nation's 130 million existing housing units were built in the 1970s. The data comprising Figure 2 also show that more than 62% of existing housing was constructed before 1980, when building energy codes first began to be adopted. A significant fraction of this stock includes components that have never been improved since their original construction. Many comprise subdivisions and neighborhoods with similar home designs and construction types. These neighborhoods provide significant opportunities for targeted delivery of community-scale retrofit programs and projects.



Source: U.S. Census Bureau, Table 1-1, Introductory Characteristics - All Housing Units
http://www.census.gov/hhes/www/housing/ahs/ahs09/ahs09.html

Figure 2. U.S. Census Bureau data on existing housing unit construction vintage by decade

This study investigates the cost effectiveness of a large number of potential home energy retrofit measures using pre-code home archetypes that can be considered typical in a range of climates throughout the United States. The analysis is conducted using an in-house optimization version of EnergyGauge USA v.2.8.05 (EnergyGauge CostOpt) that has been configured to perform economic cost-effectiveness analysis in accordance with recent standards (RESNET 2012).

Similar cost-effectiveness analysis was conducted by Casey and Booten (2011) using BEopt software (Christensen et al. 2006; Polly et al. 2011). This investigation parallels this previous work, using a somewhat different economic model specified by a recent RESNET Standard (RESNET 2012). This study also uses home archetypes that vary from those used in the previous analyses. For example, the previous study did not evaluate housing archetypes with concrete masonry wall construction that is prevalent in the southeastern United States. This study also allows fuel switching (changing from electric equipment to gas equipment and vice versa) and examines how this can impact cost effectiveness under local climate and utility rate structures. This investigation also directly analyzes solar hot water and solar photovoltaics (PV). Also, contrary to the BEopt optimization scheme, the CostOpt method focuses on reductions to site energy cost rather than source energy use, as this is what consumers pay.

2 Methodology

2.1 Archetypes

The archetype home characteristics used in this investigation are presented in Table 1. They are largely characterized by the International Energy Conservation Code (IECC) climate zone in which the archetype is located. At 1,600 ft^2, the conditioned floor area is significantly smaller than current practice but, according to the U.S. Census Bureau, this is consistent with homes constructed before 1980 (see Figure 3).[1]

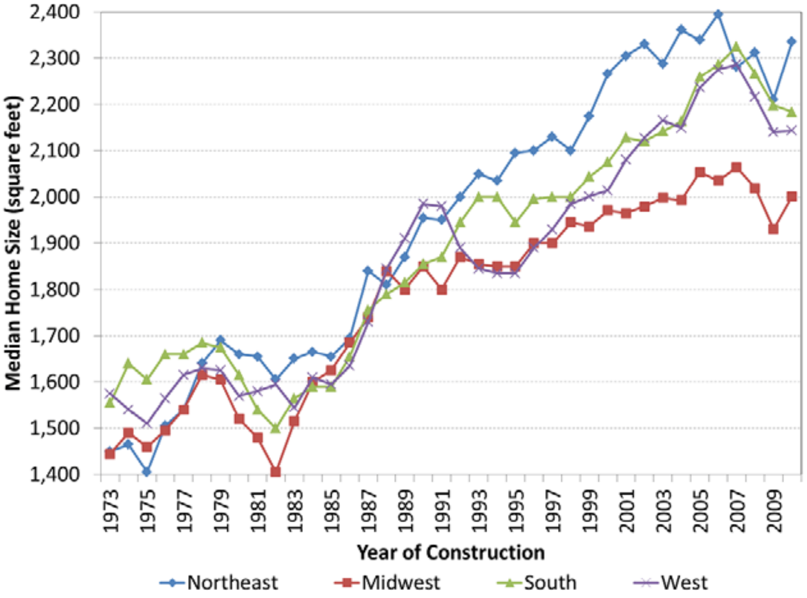


Figure 3. Median U.S. home size from U.S. Census Bureau data: 1973–2010

These archetypes are similar to those used by Casey and Booten (2011) and by Parker et al. (1998), but they differ in some important ways. In climate zone 1 (southern Florida), only concrete masonry walls are considered and in climate zone 2 concrete masonry and frame wall system are considered. Additionally, the assumed archetype envelope and duct air leakage characteristics differ from those used by Casey and Booten. For example, Casey and Booten used envelope air leakage of 19 ACH50 in all locations; this investigation uses 12, 9, and 7 ACH50 in climate zones 1–2, 3–4, and 5–6, respectively. These much lower envelope leakage rates are supported in part by data collected in Florida on a large number of existing homes (McIlvaine 2011) and are reasoned to more accurately characterize air leakage rates in other climates where a significant cost penalty is incurred for very leaky homes, inducing homeowners to caulk and weather strip their homes as matter of common do-it-yourself practice. That homes are somewhat tighter in colder climates has also been observed in evaluations of large databases with tested fan pressurization data (Sherman et al. 1986).

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[1] U.S. Census Bureau. http://www.census.gov/const/C25Ann/sftotalmedavgsqft.pdf

Table 1. Pre-Code Vintage Existing Archetype Home Characteristics by IECC Climate Zone

Archetype Characteristics	CZ 1-2	CZ 3-4	CZ 5-6
Conditioned floor area (ft^2)	1,600	1,600	1,600
Foundation type	SOG	Crwl	UC Bsmt
AHU location	Garage	Crwl	UC Bsmt
Duct location	Attic	Crwl	UC Bsmt
Duct insulation R-value	4.2	4.2	4.2
Duct leakage (cfm25/ft^2 floor area)	0.11	0.11	0.08
Envelope ACH50	12	9	7
Roof solar absorptance	0.85	0.85	0.85
Wall solar absorptance	0.55	0.55	0.55
Ceiling R-value	10	15	20
Frame wall insulation R-value	1.5	5	7
Block wall insulation R-value	none	n/a	n/a
SOG perimeter R-value	none	n/a	n/a
Crawlspace floor R-value	n/a	5	n/a
Basement ceiling (house floor) R-value	n/a	n/a	none
Basement wall R-value	n/a	n/a	none
Window U-factor	1.2	0.75	0.6
Window SHGC	0.8	0.7	0.6
Door U-factor	0.5	0.4	0.3
HP HSPF (y2004; standard; degraded)	6.5	6.5	6.5
HP SEER (y2004; standard; degraded)	9.6	9.6	9.6
AC SEER (y2004; standard; degraded)	9.6	9.6	9.6
Furnace AFUE (y2004; standard; degraded)	76%	76%	76%
Gas HW EF (y2004; 40 gal; standard)	0.59	0.59	0.59
Elec HW EF (y2004; 40 gal; standard)	0.92	0.92	0.92
HW pipe insulation R-value	none	none	none
Lighting % fluorescent or equivalent	10%	10%	10%
Lighting kWh/yr	1,736	1,736	1,736
Refrigerator kWh/yr (y2004; 20 cf; SS/TDI)	717	717	717
Range/oven kWh/yr	447	447	447
Dishwasher kWh/yr (y2004; standard)	171	171	171
Clothes Washer kWh/yr (y2004; standard)	69	69	69
Clothes Dryer kWh/yr (y2004; standard)	970	970	970
Miscellaneous kWh/yr	2,000	2,000	2,000

Key to Table 1 abbreviations:

ACH 50:	air changes per hour at a 50 Pascal pressure difference
AFUE:	Annual fuel utilization efficiency
AHU:	Air handling unit
CFM:	Cubic feet per minute
Crwl:	Crawlspace foundation
EF:	Energy factor
HSPF:	Heating seasonal performance factor
HW:	Hot water
SEER:	Seasonal energy efficiency ratio
SHGC:	Solar heat gain coefficient
SS/TDI:	Side-by-side, through the door ice
SOG:	Slab-on-grade foundation
UC Bsmt:	Unconditioned, unfinished basement foundation

Air distribution system leakage values are also supported by Walker (1998) and reinforced by recent measured Florida data (McIlvaine 2011; Walker 1998). These rates are expected to be consistent across a wide swath of the country. However, for the unconditioned basement archetypes (climate zones 5 and 6) it is reduced to account for leakage in basements, which results in significant regain and much less loss to the outdoors compared to cases where ducts are located in vented attics or crawlspaces. For instance, recent work in Wisconsin in unconditioned basement homes found that average tested duct leakage to the outside was only about 5% (Pigg and Francisco 2006)—one third the typical leakage rate in homes with attic ducts.

Equipment efficiencies for the archetypes are based on the assumption that all equipment is 2004 vintage (currently 8 years old and halfway through its life expectancy) and is slightly degraded using a maintenance factor of 0.005 (see Hendron 2006). Lighting and appliance energy uses are based on the default values provided by RESNET (2012).

3 Simulation Modeling

The simulation analysis is conducted using EnergyGauge CostOpt, an implementation of EnergyGauge USA v.2.8.05 with cost optimization capability. CostOpt uses an enhanced version of DOE-2.1E to conduct detailed hourly simulations, including air distribution system leakage, duct system heat transfer, improved HVAC systems modeling that includes improved relative humidity (RH) and part load characterization as well as solar hot water and PV systems performance prediction.

CostOpt performs cost optimization using an iterative incremental assessment method. The analysis is "incremental" in that within any given category of improvement, such as insulation or equipment efficiency, a number of options are presented to the software such that various insulation values for each component, equipment efficiency, and their associated costs are evaluated against each other simultaneously during each iteration. An iteration comprises a simulation of each available improvement case on a measure-by-measure basis. At the conclusion of each iteration, the improvement measure with the largest present value savings to investment ratio (SIR; also known as the benefit to cost ratio) is incorporated into the home and the remaining improvement measures are evaluated again on an incremental measure-by-measure basis for the next iteration. This iterative process is continued until all available measures that meet the user-specified SIR lower limit have been incorporated into the home.

CostOpt has been configured to "rank" measures within each iteration by net present value (NPV). Although this option is not used in this investigation, it is often considered the economic indicator of choice and, because it incorporates the improvement measures with the largest NPV first, it passes over many measures that are incorporated incrementally and later improved by the SIR ranking method. Thus, the NPV ranking method runs many fewer simulations (finishes faster). Nonetheless, the SIR ranking method is chosen for this investigation for two reasons:

- It provides the incremental cost effectiveness of multiple options within a category of measures (e.g., it will select R-19 ceiling insulation and then later replace it with R-30 insulation, usually installing other improvement measures).
- It provides an opportunity to answer an important question: What are the most cost-effective improvement measures to select if one has only a limited budget? This is a frequent constraint in many retrofit projects.

4 Other Considerations in the Optimizations

Other noteworthy simulation considerations:

- Optimization simulations generally allow fuel switching. The exception is in climate zone 1, where there is little, if any, reasonable access to residential natural gas.
- Gas furnaces (without an air conditioning component) were not allowed to compete in the simulations if the baseline archetype did not contain a gas furnace. However, gas furnace-air conditioner combinations were always allowed to compete in the simulations, regardless of the equipment used for the baseline archetype.
- For the unconditioned basement homes, floor insulation (in the basement ceiling) was limited to climate zone 5, where house floor insulation measures were allowed to compete with basement wall insulation measures. For the coldest climate zone 6, floor insulation was not allowed to compete out of concern that it could lower basement space temperatures enough to allow freezing. In climate zone 6 archetypes, only basement wall insulation was allowed as a basement thermal improvement.
- PV systems are evaluated assuming full net metering such that each kilowatt-hour the PV system displaces is valued at the retail cost of electricity. This is true even when the PV system produces more electricity than the home actually uses. This situation is seldom encountered
- HVAC system sizing is dynamic in CostOpt. The building loads are calculated at the beginning of each iteration using the building configuration resulting from previous iterations. As a result, the building loads and required system capacity will decrease as improvements are made. This, in turn, reduces HVAC improvement costs commensurate with the reduction in building load and HVAC system capacity. HVAC measures are much more likely to become cost effective following improvements than they are at the start of the optimization.

5 Economic Model

CostOpt incorporates an economic model based on the Duffie and Beckman (1980) P1-P2 methodology. This procedure calculates two factors (P1 and P2) that can be applied comprehensively to understand the cost effectiveness of energy-saving measures.

P1 is the ratio of the present value of the energy savings over the analysis period to the first year energy cost savings. P2 is the ratio of the present value of the improvement costs over the analysis period to the first cost of the improvement. In addition to standard rate parameters (general inflation, fuel inflation, mortgage interest, and discount rate), both P1 and P2 incorporate the full range of applicable economic factors, including measure life, replacement cost, maintenance cost, property tax cost, salvage value, and income tax benefit into their calculation. As a result, if one knows the first cost of an energy improvement and the first year energy saving of the improvement, the present value SIR of the improvement is simply P1 times savings divided by P2 times cost. Likewise the NPV of the improvement is simply P1 times savings minus P2 times cost. Furthermore, one can also calculate the break-even cost (the cost at which SIR = 1) of an improvement given only the energy cost savings. This cost is simply P1 divided by P2 times the first year energy cost savings.

A large part of this model (except income tax benefit and property tax cost) has recently been adopted by RESNET as part of its national consensus standard (RESNET 2012). In addition to the economic model, the RESNET standard specifies a standard methodology of determining the economic parameters values used in the model. The standard also dictates an economic analysis period of 30 years. A full description of the RESNET implementation, which is used in this investigation, is provided in Appendix A. In accordance with its standards, RESNET also publishes the economic parameter values[2] that are intended for use in determining cost effectiveness (see Table 2).

Table 2. Economic Parameter Values

General Inflation Rate (GR)	2.39%
Discount Rate (DR)	4.39%
Mortgage Interest Rate (MR)	6.15%
Down Payment Rate (DnPmt)	10.00%
Energy Inflation Rate (ER)	4.42%

The economic model used here differs from that proposed by Casey and Booten (2011) in several important ways.

5.1 General Inflation Rate and Discount Rate

The model used in this investigation differentiates between the general inflation rate and the discount rate; the model used by Casey and Booten sets them equal. The impact of setting these two economic parameters equal is to say that the investor expects no return on investment. However, it is not clear from Casey and Booten (2011) whether the discount rate they specify is

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[2] See http://www.resnet.us/standards/mortgage

the nominal discount rate or the real discount rate. For clarification, the discount rate provided in Table 2 is taken as the nominal discount rate, making the real discount rate for the analysis reported here equal to 1.95%.

The Casey and Booten analysis also appears to set the energy inflation rate equal to the general inflation rate. The history of household energy costs during the past 10 years seems to contradict this assumption. Table 3 presents U.S. Bureau of Labor Statistics data on the household energy cost index since 2000.[3] These data show that household energy costs rose at an annual compound rate of 4.42% between 2000 and 2010.

Table 3. Household Energy Cost Index[4]

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
HHeI	122.8	135.4	127.2	138.2	144.4	161.6	171.1	181.7	200.8	188.1	189.3

HHeI = household energy cost index

Further evidence from the U.S. Energy Information Administration (EIA) shows that U.S. average revenue-based residential electricity rate rose from $0.0824/kWh in 2000 to $0.11.54/kWh in 2010. The annual compound rate for this rate change is 4.09%.

5.2 Optimization Method

The optimization method and philosophy used by BEopt (Polly et al. 2011) differ from that used by CostOpt. BEopt ranks available improvement measures based on the least equivalent annual cost (EAC) per percentage savings of annual average source energy use (AEU). Measures are thus selected that emphasize source energy use savings. On the other hand, CostOpt uses consumer-borne site energy costs, ranking available improvement measures based solely on the life cycle present value SIR of the improvement measure over the analysis period. This results in a different order of measure ranking and selection. Although source energy savings may be a good societal objective, the methodology employed here reflects energy costs that will be best appreciated by consumers.

5.3 Equipment Replacement

Another important methodological difference in the two methods is that BEopt assumes future costs and energy savings for replacing equipment on burnout for the baseline home (Minimum Upgrade Reference Scenario or MURS); CostOpt does not. Philosophically, the BEopt method can be justified from the perspective that these costs and savings will occur at some time in the future because equipment fails and minimum equipment standards may exceed those of the equipment in the home. The BEopt cash flow analysis assumes that these future payments will be in monies spent at the time of replacement and includes these payments (as well as the energy savings they induce) in the equivalent annual energy cost calculation for the upgrade. As a result, in the BEopt scenario, the equivalent annual cost for the MURS is higher than what consumers would normally consider when they shop for the lowest cost improvement or the lowest proposed bid.

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[3] These data used in determining economic parameter values in RESNET (2012).

[4] U.S. Bureau of Labor Statistics, Table 3A. Consumer Price Index for all Urban Consumers (CPI-U): U.S. city average, detailed expenditure categories http://www.bls.gov/cpi/cpi_dr.htm

The BEopt optimization analysis also allows this equipment to be replaced in the retrofit home in year 1 using a finance mechanism (5 years at 7% in the case of the Casey and Booten analysis). Thus, the cost of the year 1 replacement is effectively reduced by the difference between the present value of the future equipment replacement cost in the MURS and the year 1 replacement cost (including financing) in the retrofit case. Thus, older equipment will often be considered as having a lower retrofit cost than the out-of-pocket expense for its replacement. The impact of this assumption is large in the NREL assessment, as equipment and appliances are assumed to be halfway through their useful service life.

This approach makes a credible academic argument (and a reasonable way to consider financing from a societal perspective); however, in reality the full cost of any retrofit must be borne by the homeowner at the time of replacement. Thus, discounting year 1 retrofit costs using the present value of an anticipated future replacement cost does not bear on how much the home retrofit will actually cost the consumer. On the contrary, consumers are often fixated on the out-of-pocket costs of energy-related improvements, such that the CostOpt scheme better reflects homeowner decision making.

CostOpt does not incorporate future upgrade costs and energy savings in the reference case. Thus, the full improvement cost the consumer will face for the retrofit is used to calculate the SIR for measure ranking and optimization. As a result, CostOpt is typically more conservative in measure selection (especially for equipment upgrades) and is significantly more sensitive to the financing term than BEopt, and longer term financing is significantly more productive than short-term financing. We believe this better reflects the real constraints that most consumers consider in choosing efficiency-related home improvement options.

6 Energy Price Rates

The CostOpt investigation uses statewide, revenue-based energy price rates derived from the latest annual EIA databases[5,6] for residential electricity and natural gas, respectively. In some instances (notably New York, California, and Maryland for electricity and New York, Arizona, and Florida for natural gas) the EIA residential energy price rates differ substantially from those used by Casey and Booten (2011). The energy price rates used for the 14 cities included in this investigation are given in Table 4. These may differ from the specific utility costs in the various locations, which could have a large impact on results. Further, the EIA utility revenue-based rates do not include state, local, and municipality utility taxes, which are typically 5%–15%. Thus, these rates are very conservative for our initial optimization assessment.

Table 4. Statewide Revenue-Based Energy Rates

City	State	CZ	$/kWh	$/therm
Miami	Florida	1	$0.1144	$1.844
Houston	Texas	2	$0.1160	$1.115
Atlanta	Georgia	3	$0.1007	$1.564
Los Angeles	California	3	$0.1475	$1.023
Seattle	Washington	4	$0.0804	$1.262
Phoenix	Arizona	2	$0.1097	$1.636
Minneapolis	Minnesota	6	$0.1059	$0.903
Detroit	Michigan	5	$0.1246	$1.167
New York	New York	4	$0.1874	$1.448
Ft. Worth	Texas	3	$0.1160	$1.115
San Francisco	California	3	$0.1475	$1.023
Denver	Colorado	5	$0.1104	$0.838
Baltimore	Maryland	4	$0.1432	$1.283
St. Louis	Missouri	4	$0.0908	$1.202
U.S. Average			$0.1154	$1.174

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[5] http://www.eia.gov/electricity/data.cfm#sales

[6] http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_STX_a.htm

7 Retrofit Improvement Measures

Ninety retrofit improvement measures are included in the analysis. Table 5 shows the acronyms used for these measures and their descriptions. The category names in the second column are used to affect the incremental analysis such that if two measures have the same category name, they are effectively compared against one another on a cost differential basis. For example, if R-19 ceiling insulation is accepted as the most cost-effective measure during the first iteration of the optimization, the cost for all other ceiling insulation options during subsequent iterations is equal to the difference in cost between the R-19 ceiling insulation that has already been accepted and the cost of the other ceiling insulation options that remain on the list of potential improvements. In this way, the various efficiency levels within a given category of measures are incorporated only as they become cost effective, often with intervening measures from another category incorporated in between.

Table 5. Description of Retrofit Improvement Measures

Acronym	Category	Description
SEER13HP	AC-HP	Minimum efficiency heat pump (SEER-13; HSPF-7.7)
SEER15HP	AC-HP	Improved efficiency heat pump (SEER-15; HSPF-9.0)
SEER18HP	AC-HP	High efficiency heat pump (SEER-18; HSPF-9.5)
SEER21HP	AC-HP	Very high efficiency heat pump (SEER-21; HSPF-10)
Mini-Split	AC-HP	Best efficiency mini-split heat pump (SEER-26; HSPF-12)
SEER13AC	AC-SH	Minimum efficiency air conditioner with strip heat (SEER-13; COP-1.0)
SEER15AC	AC-SH	Improved efficiency air conditioner w/ strip heat (SEER-15; COP-1.0)
SEER18AC	AC-SH	High efficiency air conditioner with strip heat (SEER-18; COP-1.0)
SEER21AC	AC-SH	Very high efficiency air conditioner with strip heat (SEER-21; COP-1.0)
SEER13GF80	AC-GF	Minimum efficiency gas furnace/minimum efficiency air conditioner (SEER-13; AFUE-80)
SEER13GF90	AC-GF	Improved efficiency gas furnace/minimum efficiency air conditioner (SEER-13; AFUE-90)
SEER13GF96	AC-GF	High-efficiency gas furnace/minimum efficiency air conditioner (SEER-13; AFUE-96)
SEER15GF90	AC-GF	Improved efficiency gas furnace/improved efficiency air conditioner (SEER-15; AFUE-90)
SEER15GF96	AC-GF	High efficiency gas furnace/improved efficiency air conditioner (SEER-15; AFUE-96)
SEER18GF96	AC-GF	High efficiency gas furnace/high efficiency air conditioner (SEER-18; AFUE-96)
AFUE-80	GF	Minimum efficiency gas furnace (AFUE-80)
AFUE-90	GF	Improved efficiency gas furnace (AFUE-90)
AFUE-96	GF	High efficiency gas furnace (AFUE-96)
SealDucts	Ducts	Seal ducts to 6 cfm25-out per 100 ft^2 conditioned floor

Acronym	Category	Description
		area
LeakFree	Ducts	Substantially leak free ducts at 3 cfm25-out per 100 ft^2 conditioned floor area
IntDucts	Ducts	Install substantially leak-fee ducts inside the conditioned space
IntAHU		Move air handler unit to inside the conditioned space
Ceil_R11	Ceiling_Ins	Insulate ceiling to R-11
Ceil_R16	Ceiling_Ins	Insulate ceiling to R-16
Ceil_R19	Ceiling_Ins	Insulate ceiling to R-19
Ceil_R30	Ceiling_Ins	Insulate ceiling to R-30
Ceil_R38	Ceiling_Ins	Insulate ceiling to R-38
Ceil_R49	Ceiling_Ins	Insulate ceiling to R-49
Ceil_R60	Ceiling_Ins	Insulate ceiling to R-60
WhShngl	Roof	Replace roof shingles with white shingles (solar absorptance = 0.75)
DrkShngl	Roof	Replace roof shingles with dark shingles (solar absorptance = 0.92)
Wht Roof	Roof	Install a white metal roof (solar absorptance = 0.30)
RBS		Install an attic radiant barrier system
CrwlFl_R11	CrwlFloor_ins	Insulate floor between crawlspace and conditioned space to R-11
CrwlFl_R19	CrwlFloor_ins	Insulate floor between crawlspace and conditioned space to R-19
CrwlFl_R30	CrwlFloor_ins	Insulate floor between crawlspace and conditioned space to R-30
SOG_R5-2h	SOG_ins	Insulate slab perimeter edge to R-5; 2 ft deep
SOG_R5-4h	SOG_ins	Insulate slab perimeter edge to R-5; 4 ft deep
Tile Floor	SOG_Floors	Install tile floors on slab
Carpet	SOG_Floors	Install carpet floors on slab
Wood Floor	SOG_Floors	Install wood floors on slab
BsmtFl_R11	BsmtFloor_ins	Insulate floor between unconditioned basement and conditioned space to R-11
BsmtFl_R19	BsmtFloor_ins	Insulate floor between unconditioned basement and conditioned space to R-19
BsmtFl_R30	BsmtFloor_ins	Insulate floor between unconditioned basement and conditioned space to R-30
CMU_R5	CMU_Ins	Add R-5 exterior insulation to concrete masonry walls
CMU_R10	CMU_Ins	Add R-10 exterior insulation to concrete masonry walls
FrmW_R13	FrameWall_ins	Insulate exterior frame walls to R-13 (drill and fill)
FrmW_R18	FrameWall_ins	Insulate exterior frame walls to R-18 (drill and fill + insulation sheathing + skin)
CrwlW_R5	CrwlWall_ins	Insulate crawlspace walls to R-5 (includes sealing crawlspace)
CrwlW_R10	CrwlWall_ins	Insulate crawlspace walls to R-10 (includes sealing crawlspace)

Acronym	Category	Description
CrwlW_R15	CrwlWall_ins	Insulate crawlspace walls to R-15 (includes sealing crawlspace)
Crwl_noVnt	CrwlWall_ins	Seal vented crawlspace (includes required ground cover)
BsmtW_R11	BsmtWall_ins	Insulate unconditioned basement walls to R-11
BsmtW_R19	BsmtWall_ins	Insulate unconditioned basement walls to R-19
BsmtW_R30	BsmtWall_ins	Insulate unconditioned basement walls to R-30
Lgtwalls		Paint exterior walls light color (solar absorptance = 0.40)
Darkwalls		Paint exterior walls dark color (solar absorptance = 0.70)
Tight	Infiltration	Air seal to ACH50 = 7
Tighter	Infiltration	Air seal to ACH50 = 5
VTight	Infiltration	Air seal to ACH50 = 3
StrmWin	Windows	Add storm windows
WinTint	Windows	Add window tint film to windows
SGreflect	Windows	Replace with single-pane reflective windows (U = 0.78; SHGC = 0.24)
DGLES	Windows	Replace with double-pane low-e solar windows (U = 0.39; SHGC = 0.28)
DGLEH	Windows	Replace with double-pane low-e heating windows (U = 0.39; SHGC = 0.52)
DGLEArH	Windows	Replace with double-pane low-e, argon heating windows (U = 0.29; SHGC = 0.48)
DGLEArS	Windows	Replace with double-pane low-e, argon solar windows (U = 0.29; SHGC = 0.24)
TGLEArH	Windows	Replace with triple-pane low-e, argon heating windows (U = 0.20; SHGC = 0.43)
Lgts_50%	Lighting	Install 50% high efficiency lighting
Lgts_75%	Lighting	Install 75% high efficiency lighting
Lgts_100%	Lighting	Install 100% high efficiency lighting
HWwrap		Add R-10 hot water tank wrap
LowFloSh		Replace shower heads with low-flow shower heads
Std_EHW	Water_Heater	Replace with minimum standard electric hot water system (EF = 0.92)
Std_GHW	Water_Heater	Replace with minimum standard gas hot water system (EF = 0.59)
ES_GHW	Water_Heater	Replace with ENERGY STAR gas hot water system (EF = 0.62)
TGWH	Water_Heater	Replace with tankless gas hot water system (EF = 0.82)
SHW_40/80PV	SolarHW	Replace with 40-ft^{2,} 80-gal, PV-pumped solar hot water system
SHW_ICS40	SolarHW	Replace with 40-gal, integrated collector storage solar hot water system
SHW_ICS-HP	SolarHW	Replace with 40-gal ICS solar hot water system with HPWH backup
HRUnit		Install hot water heat recovery unit on HVAC system
HPWH	HPWH	Install heat pump hot water heater (COP = 2.0)

Acronym	Category	Description
Dryer	Dryer	Replace with high efficiency clothes dryer (809 kWh/yr)
ES_Fridge		Replace with ENERGY STAR refrigerator (460 kWh/yr)
ES_dWash		Replace with ENERGY STAR dishwasher (EF = 0.68)
ES_Washer		Replace with ENERGY STAR washer (washer = 123 kWh/yr; dryer = 618 kWh/yr)
Misc/HEM	Misc	Home energy management (reduces lighting and appliance use by 480 kWh/yr)
WHFan		Install whole-house ventilation fan (produces 2.5 ACH ventilation when running)
PipeIns		Add R-2 Insulation to exposed hot water piping
Ins_Door		Replace exterior doors with insulated doors (U = 0.29)
5kW-PV	PV	Install 5-kW PV system

8 Improvement Cost Model

In most cases, improvement costs used in this investigation parallel those available from the National Renewable Energy Laboratory's (NREL) National Residential Efficiency Measure Database.[7] However, this study includes measures for which costs are not available in the NREL database (such as solar water heating and PV).

For heating and air conditioning equipment, costs were incorporated based on a separate study whereby the costs are expressed in an equation as a function of the equipment capacity and efficiency along with an offset. The data and analysis that underlie these 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 fibrous insulation reveals that the cost of fibrous insulation is approximately $\$0.035/\text{ft}^2$ per R-value. For these types of improvements these costs were cast in such terms. For most other costs, the costs contained in the NREL database were adopted.

For HVAC equipment, CostOpt uses the following equations to calculate installed retrofit costs (see also 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
kBtu = gas furnace capacity, which is limited to a minimum value of 45

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

For other options, costs depend on either the building configuration or the quantity of items required. We generally use the following equation to define measure costs as a function of the home geometry or number of items required.

TMC = FMC + (pSFpR*ΔR*GSF) + (pNSF*NSF) + (pGSF*GSF) + (pLF*LF) + (pCF*CF) + (pEA*EA) or MMC, whichever is less

where:
TMC = Total measure cost ($)
FMC = Fixed measure cost (coming out charge, etc.)
MMC = Minimum measure cost (cost below which the measure will not be implemented)
pSFpR = Unit cost per square foot per ΔR (normally blown insulation applied to GSF)

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

ΔR = R-value difference between existing home and improvement measure
GSF = Gross square feet
pNSF = Unit cost per net square foot (normally applied to walls only)
NSF = Net square feet
pGSF = Unit cost per gross square foot (normally for skin finish cost)
pLF = Unit cost per linear foot (normally the perimeter)
LF = Linear feet
pCF = Unit cost per cubic foot (normally the house volume)
CF = Cubic feet
pEA = Unit cost per each item (normally appliances, etc.)
EA = Number of each

Table 6 presents an example of the measure cost determination used by CostOpt. Where the measure cost is shown as $0, there is no construction component for the specific home being modeled.

Table 6. Example Cost Calculations for 1600 ft^2, SOG, Wood-Frame Archetype Home

RunName	MeasureCost	MeasureLife	Incentive	IncrementalCost	MaintFrac	IncBasis (fullCost - IncBasis = incCost)	MMC (min measure cost)	FMC (fixed measure cost)	pSFpR (per sq.ft. per ΔR)	units of pSFpR	ΔR-value	pNSF (per net sq.ft.)	units of pNSF	pGSF (per gross sq.ft.)	units of pGSF	pLF (per linear ft.)	units of pLF	pCF (per cu.ft.)	units of PCF	pEA (per each item)	units of EA	description of EA
SealDucts	$500	20	$0	$500		0								$1.25	400							
LeakFree	$900	20	$0	$900		0								$2.25	400							
IntDucts	$6,400	50	$0	$6,400		0								$4.00	1600							
IntAHU	$1,600	15	$0	$1,600		0								$1.00	1600							
Ceil_R11	$300	50	$0	$300		0	$300		$0.035	1600	1											
Ceil_R16	$336	50	$0	$336		0	$300		$0.035	1600	6											
Ceil_R19	$504	50	$0	$504		0	$300		$0.035	1600	9											
Ceil_R30	$1,120	50	$0	$1,120		0	$300		$0.035	1600	20											
Ceil_R38	$1,568	50	$0	$1,568		0	$300		$0.035	1600	28											
Ceil_R49	$2,184	50	$0	$2,184		0	$300		$0.035	1600	39											
Ceil_R60	$2,800	50	$0	$2,800		0	$300		$0.035	1600	50											
KneeW_R11	$0	50	$0	$0		0	$300		$0.035	0	11			$0.75	0							
KneeW_R19	$0	50	$0	$0		0	$300		$0.035	0	19			$0.75	0							
KneeW_R30	$0	50	$0	$0		0	$300		$0.035	0	30			$0.75	0							
KneeW_R38	$0	50	$0	$0		0	$300		$0.035	0	38			$0.75	0							
CathC_R11	$0	50	$0	$0		0	$300		$0.035	0	11			$2.00	0							
CathC_R19	$0	50	$0	$0		0	$300		$0.035	0	19			$2.00	0							
CathC_R30	$0	50	$0	$0		0	$300		$0.035	0	30			$2.00	0							
CathC_R38	$0	50	$0	$0		0	$300		$0.035	0	38			$2.00	0							
CathC_R49	$0	50	$0	$0		0	$300		$0.035	0	49			$2.00	0							
WhShngl	$3,200	15	$0	$10		3,190								$2.00	1600							
DrkShngl	$3,200	15	$0	$10		3,190								$2.00	1600							
Wht Roof	$11,200	30	$0	$8,000		3,200								$7.00	1600							
RBS	$2,400	30	$0	$800		1,600								$1.50	1600							
CrwlFl_R11	$0	50	$0	$0		0			$0.035	0	11			$0.75	0							
CrwlFl_R19	$0	50	$0	$0		0			$0.035	0	19			$0.75	0							
CrwlFl_R30	$0	50	$0	$0		0			$0.035	0	30			$0.75	0							
RasdFl_R11	$0	50	$0	$0		0			$0.035	0	11			$2.50	0							
RasdFl_R19	$0	50	$0	$0		0			$0.035	0	19			$2.50	0							
RasdFl_R30	$0	50	$0	$0		0			$0.035	0	30			$2.50	0							
FOGar_R11	$0	50	$0	$0		0			$0.035	0	11			$2.50	0							
FOGar_R19	$0	50	$0	$0		0			$0.035	0	19			$2.50	0							
FOGar_R30	$0	50	$0	$0		0			$0.035	0	30			$2.50	0							
SOG_R5-2h	$820	50	$0	$820		0										$5.00	164					
SOG_R5-4h	$1,148	50	$0	$1,148		0										$7.00	164					
Tile Floor	$4,480	50	$0	$4,480		0								$4.00	1120							
Carpet	$3,520	50	$0	$3,520		0								$2.75	1280							

RunName	MeasureCost	MeasureLife	Incentive	IncrementalCost	MaintFrac	IncBasis (fullCost - IncBasis = incCost)	MMC (min measure cost)	FMC (fixed measure cost)	pSFpR (per sq.ft. per ΔR)	units of pSFpR	ΔR-value	pNSF (per net sq.ft.)	units of pNSF	pGSF (per gross sq.ft.)	units of pGSF	pLF (per linear ft.)	units of pLF	pCF (per cu.ft.)	units of PCF	pEA (per each item)	units of EA	description of EA
Wood Floor	$5,320	50	$0	$5,320		0								$4.75	1120							
BsmtFl_R11	$0	50	$0	$0		0	$300		$0.055	0	11											
BsmtFl_R19	$0	50	$0	$0		0	$300		$0.055	0	19											
BsmtFl_R30	$0	50	$0	$0		0	$300		$0.055	0	30											
CMU_R5	$0	50	$0	$0		0						0.96	0	$5.50	0							
CMU_R10	$0	50	$0	$0		0						1.10	0	$5.50	0							
FrmW_R13	$3,225	50	$0	$3,225		0			$0.035	1032	13			$2.10	1312							
FrmW_R18	$6,177	50	$0	$6,177		0			$0.035	1032	13			$4.35	1312							
CrwlW_R5	$0	50	$0	$0		0						1.71	0	$1.00	0							
CrwlW_R10	$0	50	$0	$0		0						1.85	0	$1.00	0							
CrwlW_R15	$0	50	$0	$0		0						2.25	0	$1.00	0							
Crwl_noVnt	$0	50	$0	$0		0								$1.00	0							
BsmtW_R11	$0	50	$0	$0		0			$0.035	0	11			$2.00	0							
BsmtW_R19	$0	50	$0	$0		0			$0.035	0	19			$2.00	0							
BsmtW_R30	$0	50	$0	$0		0			$0.035	0	30			$2.00	0							
Lgtwalls	$656	15	$0	$10		646								$0.50	1312							
Darkwalls	$656	15	$0	$10		646								$0.50	1312							
Tight	$320	20	$0	$320		0	$300											$0.025	12,800			
Tighter	$1,280	20	$0	$1,280		0												$0.100	12,800			
VTight	$2,560	20	$0	$2,560		0												$0.200	12,800			
StrmWin	$2,400	20	$0	$2,400		0								$10.00	240							
WinTint	$1,500	10	$0	$1,500		0								$6.25	240							
SGreflect	$6,720	50	$0	$240		6,480								$28.00	240							
DGLES	$7,200	50	$0	$720		6,480								$30.00	240							
DGLEH	$7,200	50	$0	$720		6,480								$30.00	240							
DGLEArH	$8,160	50	$0	$1,680		6,480								$34.00	240							
DGLEArS	$8,160	50	$0	$1,680		6,480								$34.00	240							
TGLEArH	$14,400	50	$0	$7,920		6,480								$60.00	240							
Lgts_50%	$120	5	$0	$120		0								$0.08	1600							
Lgts_75%	$240	5	$0	$240		0								$0.15	1600							
Lgts_100%	$400	5	$0	$400		0								$0.25	1600							
HWwrap	$50	12	$0	$50		0														$50	1	HWtank
LowFloSh	$70	15	$0	$70		0														$35	2	shower
Std_EHW	$408	12	$0	$10		398														$408	1	system
Std_GHW	$700	12	$0	$292		408														$700	1	system
ES_GHW	$750	12	$0	$342		408														$750	1	system
TGWH	$950	12	$0	$542	2.41%	408														$950	1	system
SHW_40/80 PV	$6,000	40	$1,800	$5,592	1.13%	408														$6,000	1	system
SHW_ICS40	$4,500	40	$1,350	$4,092	0.42%	408														$4,500	1	system

RunName	MeasureCost	MeasureLife	Incentive	IncrementalCost	MaintFrac	IncBasis (fullCost - IncBasis = incCost)	MMC (min measure cost)	FMC (fixed measure cost)	pSFpR (per sq.ft. per ΔR)	units of pSFpR	ΔR-value	pNSF (per net sq.ft.)	units of pNSF	pGSF (per gross sq.ft.)	units of pGSF	pLF (per linear ft.)	units of pLF	pCF (per cu.ft.)	units of PCF	pEA (per each item)	units of EA	description of EA
SHW_ICS-HP	$6,000	40	$1,800	$5,592	1.44%	408														$6,000	1	system
HRUnit	$1,500	15	$0	$1,500		0														$1,500	1	HRU
HPWH	$1,900	15	$300	$1,492	1.05%	408														$1,900	1	HPWH
Pstat	$150	15	$0	$150		0														$150	1	stat
cFan	$1,080	20	$0	$400		680														$270	4	Nbr+1
Dryer	$800	15	$0	$100		700														$800	1	dryer
ES_Fridge	$1,000	15	$0	$100		900														$1,000	1	fridge
ES_dWash	$400	15	$0	$75		325														$400	1	dWash
ES_Washer	$1,200	15	$0	$200		1,000														$1,200	1	cWash
Misc/HEM	$600	10	$0	$600		0														$600	1	system
WHFan	$2,350	10	$0	$2,350		0														$1,175	2	fan
PoolPump	$0	15	$0	$0		0														$320	0	pump
WellPump	$0	15	$0	$0		0														$150	0	pump
Cln_FrigCoil	$30	3	$0	$30		0														$30	1	fridge
PipeIns	$40	15	$0	$40		0														$40	1	pipe ins
Ins_Door	$600	40	$0	$250		350														$300	2	door
5kW-PV	$32,500	40	$9,750	$32,500	1.58%	0														$6.50	5,000	wattsPV

The maintenance fractions given as a percent in Table 6 are equal to the annual maintenance cost divided by the measure cost. Maintenance fractions are useful for describing differential maintenance costs as compared with the standard practice and are also a good way to include added costs for items in a system that do not last the full life of the longest lasting components of the system, such as solar systems where pumps and tanks need replacement much more often than the collector. They also allow for incorporation of performance degradation factors such as those that occur in PV systems. The maintenance fractions used by CostOpt in this investigation are shown in Table 7.

Table 7. Calculation of Annual Maintenance Costs for Specific Items

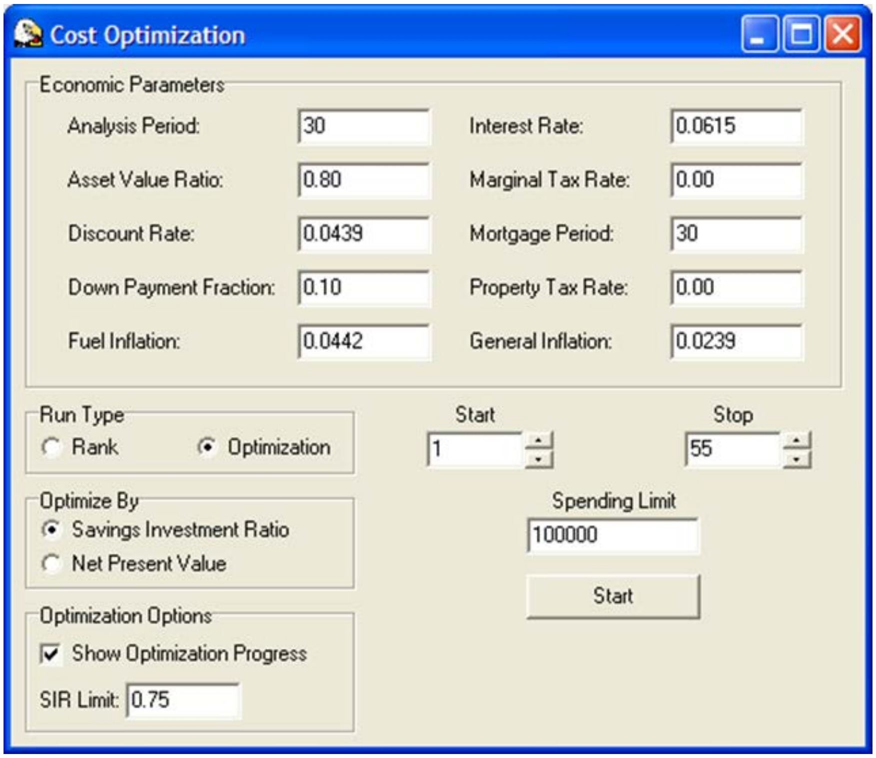
RunName	maint$/year	maint$_#1	maintPeriod_#1	maint$_#2	maintPeriod_#2	maint$_#3	maintPeriod_#3	Comments/Notes
TGWH	$22.92	$25	1					$25/yr for cleaning
SHW_40/80PV	$67.50	$150	5	$300	10	$750	20	$150 every 5 yrs for pump + $300 every 10 yrs for tank + $750 every 20 yrs for reroofing
SHW_ICS40	$18.75	$750	20					$750 every 20 yrs to remove and replace for reroofing
SHW_ICS-HP	$86.67	$750	20	$1,000	15	$150	5	$750 every 20 yrs to remove and replace for reroofing + replace HPWH every 15 yrs + 150 every 5 yrs for HPWH
HPWH	$20	$150	5					$150 every 5 yrs
5kW-PV	$350	$4,000	10	$2,000	20			$0.80/W for new inverter every 10 yrs + $0.40/W every 20 yrs for reroofing + 0.5% PV degradation

CostOpt also provides two operational “flags” for each measure that control the simulations. One is a simulation flag controlling whether a given measure is included in the list of measures to be simulated. If the measure cost evaluates to $0 (see Table 6 for examples), this flag is automatically set to false and the measure is not included in the list of measures evaluated. However, users can manipulate the simulation flag to reduce the number of simulations performed when they know that a measure is highly unlikely to be cost effective or if they do not want to consider the measure for aesthetic or practical reasons.

The second flag is the incremental cost flag, which indicates that incremental cost should be used to evaluate the measure because the option is at the end of its service life and must be replaced. This flag defaults to false for all measures. However, users can set this flag to true on a measure by measure basis, allowing measures to be evaluated on an incremental cost basis rather than a full cost basis. For example, if the HVAC equipment is no longer operational and will be replaced, the incremental flag for HVAC equipment can be set to true and the incremental cost rather than the full cost will be used by CostOpt in the optimization.

Optimization is initiated with the economic parameter and optimization control screen shown in Figure 4. Unless otherwise stated, the values shown on this screen are those used for the optimization analysis reported in this investigation. There are two notable exceptions:

- The mortgage period was set to 7 years for a selection of evaluations to study the impact of this important economic variable.
- For at least one set of optimizations the interest rate was changed to 4% to reflect rates that are available currently as a refinance (ReFi) option.


Cost Optimization

Economic Parameters

Analysis Period: 30
Interest Rate: 0.0615
Asset Value Ratio: 0.80
Marginal Tax Rate: 0.00
Discount Rate: 0.0439
Mortgage Period: 30
Down Payment Fraction: 0.10
Property Tax Rate: 0.00
Fuel Inflation: 0.0442
General Inflation: 0.0239

Run Type
○ Rank ● Optimization

Start: 1
Stop: 55

Optimize By
● Savings Investment Ratio
○ Net Present Value

Spending Limit: 100000

Optimization Options
☑ Show Optimization Progress
SIR Limit: 0.75

Figure 4. Starting screen for CostOpt

The Cost Optimization screen allows users to control the economic parameters as well as other factors affecting the analysis. The Run Type option allows either a simple rank ordering of the measures or a full optimization to be run. The Spending Limit will stop the optimization when the specified expenditure limit has been reached. Optimization iterations can be ranked by either SIR or NPV; NPV usually produces significantly fewer total simulations. An SIR limit can be set, whereby only measures that exceed this limit are accepted. CostOpt also simulates solar electric PV systems (Menicucci and Fernandez 1988).[8] If a PV system is included in the list of measures to be considered, CostOpt will automatically set the optimization SIR Limit to either the value entered on the startup screen or to the SIR for the PV system, whichever is less. A 5-$\mathrm{kWp}_{(dc)}$ PV system was included in all optimizations conducted for this investigation to investigate geographic and economic impacts of its competition with efficiency improvements.

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[8] PVFORM, developed by Sandia National Laboratory, is used for PV simulations.

9 Results

9.1 Archetype Baseline Energy

How well the baseline energy consumption represents the housing stock is relevant to the investigation. The U.S. EIA Residential Energy Consumption Survey (RECS) database provides detailed microdata for the four largest states that can be used for this purpose. Table 8 presents a comparison of the archetype baseline energy uses with the 2005 RECS data in these large states.

Table 8. Comparison of Baseline Home Energy Uses With 2005 RECS Data

New York Baseline Homes			2005 RECS Data		
Mixed Fuel Homes	Simulation	Proto error	Mean	StDev	n
kWh	8,364	–1.19%	8,465	5,331	47
Therms	1,180	3.78%	1,137	452	47
All-Electric Homes					
kWh	n/a	n/a	n/a	n/a	n/a
California Baseline Homes			**2005 RECS Data**		
Mixed Fuel Homes	Simulation	Proto error	Mean	StDev	n
kWh	6,306	–21.88%	8,072	5,153	217
Therms	418	–26.76%	570	335	217
All-Electric Homes					
kWh	11,290	–19.24%	13,980	7,323	13
Texas Baseline Homes			**2005 RECS Data**		
Mixed Fuel Homes	Simulation		Mean	StDev	n
kWh	12,282	–21.13%	15,572	9,183	109
Therms	500	–0.71%	504	257	109
All-Electric Homes					
kWh	18,830	–0.80%	18,981	7,127	56
Florida Baseline Homes			**2005 RECS Data**		
Mixed Fuel Homes	Simulation	Proto error	Mean	StDev	n
kWh	n/a	n/a	n/a	n/a	n/a
Therms	n/a	n/a	n/a	n/a	n/a
All-Electric Homes					
kWh	17,651	–2.86%	18,171	6,890	86

Generally agreement was fairly good given the geographically coarse nature of the RECS data. State RECS data are available for only the four most populous states, so these data do not provide comparison for the other climates included in this investigation or for the specific simulated locations—particularly important for a state such as California, where local climates vary significantly. Thus, the fact that the archetype energy uses are from 4% larger to 26%

smaller than the mean values derived from the RECS data is not particularly problematic. The fact that the archetype energy uses are smaller than the RECS averages probably tends to bias optimization results toward conservative energy savings estimates.

Fourteen cities with a representative range of U.S. climates were included (hot humid, mixed, cold, and marine) in the investigation. However, some cities have multiple archetype expressions. For example, climate zone 2 has a significant number of homes with concrete masonry wall systems and many with wood frame wall systems. Multiple space and water heating fuels were often considered in many locations as commonly encountered. Thus, 22 archetypes were created in the 14 cities investigated, such that differing common alternatives could be evaluated.

All-electric and mixed-fuel archetypes were created in a number of cities, and the optimization analysis for each archetype allowed these fuels to be switched when the cost effectiveness economics favored such a change.

Table 9 presents the baseline energy uses and costs for each archetype configuration. Source energy use was calculated using the Building America fuel multipliers of 3.365 for electricity use and 1.092 for natural gas use. Baseline source energy use across all archetypes varied from a high of 247 MBtu for the concrete masonry wall archetype home with a heat pump and electric water heating in Phoenix, Arizona to a low of 102 MBtu for the frame wall archetype home with gas furnace and gas water heating in Los Angeles, California.

Table 9. Archetype Descriptions, Locations, and Baseline Energy Uses and Costs

Prototype Building Description	Location		Cooling	Heating		Hot Water		L&A	Total		Total	Cost
	City	CZ	kWh	kWh	Therms	kWh	Therms	kWh	kWh	Therms	Source MBtu	$/year
1600sf-1sty-SOG-CMU-HP	Miami	1	9,264	84		2,193		6110	17,651		203	$2,021
1600sf-1sty-SOG-CMU-HP	Houston	2	5,904	2,827		2,615		6110	17,456		200	$2,025
1600sf-1sty-SOG-Frm-GF	Houston	2	6,077	156	241		152	6110	12,343	393	185	$1,870
1600sf-1sty-SOG-Frm-HP	Houston	2	6,048	2,839		2,615		6110	17,612		202	$2,042
1600sf-1sty-SOG-CMU-HP	Phoenix	2	12,000	1,146		2,257		6110	21,513		247	$2,359
1600sf-1sty-SOG-Frm-GF	Phoenix	2	11,298	57	86		132	6110	17,465	217	224	$2,272
1600sf-1sty-SOG-Frm-HP	Phoenix	2	10,945	947		2,256		6110	20,258		233	$2,261
1600sf-1sty-Crwl-Frm-HP	Atlanta	3	3,389	5,747		2,999		6110	18,245		210	$1,837
1600sf-1sty-Crwl-Frm-GF	Atlanta	3	3,337	299	480		173	6110	9,746	653	183	$2,003
1600sf-1sty-Crwl-Frm-HP	Ft Worth	3	5,826	5,270		2,842		6110	20,048		230	$2,327
1600sf-1sty-Crwl-Frm-GF	Ft Worth	3	5,824	286	442		165	6110	12,220	607	207	$2,095
1600sf-1sty-Crwl-Frm-GF	Los Angeles	3	45	70	111		173	6110	6,225	283	102	$1,209
1600sf-1sty-Crwl-Frm-HP	Los Angeles	3	115	853		2,985		6110	10,063		116	$1,483
1600sf-1sty-Crwl-Frm-GF	San Francisco	3	49	227	361		191	6110	6,386	552	134	$1,504
1600sf-1sty-Crwl-Frm-HP	San Francisco	3	62	3,045		3,300		6110	12,517		144	$1,846
1600sf-1sty-Crwl-Frm-GF	Baltimore	4	2,108	531	845		194	6110	8,749	1,038	214	$2,586
1600sf-1sty-Crwl-Frm-GF	New York	4	1,640	614	982		198	6110	8,364	1,180	225	$3,276
1600sf-1sty-Crwl-Frm-HP	Seattle	4	233	9,571		3,562		6110	19,476		224	$1,568
1600sf-1sty-Crwl-Frm-GF	Seattle	4	189	537	878		205	6110	6,836	1,083	197	$1,918
1600sf-1sty-Crwl-Frm-GF	St Louis	4	2,768	572	904		192	6110	9,450	1,096	228	$2,178
1600sf-1sty-Bsmt-Frm-GF	Denver	5	607	491	732		207	6110	7,208	939	185	$1,581
1600sf-1sty-Bsmt-Frm-GF	Detroit	5	733	629	938		211	6110	7,472	1,149	211	$2,271
1600sf-1sty-Bsmt-Frm-GF	Minneapolis	6	423	805	1187		225	6110	7,338	1,412	238	$2,051

Building Description Key:

1600sf: Square feet of conditioned space
1sty: One story
SOG: Slab-on-grade foundation
Crwl: Crawlspace foundation
Bsmt: Unconditioned, unfinished basement foundation
CMU: Concrete masonry wall system
Frm: Frame wall system
HP: Heat pump archetype (electric space and water heating)
GF: Gas furnace archetype (natural gas space and water heating)
CZ: IECC Climate Zone

The annual energy costs for the archetypes varied by climate severity, but also by local energy costs. The lowest annual energy cost of $1,209 was shown for the archetype in the mild weather of Los Angeles, also with the lowest source energy use. By way of contrast, the archetype located in the most severe cold climate, Minneapolis, Minnesota, had an annual energy cost of $2,051. While the Minneapolis archetype's source energy use was slightly greater than the New York archetype, the annual energy cost for the New York archetype was $1,225 greater given the much higher utility costs. Thus, while climate severity definitely made a significant difference to source energy use, utility rates for electricity and natural gas had a much greater impact on annual energy costs.

10 Cost Optimization Results

Four sets of optimization scenarios were conducted for this investigation, each with a different scenario of financing assumptions and a relevant retrofit business model. The four scenarios are:

1. **Default.** A 30-year mortgage at 6.15% interest at full replacement cost
2. **Homeowner finance.** A 7-year mortgage at 6.15% interest at full replacement cost
3. **HVAC contractor finance.** A 7-year mortgage at 6.15% interest; incremental HVAC costs
4. **Remodel with refinancing.** A refinanced 30-year mortgage at 4.0% interest rate at full replacement costs.

The analysis period is 30 years for all four scenarios. Optimization Scenario 1 represents the "default" economic cost-effectiveness optimization case as specified in Table 2 and in accordance with the standards promulgated by RESNET (2012). Optimization Scenarios 2–4 are designed to represent alternative business models or financing opportunities.

Optimization Scenario 2 represents the general home improvement model, where long-term financing is unavailable and either a second mortgage or an unsecured loan is used to finance the improvements over a 7-year term.

Optimization Scenario 3 represents the HVAC contractor business model, where long-term financing is not available but the HVAC system has ceased to operate and must be replaced. For Scenario 3, the cost of the replacement HVAC equipment is reduced to the incremental cost difference between the minimum standard equipment and the improved efficiency equipment.

Optimization Scenario 4 represents the home mortgage refinance case where the homeowner or homebuyer can take advantage of a reduced mortgage interest rate concurrent with a comprehensive home energy improvement as part of a general house remodel.

10.1 Optimization Scenario 1

Optimization Scenario 1, the economic parameter default case, examines 23 archetypes in 14 cities comprising six IECC climate zones ranging from climate zone 1 to climate zone 6. Summary results from this scenario of optimization runs are shown in Table 10. Six of the archetypes shown in Optimization Scenario 1 were evaluated for this scenario only. These are shaded light gray in Table 10. The remaining 17 archetypes were evaluated in each of the other Optimization Scenarios. Standard CostOpt plots for each archetype are given in Appendix C. These graphical results are useful in understanding the order in which improvement measures are selected and their relative performance in reducing energy use and influencing homeowner annual energy costs.

Table 10. Optimization Scenario 1—Default Economic Parameter Optimizations

Prototype Models	Miami_SOG-CMU-HP	Houston_SOG-CMU-HP	Houston_SOG-Frm-GF	Houston_SOG-Frm-HP	Phoenix_SOG-CMU-HP	Phoenix_SOG-Frm-GF	Phoenix_SOG-Frm-HP	Atlanta_Crwl-Frm-HP	Atlanta_Crwl-Frm-GF	FtWorth_Crwl-Frm-HP	FtWorth_Crwl-Frm-GF	LosAngeles_Crwl-Frm-HP	LosAngeles_Crwl-Frm-GF	SanFrancisco_Crwl-Frm-HP	SanFrancisco_Crwl-Frm-GF	Baltimore_Crwl-Frm-GF	NewYork_Crwl-Frm-GF	Seattle_Crwl-Frm-HP	Seattle_Crwl-Frm-GF	StLouis_Crwl-Frm-GF	Denver_Bsmt-Frm-GF	Detroit_Bsmt-Frm-GF	Minneapolis_Bsmt-Frm-GF
Climate Zone:	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	5	5	6
%Src Savings:	54	34	34	41	54	42	54	42	37	47	28	34	18	39	25	33	43	37	38	35	18	31	31
Measures																							
AFUE-96																•	•					•	•
SEER15HP									•										•				
SEER21AC	•						•																
SEER18GF96					•	•																	
SEER15GF96										•													
LeakFree	•	•		•	•		•		•	•	•					•	•	•	•	•		•	
SealDucts			•			•								•									
Ceil_R38		•	•	•				•	•	•	•					•		•	•		•		•
Ceil_R49					•	•	•										•			•		•	
Ceil_R30	•													•	•								
FrmW_R13			•	•													•	•		•			
Crwl_noVnt									•							•	•	•		•			
CrwlFl_R30														•					•				
BsmtFl_R11																					•	•	
CrwlW_R15										•	•												
CrwlFl_R19															•								
CrwlW_R10								•															
BsmtW_R19																							•
Tight	•	•	•	•	•	•	•	•	•	•	•			•	•	•		•	•				
Tighter																	•			•			
Lgts_100%	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Misc/HEM	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•				•	•
LowFloSh	•				•		•	•	•							•	•	•	•	•		•	•
PipeIns						•		•	•		•		•		•		•		•		•	•	•
HWwrap			•			•					•		•		•	•	•				•	•	•
TGWH		•		•					•	•		•		•					•	•			
SHW_ICS-HP	•				•		•	•										•					
5kW-PV					•	•	•					•	•	•	•		•						
srcSave% w/PV					97	90	100					116	110	102	93		78						

Seven instances of fuel switching are shown via yellow highlighting in Table 10. Five show fuel switching from electricity to natural gas and two show switching from natural gas to electricity. Fuel switching is largely attributed to water heating systems (five cases), where tankless gas water heating systems are selected to replace electric hot water systems. However, one instance (Ft. Worth) shows switching from electricity to natural gas for both the HVAC system and the hot water system. And in Atlanta and Seattle we see HVAC fuel switching from a gas furnace to an electric heat pump. Examination of the fuel costs provides ready explanation for these choices. In Houston and Ft. Worth electricity is more than three times the cost of natural gas and in Los Angeles and San Francisco electricity is more than four times the cost of natural gas. On the other hand, in Atlanta and Seattle, where the fuel switching is in the opposite direction, electricity is less than twice the cost of natural gas. In Baltimore, New York, Denver, Detroit, and Minneapolis, we did not run all-electric cases as this is not common, so we do not see fuel switching occurring in these climates even though it would not likely occur because electricity is more than three times the cost of natural gas in these locations.

The two Phoenix all-electric cases are quite interesting. Electricity costs in Phoenix are less than twice the cost of natural gas, but natural gas water heating is not selected for the all-electric homes in Phoenix. Rather, because of the advantageous solar potential, a solar hot water system is selected for both all-electric cases. Conversely, solar hot water is not selected in Phoenix for the gas home archetype. Instead, the hot water pipes and the hot water tank are insulated—measures that are not selected for the all-electric homes in Phoenix, where solar hot water systems are selected instead.

This illustrates the importance of the relationship between electricity and gas prices to the specific results. However, the absolute prices of gas and electricity are also very important to the selection of improvement measures and the potential to cut source energy use through retrofit measures. This is particularly true for PV, which is selected as cost effective in eight archetypes.

The five archetypes in California and New York all select 5-kW PV systems as cost effective because of the high price of electricity in those states ($0.1475/kWh and $0.1874/kWh, respectively). A 5-kW PV system is also selected as cost effective in Phoenix, where electricity prices are much lower ($0.1097/kWh), but where the solar resource is the greatest of all the climates studied. There, the generic 5-kW PV system produces 9,375 kWh/yr. In New York, San Francisco, and Los Angeles, the 5-kW PV systems produce 6,971, 8,080, and 8,424 kWh/yr, respectively. In New York, high electricity prices drive the selection of PV and in San Francisco and Los Angeles, the combination of a good solar resource plus high electricity prices enhance the desirability of the PV systems.

Utility prices also drive cost optimization from another important perspective. If utility prices are low, fewer improvement measures are selected as cost effective and smaller savings percentages are achieved. Denver, where electricity is $0.11/kWh and natural gas is $0.838/therm, offers perhaps the best example of this fact. Denver has the lowest natural gas price of all 14 cities. Thus, the cost-effective savings for the Denver natural gas archetype are only 18%, even though the weather is fairly severe. In fact, because of the price of natural gas, it is not even cost effective to improve the efficiency of the archetype 76% AFUE gas furnace in Denver, something that was done in the other cold climate archetypes (Detroit and Minneapolis).

Table 10 also illustrates the sensitivity of improvement measures to their specific performance and cost characteristics. For example, replacing 100% of the incandescent lighting with CFLs or equivalent light-emitting diodes (LEDs) is cost effective in every location and circumstance. Thus, this measure does not appear to be sensitive to either climate or utility price. Home energy management (HEM) systems also appear to be cost effective across a large variety of climates and archetypes. They are selected in all archetypes except four located in Atlanta, Seattle, St. Louis, and Denver. Electricity prices are $0.10, $0.08, $0.09, and $0.11/kWh, respectively, in these cities. We also see that for most climates, addressing duct leakage is cost effective. The notable exceptions are Los Angeles, where the cooling and heating loads are very small, and in most of the unconditioned basement archetypes, where the archetype distribution system leakage is much less substantive.

In 13 of the 23 archetypes, the hot water system is also improved. And in all cases where the hot water system is not replaced, pipe insulation, hot water tank wrap, low-flow shower heads, or some combination of these options are selected.

Ceiling insulation is also improved in all archetypes except those in Los Angeles, again illustrating how benign this climate is with respect to heating and cooling loads. In fact, these loads are so limited in Los Angeles that up to 34% source energy savings are achievable through lighting, HEM, and water heating retrofits. However, this savings level is achievable only if the archetype is all-electric. If the archetype has a gas space and water heating, only 18% efficiency savings are cost effective. Against that limitation, however, >100% source energy savings are cost effective in both Los Angeles archetypes with 5-kW PV systems that are indicated.

Optimization Scenario 1 achieves weighted average source energy savings or 37.4% without the selected PV systems. If the five cases where PV is selected are included, the weighted average source energy savings increase to 51.2%. Weighted average source energy savings are calculated as the sum of the source energy savings for all archetypes divided by the sum of the base home source energy use for all archetypes.

10.2 Optimization Scenario 2: Homeowner Financing

Optimization Scenario 2 is designed to study the cost effectiveness of a standard home improvement mortgage, typically financed by the homeowner over a short 7-year period. A total of 17 archetypes in 14 cities are evaluated. The mortgage period is set to 7 years and all other economic parameter values are as in Scenario 1. The summary results are presented in Table 11. Standard CostOpt plots for each archetype are given in Appendix D. These graphical results are useful in understanding the order in which improvement measures are selected.

Table 11. Optimization Scenario 2—Home Improvement Mortgage Optimizations

Prototype Models	Miami_SOG-CMU-HP	Houston_SOG-Frm-HP	Phoenix_SOG-Frm-GF	Phoenix_SOG-Frm-HP	Atlanta_Crwl-Frm-HP	FtWorth_Crwl-Frm-HP	FtWorth_Crwl-Frm-GF	LosAngeles_Crwl-Frm-GF	SanFrancisco_Crwl-Frm-GF	Baltimore_Crwl-Frm-GF	NewYork_Crwl-Frm-GF	Seattle_Crwl-Frm-HP	Seattle_Crwl-Frm-GF	StLouis_Crwl-Frm-GF	Denver_Bsmt-Frm-GF	Detroit_Bsmt-Frm-GF	Minneapolis_Bsmt-Frm-GF
Climate Zone:	1	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	6
%Src Savings:	26	33	25	30	12	31	16	17	12	27	34	7	23	23	17	17	8
Measures																	
AFUE-96											●						
SealDucts			●	●	●	●	●					●					
LeakFree	●	●								●	●		●	●			
Ceil_R30	●	●				●	●						●	●	●		●
Ceil_R38			●	●						●	●					●	
Ceil_R19					●												
Crwl_noVnt						●				●	●			●			
BsmtFl_R11															●	●	
CrwlFl_R19													●				
Tight	●	●	●	●		●	●			●	●		●	●			
Lgts_100%	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●
HWwrap	●		●		●			●	●	●	●	●	●	●	●	●	●
PipeIns			●				●	●	●		●		●		●	●	●
Misc/HEM	●	●	●	●		●		●	●	●	●						
LowFloSh	●			●	●					●	●	●	●	●			
Lgts_50%												●	●				
TGWH		●		●		●											

The average source energy savings for these same archetypes in Optimization Scenario 1 is 36%. For Optimization Scenario 2, the average is 21%—a 15% reduction in average source energy savings from the reduced mortgage period. Reducing the mortgage term from 30 years to 7 years means that monthly mortgage payments will be greater. This increase in short-term payments is offset some by the fact that the analysis period remains 30 years and the energy cost benefits continue to accrue after the mortgage is paid. However, the earlier and larger mortgage payments result in less out-year discounting of the improvement costs while the future energy benefits are discounted for the full period of the analysis. As a result, fewer measures are cost effective and overall source energy savings are reduced.

Source energy savings of 30% are achievable in only three archetypes (Houston, Phoenix, and New York) where tankless gas water heaters are cost effective. Two archetypes result in only single-digit savings. The heat pump archetype in Seattle shows savings of only 7% and the Minneapolis archetype shows savings of only 8%. This is explained by the fact that Seattle has an electricity cost of only $0.08/kWh and Minneapolis has a gas cost of only $0.90/therm. Once again, the strong influence of utility costs becomes evident in the level of improvements that can be economically justified. For example, in New York where both electricity and natural gas costs are relatively much greater ($0.18/kWh and $1.45/therm), the cost-effective energy savings are 34%.

The savings (and the installed measures) for Denver are almost identical for Optimization Scenarios 1 and 2. The sole difference is that ceiling insulation goes to R-38 for Optimization Scenario 1 but only R-30 for Optimization Scenario 2. Thus, again the very low cost of natural gas in Colorado significantly reduces the cost effectiveness of improvement measures, nearly irrespective of mortgage period.

Optimization Scenario 2 achieves weighted average source energy savings across all archetypes and all climates of 21.5%. This is almost 16% less than the default scenario without PV and almost 30% less than the default scenario with PV included in the average. The 5-kW PV system is not cost effective for any location when the mortgage period is reduced to 7 years. On the other hand, the 5-kW PV system proved cost effective for five archetypes when the mortgage period was 30 years (Optimization Scenario 1).

10.3 Optimization Scenario 3: HVAC Contractor Financing

Many energy-using components in a home will eventually need replacement. A key ability of the economic methods used in our evaluation has been to account for replacement—sometimes multiple times—over the analysis time horizon. However, a less considered issue concerns how components and equipment are considered that need replacement at the time, or very close to the time, the retrofits are contemplated.

This circumstance is important because the incremental cost of choosing more efficient equipment is often quite low at the time of replacement. For instance, in our base analysis, which considers only outright replacement of functional equipment and components at full cost, changing to a more efficient electric heat pump and more efficient windows will seldom be selected in the optimization process. This is because replacing a working heat pump will often cost $5,000 or more and replacing functional windows can cost easily cost twice that.

If the heat pump is no longer working and is at the end of its useful life, the incremental cost of changing to a SEER-15/ HSPF-10 heat pump will often be only $500 after considering the $300 federal tax credit. The same is true for windows that need replacing, where the cost of replacing standard double-glazed units with well-insulated, solar control low-e ones will only be a few thousand dollars as opposed to $10,000 or more for outright replacement. On the other hand, options such as PV systems or whole-house fans have incremental replacement costs that are the same as those for outright replacement, because they are not otherwise necessary for a functional household.

In the CostOpt analysis, it is possible to designate that certain items or equipment needs replacement at the time of the retrofits. This causes the analysis to use the “incremental cost” over the same less efficient minimum efficiency component to evaluate cost effectiveness. This often results in options being selected that are otherwise not selected in the outright replacement paradigm. Based on our evaluation, this often includes ENERGY STAR appliances, HVAC systems, windows, changes to wall and roof color. These items are often cost effective, but only at the time of natural replacement when a conventional replacement must be purchased anyway.

Figure 5 and Figure 6 reproduce two sets of optimization results for Ft. Worth, Texas. The figures are in a standard CostOpt format that plots the cumulative investment costs and the cumulative NPV of the investments on the left-hand vertical axis and the cumulative source energy savings percentage on the right-hand axis. Thus, if an individual improvement measure has an SIR greater than unity, cumulative NPV will increase. However, if an individual measure has an SIR less than unity, cumulative NPV will decrease. Therefore, the point at which the NPV is largest is the optimum cost effectiveness from the consumer’s perspective. However, measures often come in at the end of the optimization that have an individual measure SIR less than unity but that do not cause the cumulative NPV to drop below zero. These measures are also cost effective from a societal perspective in that they are “paid for” by the earlier highly cost-effective measures. Thus, the neutral cost point from the CostOpt perspective is the line where the cumulative NPV equals zero. Because the optimization method is incremental, a number of measures are selected and then later replaced by higher efficiency measures in the same category. For ease of understanding, the final selections in each category are highlighted in light green on the plots.

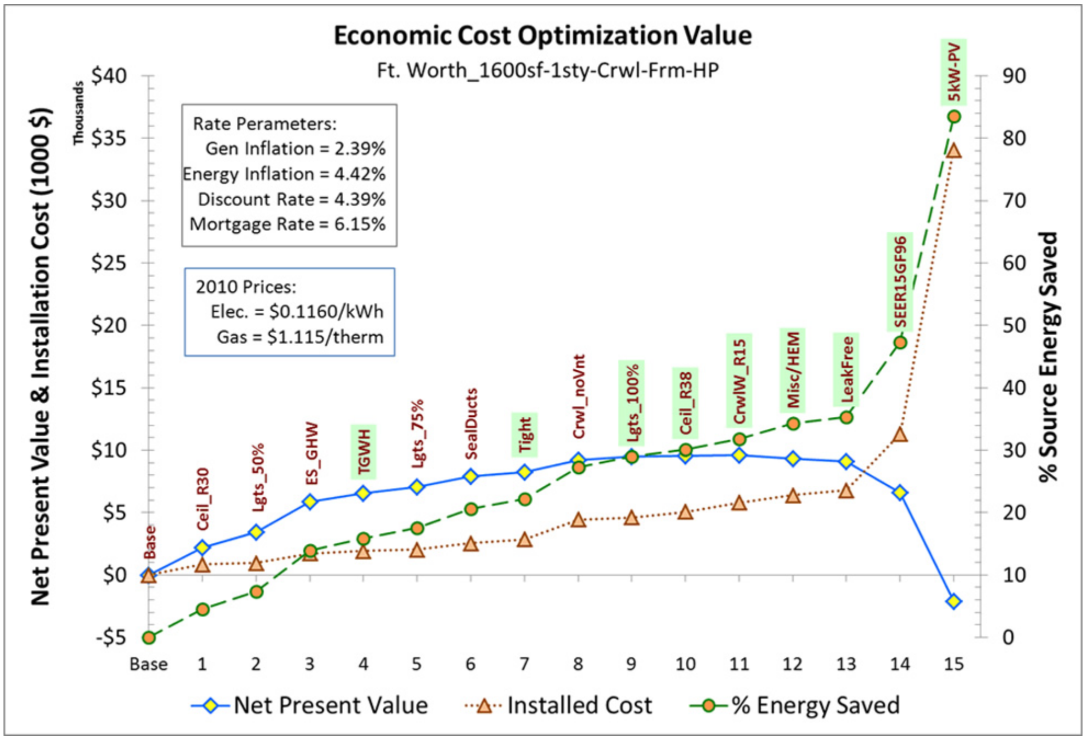

Figure 5. Ft. Worth analysis using full costs for all measures and outright replacement

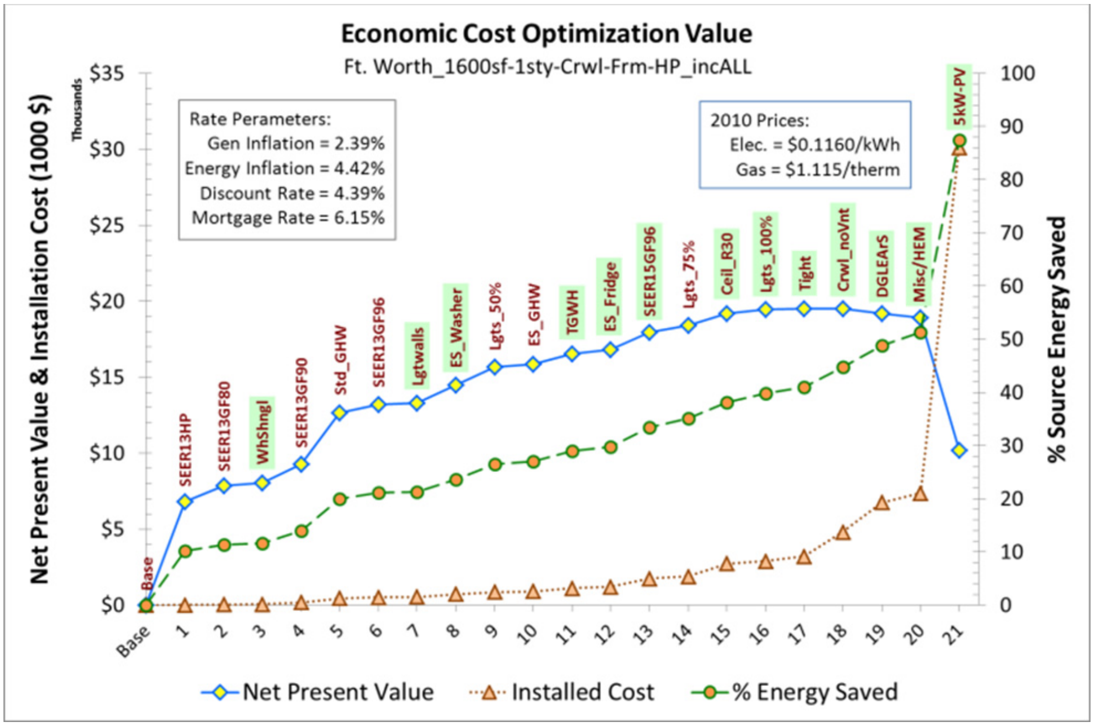

Figure 6. Ft. Worth analysis using incremental costs (natural replacement costs) for all measures

Figure 5 shows results from the conventional "outright replacement" paradigm (Optimization Scenario 1) where things are changed only if it is cost effective to pay full cost for removing and replacing them with more efficient equipment and components. As the heat pump is still good, its duct system is sealed and lighting is changed to CFLs or equivalent LEDs over the entire home. Other parts of the building envelope are further improved—notably ceiling insulation goes to R-38 and the crawlspace is sealed and insulated to R-15 on the exterior crawlspace walls. Because of the cost advantage of natural gas in Texas, the optimization decides to replace the standard electric water heater with a tankless gas model. The last installed measure with an SIR greater than unity is the R-15 crawlspace wall insulation. At that point in the analysis, the NPV of the improvements is maximized at $9,613 and an overall source energy savings of 32% is achieved. This includes a reduction in electricity use of 7,514 kWh/yr and adds 115 therms/yr of natural gas to cover water heating.

If the homeowner wants to install PV, the analysis indicates that other measures are cost effective before that point—notably energy feedback with a HEM system, a fully condensing gas furnace with a SEER-15 air conditioner, and leak-free ducts. The combination of all the measures with a 5 kW PV system is able to bring the building to a net annual electricity use of less than zero over the year (–188 kWh) and a source energy savings of 84%. The cumulative package SIR to achieve a near zero energy building is slightly less than unity (0.964).

Figure 6 shows the results where all available items in the retrofit library are indicated as needing replacement. The clothes washer and refrigerators are now cost effective to replace with ENERGY STAR models and the heat pump is changed to a SEER-15 air conditioner with a 96% efficient fully condensing natural gas furnace. The higher efficiency of the replaced HVAC system has the impact of only justifying R-30 ceiling insulation and making the sealed crawlspace with R-15 walls just outside the cost effectiveness limit (SIR = 1.0).

As before, fuel switching is also seen for water heating, where the optimization eventually chooses a tankless gas water heater. Other observed differences include the call for replacing the roofing with white shingles and choosing a light color for the house exterior walls when they need repainting. Double-glazed, argon-filled low-e solar control windows are on the edge of cost effectiveness when their replacement is required. Practically, this would be the indicated choice for consumers needing to replace windows in Ft. Worth. A 41% source energy savings is achieved at the last measure with an SIR greater than unity (tightening house leakage). This comprises a reduction in electricity use of 12,478 kWh and adds 434 therms of natural gas use for space and water heating.

The measures installed to this point of maximum cost effectiveness are sufficient to “pay for” additional improvements before the “neutral cost point” for this home is reached. Figure 5 shows that the 5-kW PV system drives NPV below zero; in Figure 6, the cost effectiveness of the improvements (because they are all evaluated at their incremental cost rather than their full cost of replacement) is large enough to “pay for” a number of additional improvement measures, including the 5-kW PV system, still leaving a cumulative NPV for the cumulative improvement investments of $10,176.

When the 5-kW PV system is added within the incremental analysis, three additional measures are cost justified before PV: an unvented crawlspace, high efficiency windows and an energy feedback system. Total annual electricity use is then –1,101 kWh and source energy savings over the year are >87%.[9]

A practical interpretation of the results of the incremental optimization in each location is that while the outright replacement selection identifies robust measures that will always be included, the incremental measures should be added to the package , if any of the chosen items in the incremental analysis are in need of replacement at the time of retrofit.

For consumers, the results of the incremental optimization analysis indicates that even after the retrofits are undertaken, the additional efficiency upgrade options indicated in the incremental optimization should be considered to improve household efficiency over time as equipment and components need replacement.

Generally the full incremental cost evaluation in higher electricity cost locations tended to call for every means of reducing appliance electricity (particularly in cooling-dominated climates); analysis in low-cost gas locations with gas appliances tends to justify lower potential savings from selected retrofits.

One component of incremental cost analysis is of particular interest to this study—the replacement of nonfunctioning HVAC systems. This is the focus of Optimization Scenario 3: HVAC Contractor Financing. Optimization Scenario 3 is designed to study the cost effectiveness of home improvements when the HVAC system requires replacement—the enlightened HVAC contractor business model. HVAC systems have a useful lifetime of 12–18 years. Thus, approximately 6% of all HVAC systems will be replaced each year. According to U.S. Census data, there are approximately 82 million existing single-family homes. This means that approximately 5 million HVAC replacements occur in American homes each year. From a retrofit business model perspective, this represents a particularly intriguing opportunity to influence energy efficiency decision making by homeowners. It is unlikely that the minimum efficiency HVAC system will ever be the most cost-effective option for the homeowner when the incremental cost of an upgrade is the economic cost effectiveness consideration. In addition, as shown in Figure 6, such upgrades provide significant economic benefits that will effectively “pay for” additional energy improvements to the home.

Seventeen archetypes in 14 cities are evaluated. The incremental cost of HVAC systems is used in the analysis and the mortgage period is set to 7 years. All other economic parameter values are as in Optimization Scenario 1. The summary results for Optimization Scenario 3 are presented in Table 12. Standard CostOpt plots for each archetype are given in Appendix E. These graphical results are useful in understanding the order in which improvement measures are selected.

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[9] This analysis does not consider utility pricing schemes for PV-powered homes that generate more than they use. Some utilities will not pay anything for excess power produced annually beyond personal use. Others will pay the customer for the power at the end of the year at the wholesale rate. A few will reimburse the homeowner at the retail rate. Except in the latter case, an economically rational approach for the consumer would be to not change over appliances to natural gas so that what would be an excess with gas appliances can be applied to reducing homeowner costs to an absolute minimum. This can be accomplished simply in CostOpt by turning off the simulation flags that allow fuel switching.

Table 12. Optimization Scenario 3—HVAC Replacement Optimizations

Prototype Models	Miami_SOG-CMU-HP	Houston_SOG-Frm-HP	Phoenix_SOG-Frm-GF	Phoenix_SOG-Frm-HP	Atlanta_Crwl-Frm-HP	FtWorth_Crwl-Frm-HP	FtWorth_Crwl-Frm-GF	LosAngeles_Crwl-Frm-GF	SanFrancisco_Crwl-Frm-GF	Baltimore_Crwl-Frm-GF	NewYork_Crwl-Frm-GF	Seattle_Crwl-Frm-HP	Seattle_Crwl-Frm-GF	StLouis_Crwl-Frm-GF	Denver_Bsmt-Frm-GF	Detroit_Bsmt-Frm-GF	Minneapolis_Bsmt-Frm-GF
Climate Zone:	1	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	6
%Src Savings:	50	44	54	48	38	46	39	25	15	37	36	33	38	31	28	33	30
Measures																	
SEER13GF96									●					●	●	●	●
SEER15GF96		●				●	●			●	●						
SEER15HP					●							●	●				
SEER13HP								●									
MiniSplit			●														
SEER18AC				●													
SEER21AC	●																
SealDucts	●	●			●	●						●		●		●	
LeakFree							●			●	●		●				
Ceil_R30	●	●	●	●	●							●		●	●		
Ceil_R38						●	●			●	●		●			●	●
Crwl_noVnt						●	●			●	●			●			
CrwlFl_R30													●				
BsmtFl_R11															●	●	
BsmtW_R19																	●
Tight	●	●	●	●	●	●	●			●	●		●	●			
Lgts_100%	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LowFloSh	●			●	●	●	●			●	●	●	●	●	●	●	
Misc/HEM	●	●	●	●	●	●	●	●		●	●				●	●	
PipeIns	●		●				●	●		●	●			●	●	●	●
HWwrap					●		●	●		●	●			●	●	●	●
TGWH		●		●	●	●						●	●			●	
HPWH	●																

Table 12 clearly illustrates how incremental HVAC costs impact optimization results compared with full HVAC costs. Save mild Los Angeles, every archetype installs an improved HVAC system versus a minimum efficiency system. Fuel switching occurs from electric to gas space heating in both Houston and Ft. Worth, where natural gas prices are relatively low compared to electricity prices. Gas space heating switches to electric space heating in Seattle, where electricity prices are relatively low compared to natural gas prices. There is also fuel switching for tankless gas hot water systems where gas prices are advantageous.[10] A heat pump hot water heater is selected only in Miami where gas was not available, although it would likely have been chosen in other locations had there been a fixed cost associated with switching from electricity to natural gas.

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[10] The identified level of fuel switching to gas may be lower in cases where gas service is not already available at the home site as this cost is often $200–$500, depending on distances involved.

Weighted source energy savings for Optimization Scenario 3 are almost the same as for Scenario 1. However, again if the 5-kW PV systems are included, Scenario 3 achieves 13.6% less source energy savings than Scenario 1—again because a 7-year mortgage will not support the relatively large first cost for the 5-kW PV system.

10.4 Optimization Scenario 4: Home Remodel Refinancing

Scenario 4 represents the home refinance model. The summary results for Optimization Scenario 4 are presented in Table 13. Standard CostOpt plots for each archetype are given in Appendix F. These graphical results are useful in understanding the order in which improvement measures are selected.

Table 13. Optimization Scenario 4—Home Refinance Optimizations

Prototype Models	Miami_SOG-CMU-HP	Houston_SOG-Frm-HP	Phoenix_SOG-Frm-GF	Phoenix_SOG-Frm-HP	Atlanta_Crwl-Frm-HP	FtWorth_Crwl-Frm-HP	FtWorth_Crwl-Frm-GF	LosAngeles_Crwl-Frm-GF	SanFrancisco_Crwl-Frm-GF	Baltimore_Crwl-Frm-GF	NewYork_Crwl-Frm-GF	Seattle_Crwl-Frm-HP	Seattle_Crwl-Frm-GF	StLouis_Crwl-Frm-GF	Denver_Bsmt-Frm-GF	Detroit_Bsmt-Frm-GF	Minneapolis_Bsmt-Frm-GF
Climate Zone:	1	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	6
%Src Savings:	56	33	46	52	43	50	41	24	32	55	46	42	38	35	30	36	32
Measures																	
AFUE-96										●	●				●	●	●
SEER15GF96			●			●	●										
SEER15HP													●				
SEER21AC	●																
LeakFree	●	●		●		●	●			●	●	●	●	●		●	
SealDucts			●		●												
Ceil_R49			●	●			●			●				●	●	●	●
Ceil_R38		●			●	●			●			●	●				
Ceil_R30	●							●									
Ceil_R60											●						
FrmW_R13										●	●	●		●			
CrwlFl_R30									●		●		●				
CrwlW_R15					●	●	●										
BsmtFl_R11															●	●	
Crwl_noVnt												●		●			
BsmtW_R19																	●
Tight	●	●	●	●	●	●	●		●			●	●				
Tighter										●				●		●	
VTight											●						
StrmWin											●						
DGLEArS				●													
Lgts_100%	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
LowFloSh	●		●		●	●	●	●	●	●	●	●	●	●	●	●	●
Misc/HEM	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●
PipeIns			●		●		●	●	●		●		●		●	●	●
HWwrap							●	●	●						●	●	●
ES_Washer						●		●	●	●	●					●	
TGWH		●				●				●	●		●	●			
SHW_ICS-HP	●			●	●							●					
SHW_40/80PV			●														
5kW-PV	●	●	●	●	●	●	●	●	●	●	●				●	●	
PV srcSave%	100	74	93	93	84	86	80	117	100	82	89				79	69	

Table 13 illustrates the much larger number of retrofit measures that qualify as cost effective when the 30-year mortgage rate is reduced from 6.15% to 4.0%. Under the Remodel Refinance scenario, the 5-kW PV system is cost effective in 13 of the 17 archetypes—eight more than under Scenario 1. It is also apparent that the lower mortgage rate allows a larger fraction of high first cost measures to qualify that did not qualify in Scenario 1. For example, HVAC systems are improved in 10 archetypes under Scenario 4; only eight qualify under Scenario 1. High-cost window replacements occur in two archetypes under Scenario 4; none occur in Scenario 1.

Weighted average source energy savings for Scenario 4 are 74% (41.3% without PV systems). This is 23% larger than Scenario 1 with PV included.

Table 14 summarizes the achieved weighted average source energy savings and average NPV for each of the four Optimization Scenarios. Weighted averages are calculated by taking the sum of the source energy savings for all 17 archetypes in the sample set and dividing by the sum of the original source energy use for all 17 archetypes. Average NPV is the simple average, calculated as the sum of all seventeen individual NPVs divided by 17. Some business models are shown to be more productive than others.

Table 14. Weighted Average Source Energy Savings and Average NPV for Four Optimization Scenarios

Optimization Scenario	Source Savings		NPV		Measures Selected
	Without PV	With PV	Without PV	With PV	
Scenario 1: Default	37.4%	51.2%	$5,463	$5,586	27
Scenario 2: Homeowner Finance	21.5%	–	$1,019	–	18
Scenario 3: HVAC Finance	37.6%	–	$3,853	–	23
Scenario 4: Remodel Refinance	41.3%	74.0%	$6,631	$6,904	31

The smallest weighted average source energy savings and average NPV are achieved by Scenario 2, the homeowner-financed improvement mortgage with a 7-year term. Likewise, the largest weighted average source energy savings and average NPV are achieved by Scenario 4, the home refinance model. Because PV is cost effective in a number of locations examined by this study, weighted average source energy savings and average NPV are both increased when PV savings are included in the averages. For Scenario 1, the inclusion of cost-effective PV systems raises the weighted average source energy savings from 37.4% to 51.2%. And for the remodel refinance scenario, the weighted average source energy savings climbs from 41.3% to 74%—a 33% increase. A similar pattern can be observed in the number of selected measures in each scenario. The smallest number is selected for Scenario 2, where financing is poorest and the largest number is selected for Scenario 4, where financing is optimized.

Examination of the source energy savings bins achieved in each Optimization Scenario provides additional insight into the results. Figure 7 presents the achieved source energy savings (excluding any PV savings) for the 17 archetypes common to all Optimization Scenarios in the study. This figure shows that homeowner financing (Scenario 2) offers the smallest potential for cost effective home improvement with more than 75% of the archetypes achieving less than 30% source energy savings. At the other extreme, the remodel/refinance (Scenario 4) usually produces >30% source energy savings. The largest fraction of deep retrofit savings are also achieved through the home refinancing in Scenario 4 with average savings of 74% (41% if PV is excluded) (a 5-kW PV system was cost effective in 13 of the 17 archetypes).

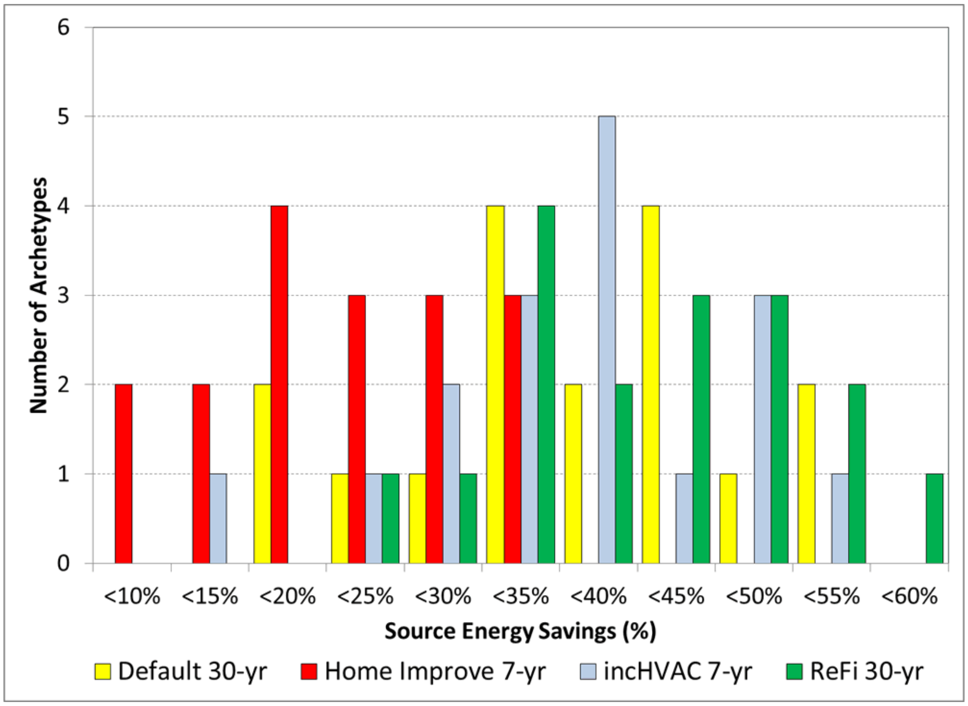

Figure 7. Source energy savings bins for the four optimization scenarios

A summary of the findings relative to specific measures and how they perform across climates, utility costs, and financing scenarios follows:

- **What works everywhere.** CFLs, duct sealing, ceiling insulation, hot water tank wraps, low-flow fixtures.
- **What works in some places.** Frame wall insulation, crawlspace wall insulation, solar water heating, heat pump water heaters, PV systems, appliances that need replacement and have low incremental costs.
- **What does not work anywhere.** Outright replacement of windows; most expensive HVAC systems, and roof replacement.

10.5 Method in Action: Optimization Results for a Specific Home

In real-world use, the retrofit optimization method would not use averages, but specifics for an individual house. This would include the pre-existing insulation and construction specifics, relevant appliances and equipment efficiencies, and a list of the appliances and equipment in likely need of replacement. House-specific thermostat preference and water consumption intensity should likely be considered. Further, the specific utility costs and financing arrangements would need to be realistically applied.

To illustrate how the described method would work in application, we show a case where a home is audited in order to be retrofitted based on its particular situation. This home is exactly the same as the standard building used in our analysis, but a number of differences are used to illustrate how the starting efficiency and equipment, utility rates, and replacement status can influence results. We used the default financing arrangements that are appropriate to a 30-year re-mortgage associated with a remodeling effort, coordinated by an HVAC contractor to replace an aging electric heat pump. The HVAC contractor works with auditors to perform a top-to-bottom evaluation of the home's energy upgrade needs and then recommends a comprehensive series of measures targeted for the specific circumstances.

In our scenario, the home has just been purchased by a family of four in Ft. Worth, Texas. The home has no natural gas access, the providing utility is TXU Energy, and the residential electricity rate is $0.134/kWh. The home is 1974 vintage with a dark gray exterior. It needs painting; the windows are leaking and need to be replaced. There are dense shade trees on the east and west sides. The frame walls have no insulation, but there is R-19 blown insulation in the attic. The crawlspace floors have no insulation. The heat pump needing replacement is assumed to have an equivalent SEER of 9 Btu/Wh, although the owners had a utility duct sealing program performed with the measured leakage to represent of Qn of 0.05. The new homeowners aim to replace the heat pump and the aging dishwasher, and to purchase a new washing machine. The household likes cool inside temperatures: 75°F in summer and 65°F in winter. The electric resistance hot water tank is 10 years old and has an EF of 0.86. This family has two teenagers, so the tank is set to 130°F to accommodate a large amount of hot water used each day (60 gal). The original 25-ft^3 side-by-side refrigerator was audited and measured to use more than 4 kWh/day.

In the analysis, the equipment, settings, and insulation levels were adjusted and the following items on the upgrade list were set to have incremental replacement costs: heating and air conditioning, windows, dishwasher, clothes washer, and house paint. All natural gas options were eliminated because access was lacking, and the prevailing utility costs were input. The chosen objective for the home was to reach zero net annual source energy given the inputs.

Figure 8 shows that the specification of high higher utility rates and the incremental costs for some measures have a dramatic impact on measure selection. The no-cost choice of a lighter exterior color is made first; a SEER 15 heat pump and ENERGY STAR washer and dishwasher soon follow. Low-e double glazed windows with argon fill are then selected. Some measures, such as CFLs, airtightness, and ceiling insulation, are always chosen, although higher levels of ceiling insulation are called for. Wall and floor insulation is selected for the uninsulated parts of the structure and an ENERGY STAR refrigerator is specified along with an ICS solar water heater supplying a heat pump water heater. Interestingly, the last measure selected was to change the ducted central system for room-based mini-split heat pumps to eliminate duct losses.

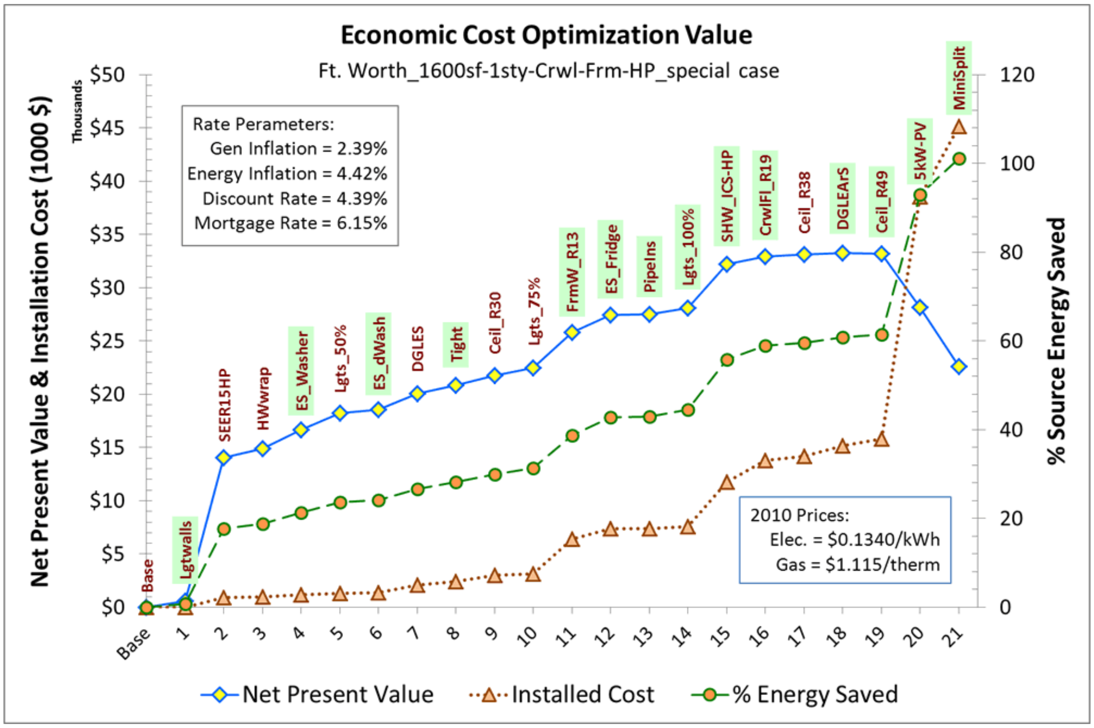

Figure 8. Optimization results for a specific home in Ft. Worth, Texas

The indicated source energy savings were just over 100% at an installed cost of $45,000 and a first-year energy savings of $3,100. Even considering the added mortgage, the homeowners still save $200/yr. The combination of higher utility prices, a more intensive use of cooling and hot water, and replacement pricing for some options allows a greater justified level of energy savings. The example also illustrates how modeling specific circumstances allows for a rational method of selecting retrofit measures for specific homes.

11 Conclusions

We describe the results of using a comprehensive cost optimization model (EnergyGauge CostOpt) across a range of representative climates in the United States. Similar to BEopt, the model uses an iterative evaluation of all available measures, selecting the best performing option before then reassessing all remaining options for future selection. The optimization process typically takes 300–500 simulations before reaching the best performing package of 6–20 retrofit measures that are most cost effective.

The purpose of the exercise was to critically evaluate a large library of potential retrofit options with representative costs and performance and examine the various influences on potentials to cost-effectively reduce energy use in existing U.S. housing. The predicted energy uses of developed archetypes for the 14 locations simulated were favorably indexed where possible to available RECS data. For the most part, cost data came from the NREL National Residential Efficiencies Database, although augmented for estimating HVAC costs and those for renewable energy systems. Energy costs were the revenue-based EIA utility averages in each state, averaging $0.115/kWh and $1.174/therm. These are considered conservative in that they are now two years old and do not include relevant utility state, local, and municipality taxes that are often 5%–15% greater than the EIA based numbers. The evaluation was carried out over a 30-year time horizon with documented economic parameters used for the assessment.

BA-PIRC evaluated measures appropriate to addressing poorly insulated and equipped housing stock 20 years or older. This located greatest opportunities, but the same approach can apply to newer existing housing, although with often many fewer options chosen. Thus, the starting point for an individual home will be important to its realistic savings potential. Still, many homes will also be worse than the average starting point such that the savings potentials will remain very large.

A key finding was that the energy efficiency levels of even older, inefficient homes can be dramatically improved such that they can reach performance levels associated with zero energy homes when evaluated on an annual source energy basis.

The results shown in the report can be considered conservative given that a small error in the P2 parameter was discovered at the end of report preparation which would tend to improve the cost-effectiveness results for options with no maintenance and a long service life (e.g., insulation). Also, two recent major studies (Hohen et al. 2011; Kok and Kahn 2012) reveal that the real estate valuation of efficiency and PV measures is much higher than anticipated (approaching 90% of the investment cost at 5 year resale). Addressing this in the established economic structure would entail reducing the rate at which resale/salvage values are discounted. This will tend to improve cost effectiveness determinations, particularly for short-term financing. We propose that the report eventually be reissued with the P2 error addressed as well as further evaluation of the sensitivity to the rate of discounting of the salvage/resale value.

Source energy savings were greatest for the most extreme climates, but chosen measures were very sensitive to measure cost and to prevailing utility costs. Where multiple fuels were considered, some fuel switching was observed where the ratios of natural gas to electricity costs were favorable. The analysis found a series of generic measures that were cost effective in nearly all locations (such as greater ceiling insulation, lighting, low-cost hot water measures, and duct sealing), whereas other options such as wall insulation and high-efficiency hot water systems depend on relative climate severity and/or utility costs.

A number of measures (such as all ENERGY STAR appliances) were highly cost effective, but only at the time of natural replacement. Some measures, such as high performance windows, were cost effective only in the most severe climates. This finding indicates that in a real program, the audited performance of each home, along with the remaining life of appliances and equipment, and operational related characteristics could be favorably used with a tool such as CostOpt to tailor a series of measures that are appropriate for that case so maximum savings are achieved in the most cost-effective manner possible.

Relative to results from the optimization analysis, the highest nonrenewable energy savings were achieved in hotter locations where more expensive electricity is used for cooling and potential savings are large. Across locations, the lowest achievable savings tended to be in milder climates, but in particular in locations with low natural gas prices.

The average achieved optimization savings were highly sensitive to the financing scheme and interest rates used to pay for the retrofits. Using the default 6.15% financing over a 30-year period, 51% source energy savings were indicated when including PV. Excluding PV, the savings were 37%, indicating the increasing relevance to solar electric generation to the retrofit approach now available.

Financing schemes were quite important—a fact with direct relevance to policy decisions relative to energy savings programs for existing U.S. housing. Homeowner-financed energy retrofits failed to achieve average savings >21% because of the higher annual costs incurred by the short finance period.

A financing model where retrofits are installed along with replacement of the HVAC system was superior to homeowner financing. In this scenario, the incremental HVAC costs were applicable, resulting in higher achieved source energy savings (37%), although many potential measures with high savings are still ignored because of the short financing terms.

The greatest energy savings—averaging 74% when PV was included—were based on a 30-year home remodel/refinancing scheme for which the interest rate was 4%. Programmatically, such a program might focus on home remodeling and refinancing and/or on the same at the time of resale. Another possibility would be to improve homes in the foreclosure market prior to resale.

Interestingly, this scenario showed solar electricity to be cost effective or near cost effective in most U.S. locations at $6.50/W installed. At a cost of $5/W installed, such systems would be cost effective across the United States, as long as the federal tax credit remains applicable. In particular, the results of the home refinance scenario results indicated that near zero source energy (>80% savings) was cost effective in eight of the 14 U.S. climates. These tended to be those with sunnier conditions and higher applicable electricity prices.

Observing the very large identified energy savings in older housing stock in the United States, implementation concerns become central—particularly given the lack of homeowner knowledge and motivation. Accordingly, the results suggest that:

- Efforts should be made to create a national retrofit program that seeks to match long-term financing with multiple retrofit options that are effectively bundled together.
- Program participation could be matched to replacement of major HVAC system or hot water system improvements. These could be contracted at once with tailored retrofit measures chosen by a customized computerized evaluation that considers the starting point of home features and equipment along with local utility pricing.
- Participating households should have an evaluation of appliance age and functionality to take advantage of cost-effective opportunities for appliance replacement during the retrofit process.

References

Casey, S.; Booten C. (2011). *Energy Savings Measure Packages: Existing Homes*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-53023. www.nrel.gov/docs/fy12osti/53023.pdf.

Christensen, C.; Anderson, R. Horowitz, S; Courtney A.; Spencer, J. (2006). *BEopt Software for Building Energy Optimization: Features and Capabilities*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-550-39929. www.nrel.gov/buildings/pdfs/39929.pdf.

Duffie, J.A.; Beckman, W.A. (1980). *Solar Engineering of Thermal Processes*, pp. 381-406, New York: John Wylie & Sons, Inc.

Hendron, R. (2006). *Building America Performance Analysis Procedures for Existing Homes*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-550-38238. http://www.nrel.gov/docs/fy06osti/38238.pdf

Hohen, B.; Wisser, R.; Cappers, P.; Thayer, M. (2011). *An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in the California Market*, Berkeley, CA: Lawrence Berkeley National Laboratory, LBNL-4476e, April 2011.

Kok, N.; Kahn, M.E. (2012). *The Value of Green Labels in the California Housing Market*, UC Berkeley and UCLA.

McIlvaine, J.R. (2011). "NREL Submission Work," unpublished test results spreadsheet and email to D. Parker, dated 9 June 2011.

Menicucci, D.F.; Fernandez, J.P. (1988). *User's Manual for PVFORM: A Photovoltaic System Simulation Program for Stand-Alone and Grid-interactive Applications*. Albuquerque, NM: Sandia National Laboratories. Report 85-0375. http://prod.sandia.gov/techlib/access-control.cgi/1985/850376.pdf.

Parker, D.; Huang, Y.; Konopacki, S.; Gartland, L.; Sherwin J.; Gu, L. (1998). "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings." *ASHRAE Transactions*, Vol. 104, Pt. 1, Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Pigg, S.; Francisco, P. (2006). A Field Study of Exterior Duct Leakage in New Wisconsin Homes, ECW.

Polly, B.; Gestwick, M.; Bianchi, M.; Anderson, R.; Horowitz, S.; Christensen, C.; Judkoff, R. (2011). *Method for Determining Optimal Residential Energy Efficiency Retrofit Packages*. Golden, CO: National Renewable Energy Laboratory. TP-5500-50572; DOE/GO-102011-3261. www.nrel.gov/docs/fy11osti/50572.pdf.

RESNET. (2012). *Mortgage Industry National Home Energy Rating Systems Standards,* Section 303.3.3 Economic Cost Effectiveness. Oceanside, CA: Residential Energy Services Network. www.resnet.us/standards/mortgage.

Sherman, M.H.; Wilson, D.J.; Kiel, D.E. (1986). “Variability in Residential Air Leakage,” in *Measured Air Leakage in Buildings*, ASTM Special Publication 904, Philadelphia, PA.

Walker, I.S. (1998). Technical Background for Default Values used for Forced Air Systems in Proposed ASHRAE standard 152P. *ASHRAE Trans. Vol.104 Part 1.* Presented at ASHRAE TC 6.3 Symposium, January 1998. LBNL 40588.

Appendix A. Calculation of Economic Cost Effectiveness Section of RESNET Standards

303.3.3 Economic Cost Effectiveness. If ratings are conducted to evaluate energy saving improvements to the home for the purpose of an energy improvement loan or energy efficient mortgage, indicators of economic cost effectiveness shall use present value costs and benefits, which shall be calculated as follows:

$$\mathbf{LCC_E = P1*(1^{st}\ Year\ Energy\ Costs)} \qquad \text{(Eq 303.3.3-1)}$$

$$\mathbf{LCC_I = P2*(1^{st}\ Cost\ of\ Improvements)} \qquad \text{(Eq 303.3.3-2)}$$

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:

$$\mathbf{LCC_S = LCC_{E,b} - LCC_{E,i}} \qquad \text{(Eq 303.3.3-3)}$$

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:

$$\mathbf{SIR = (LCC_S) / (LCC_I)} \qquad \text{(Eq 303.3.3-4)}$$

$$\mathbf{NPV = LCC_S - LCC_I} \qquad \text{(Eq 303.3.3-5)}$$

where:

SIR = Present Value Savings to Investment Ratio
NPV = Net Present Value of Improvements

303.3.3.1 Calculation of P1 and P2. The ratios represented by P1 and P2 shall be calculated in accordance with the following methodology[11]:

$$\mathbf{P1 = 1/(DR-ER)*(1-((1+ER)/(1+DR))^{\wedge}nAP)} \qquad \text{(Eq 303.3.3-6a)}$$

or if DR = ER then

$$\mathbf{P1 = nAP / (1+DR)} \qquad \text{(Eq 303.3.3-6b)}$$

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[11] Duffie, J.A. and W.A. Beckman, 1980. *Solar Engineering of Thermal Processes*, pp. 381-406, John Wylie & Sons, Inc., New York, NY.

where:
P1 = Ratio of Present Value Life Cycle Energy Costs to the 1st year Energy Costs
DR = Discount Rate as prescribed in section 303.3.3.2
ER = Energy Inflation Rate as prescribed in section 303.3.3.2
nAP = number of years in Analysis Period as prescribed in section 303.3.3.2

$P2 = DnPmt + P2_A + P2_B + P2_C - P2_D$ (Eq 303.3.3-7)

where:
P2 = Ratio of Life Cycle Improvement costs to the first cost of improvements
DnPmt = Mortgage down payment rate as prescribed in section 303.3.3.2
$P2_A$ = Mortgage cost parameter
$P2_B$ = Operation & Maintenance cost parameter
$P2_C$ = Replacement cost parameter
$P2_D$ = Salvage value cost parameter

$P2_A$ = (1-DnPmt)*(PWFd/PWFi) (Eq 303.3.3-8a)

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 as prescribed in section 303.3.3.2
MR = Mortgage interest Rate as prescribed in section 303.3.3.2
nAP = number of years of the Analysis Period as prescribed in section 303.3.3.2
nMP = number of years of the Mortgage Period

$P2_B$ = MFrac*PWinf (Eq 303.3.3-8b)

where:
MFrac = annual O&M costs as a fraction of first cost of improvements[12]
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 as prescribed in section 303.3.3.2

$P2_C$ = Sum {1/((1+(DR-GR))^(Life*i))} for i=1, n (Eq 303.3.3-8c)

where:
i = the i^{th} replacement of the improvement

---

[12] The maintenance fraction includes all incremental costs over and above the operating and maintenance cost of the "standard" measure. Where components of a system have various lifetimes, the longest lifetime may be used and the components with shorter lifetimes may be included as a maintenance cost at the present value of their future maintenance cost. The maintenance fraction may also be used to represent the degradation in performance of a given system. For example, photovoltaic (PV) systems have a performance degradation of about 0.5% per year and this value can be added to the maintenance fraction for PV systems to accurately represent this phenomenon in this cost calculation procedure.

Life = the expected service life of the improvement

$P2_D$ = RLFrac / ((1+DR)^nAP) [13] **(Eq 303.3.3-8d)**

where:
RLFrac = Remaining Life Fraction following the end of the analysis period

303.3.3.2 Determination of Economic Parameters. The following economic parameter values shall be determined by RESNET in accordance with this Section each January using the latest available specified data and published on the RESNET website.

- General Inflation Rate (GR)
- Discount Rate (DR)
- Mortgage Interest Rate (MR)
- Down Payment Rate (DnPmt)
- Energy Inflation Rate (ER)

The economic parameter values used in the cost effectiveness calculations specified in Section 303.3.3.1 shall be determined as follows:

303.3.3.2.1 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,[14] where ACR shall be calculated as follows:

ACR = ((endVal)/(startVal))^(1.0/((endYr)-(startYr)))-1.0 (Eq 303.3.3-9)

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

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

303.3.3.2.3 Mortgage Interest Rate (MR) shall be defaulted to 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 unless the mortgage interest rate is specified by a program or mortgage lender, in which case the specified mortgage

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[13] Based on recent research by Kok and Kahn (2012) and Hohen et al. (2011), energy efficiency and PV system improvements are strongly valued by the public at resale—up to 90% of original value at the time of resale at five years. This would indicate that the salvage/resale value parameter should be only very lightly discounted—perhaps half the conventional discount rate. Although this was not evaluated in this study, sensitivity might be investigated in the future. In any case, not incorporating this real market influence represents conservatism in this study.

[14] http://www.bls.gov/CPI/#tables

interest rate shall be used. The mortgage interest rate used in the cost effectiveness calculation shall be disclosed in reporting results.

303.3.3.2.4 Down Payment Rate (DnPmt) shall be defaulted to 10% of 1st cost of improvements unless the down payment rate is specified by a program or mortgage lender, in which case the specified down payment rate shall be used. The down payment rate used in the cost effectiveness calculation shall be disclosed in reporting results.

303.3.3.2.5 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[15] as calculated using Equation 303.3.3-9.

303.3.3.2.6 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.

303.3.3.2.7 Analysis Period (nAP) shall be 30 years.

303.3.3.2.8 Remaining Life Fraction (RLFrac) shall be calculated as follows:

$$\text{RLFrac} = (\text{nAP}/\text{Life}) - (\text{Integer}(\text{nAP}/\text{Life})) \qquad \text{Eqn. 303.3.3-10}$$

or if Life > nAP

$$\text{RLFrac} = (\text{Life}-\text{nAP}) / \text{nAP}$$

where:

Life = useful service life of the improvement(s)

303.3.3.2.9 Improvement Costs. The improvement cost for Energy Conservation Measures (ECMs) shall be included on the Economic Cost Effectiveness Report.

303.3.3.2.9.1 For New Homes the improvement costs shall be the full installed cost of the improvement(s) less the full installed cost of the minimum standard or code option less any financial incentives that accrue to the home purchaser.

303.3.3.2.9.2 For Existing Homes the improvement costs shall be the full installed cost of the improvement(s) less any financial incentives that accrue to the home purchaser.

303.3.3.2.10 Measure Lifetimes. The ECM service life shall be included on the Economic Cost Effectiveness Report. Appendix C of this standard provides informative guidelines for service lifetimes of a number of general categories of ECMs.

303.3.3.3 The annual energy cost savings for the Rated home shall be estimated by comparing the projected annual energy cost of the Rated home to the projected annual energy cost of a baseline home. For new homes, the most recent HERS Reference home shall be the baseline, except when an

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[15] http://www.bls.gov/cpi/cpi_dr.htm

alternative reference home is specified by the lender or program underwriter. For existing homes, the unimproved home shall be used as the baseline.

303.3.3.4 The estimated monthly energy cost savings for the Rated home shall be equal to the annual energy cost savings divided by 12.

303.3.3.5 For FHA and Freddie Mac energy mortgages, the present value of energy savings shall be calculated in accordance with Equation 303.3.3-3 where the baseline home is as specified by the most current HUD Mortgage Letter.

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 the CostOpt optimizations. 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 9.

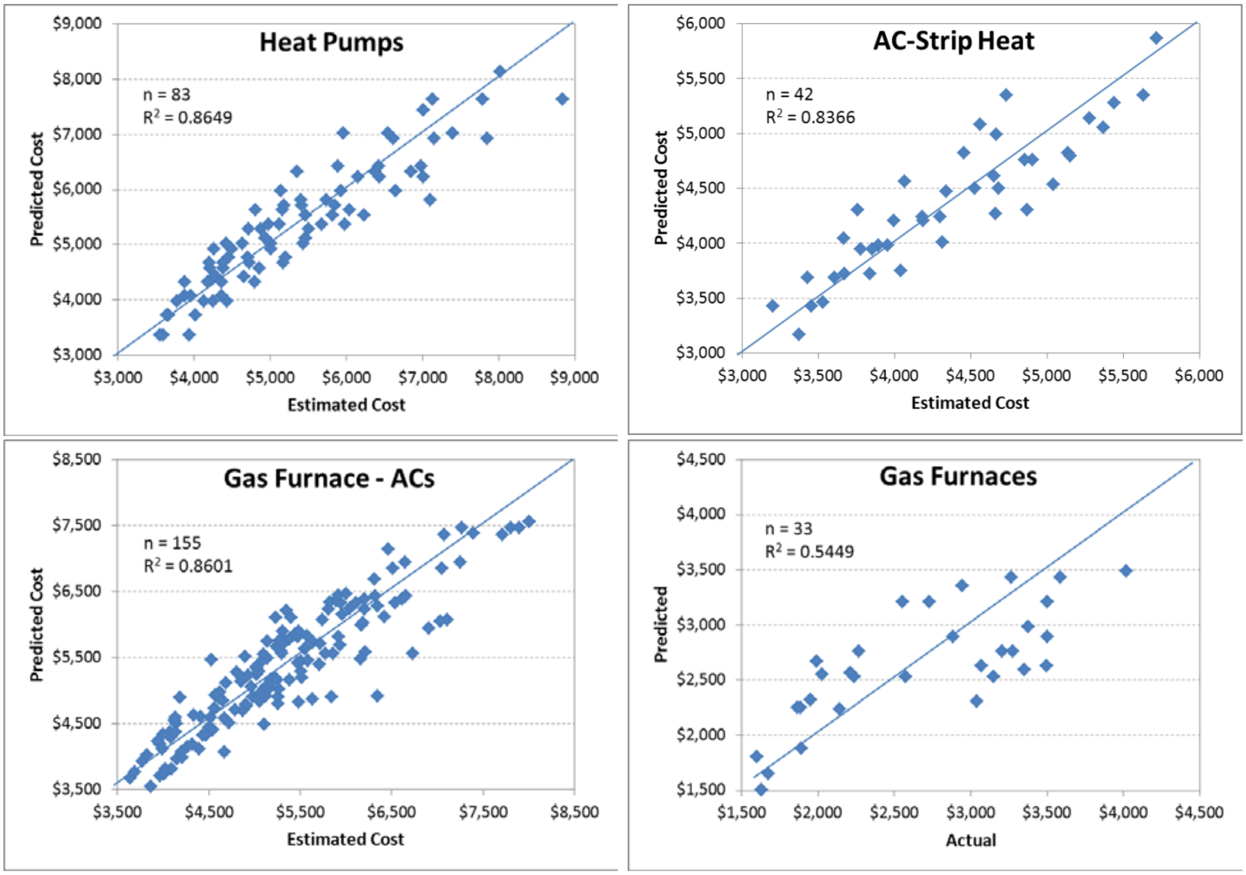


Figure 9. Results from regression analysis of CostOpt HVAC cost estimates

Considering the variability of the marketplace, the correlation coefficients are reasonable for these regressions. For comparison, Tables 15 through Table 17 show the range of costs provided by the NREL database for replacement heat pumps, air conditioners, and gas furnaces.

Table 15. 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 16. 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 17. 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 9, with gas furnaces showing the largest variance.

BA-PIRC evaluated the CostOpt estimates against those provided by the NREL database average cost estimates for heat pumps and gas furnaces. Figure 10 presents the results of this comparison.

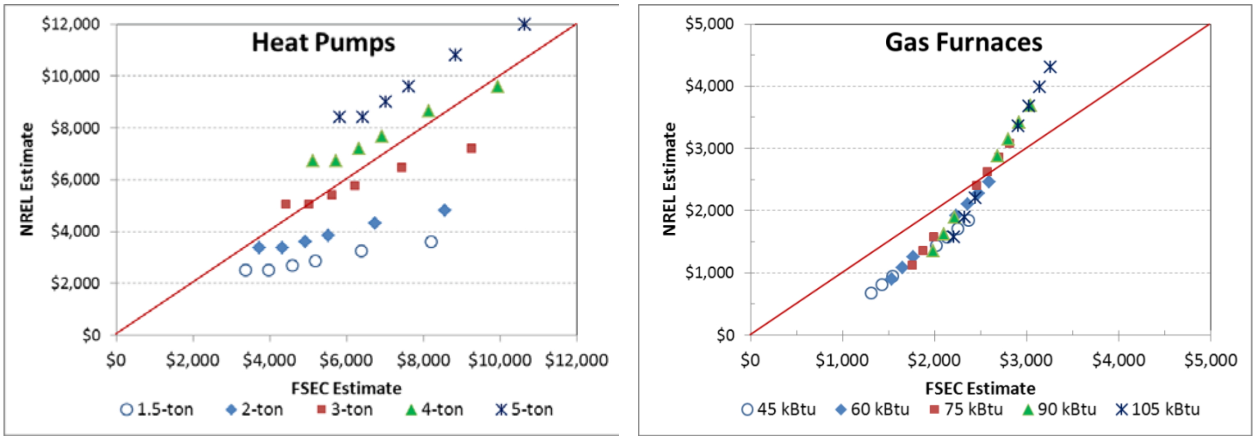


Figure 10. Comparison of *CostOpt* HVAC cost estimates and NREL HVAC cost estimates

In Figure 10 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.

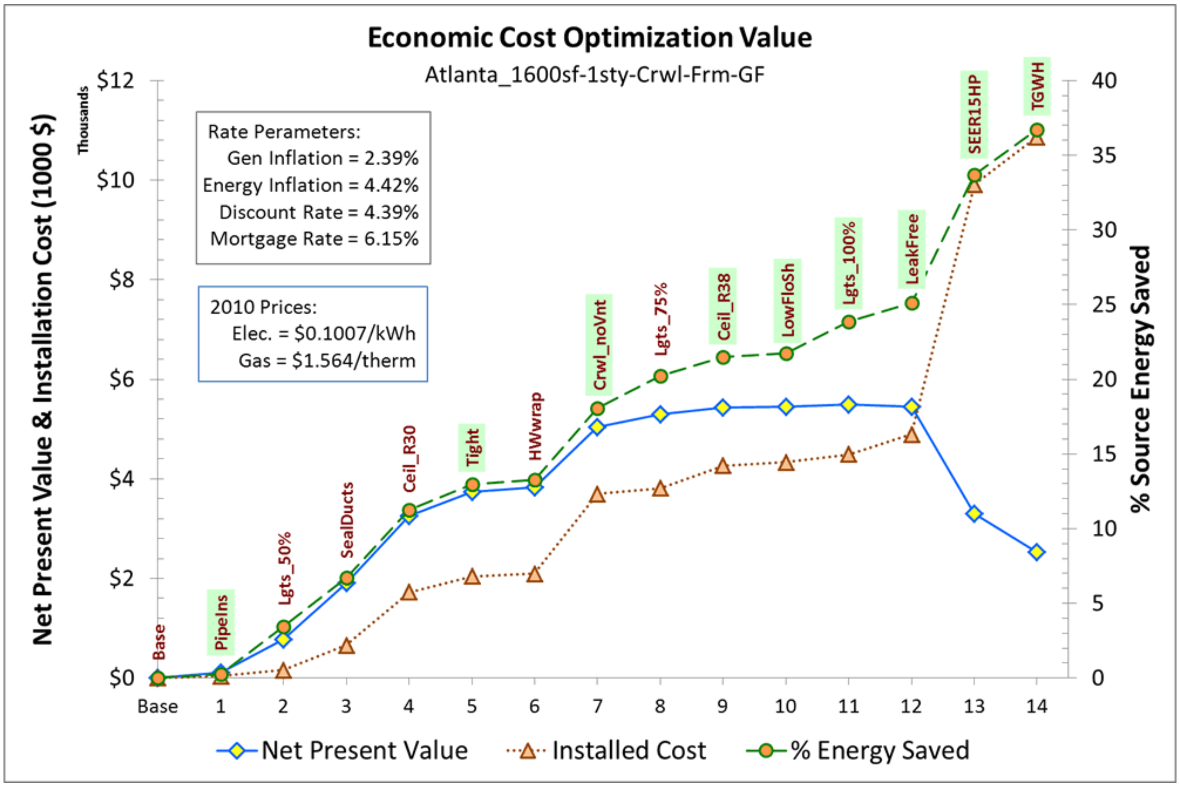
Both charts show that the CostOpt estimates are larger for the lower capacity and smaller for the larger capacity equipment. The charts also show that, on average, the CostOpt estimates are consistent with the NREL estimates. However, the fact that the CostOpt estimates treat fixed costs more explicitly is evident on both charts. In a practical sense, the CostOpt 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.

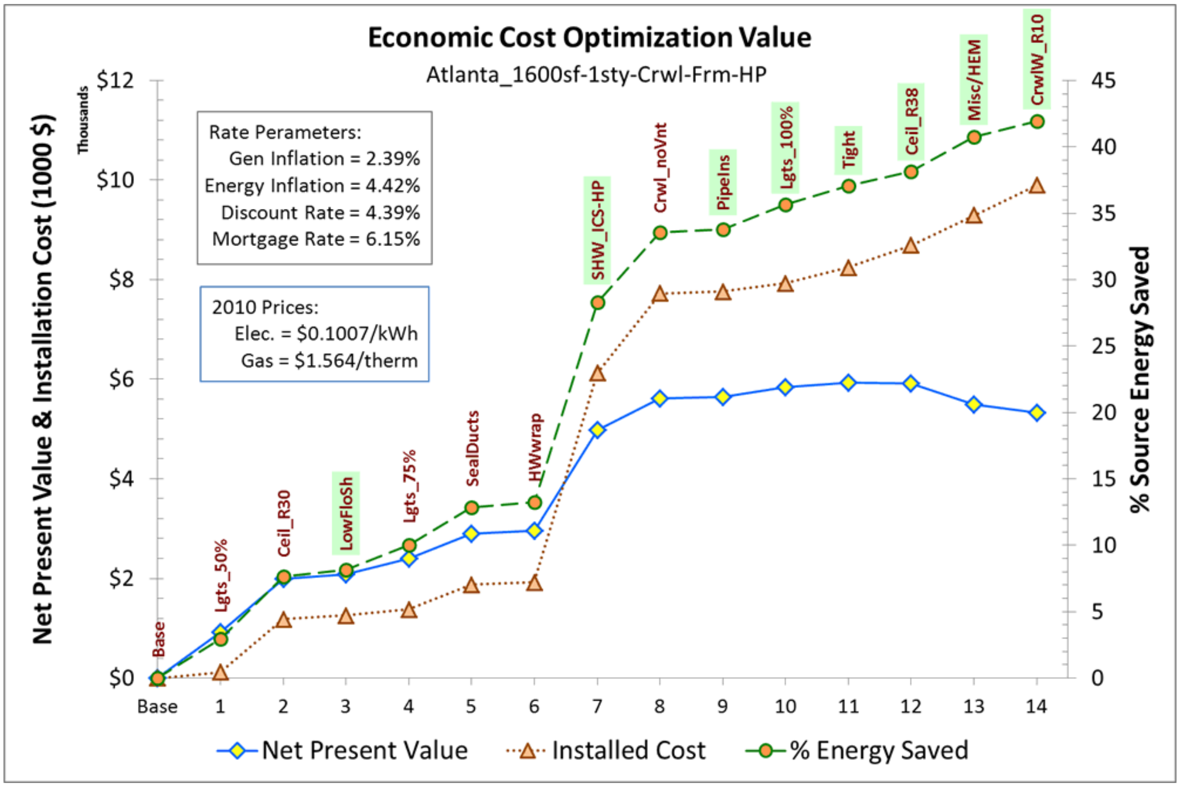
Appendix C. Optimization Scenario 1—Default Economic Parameter Model

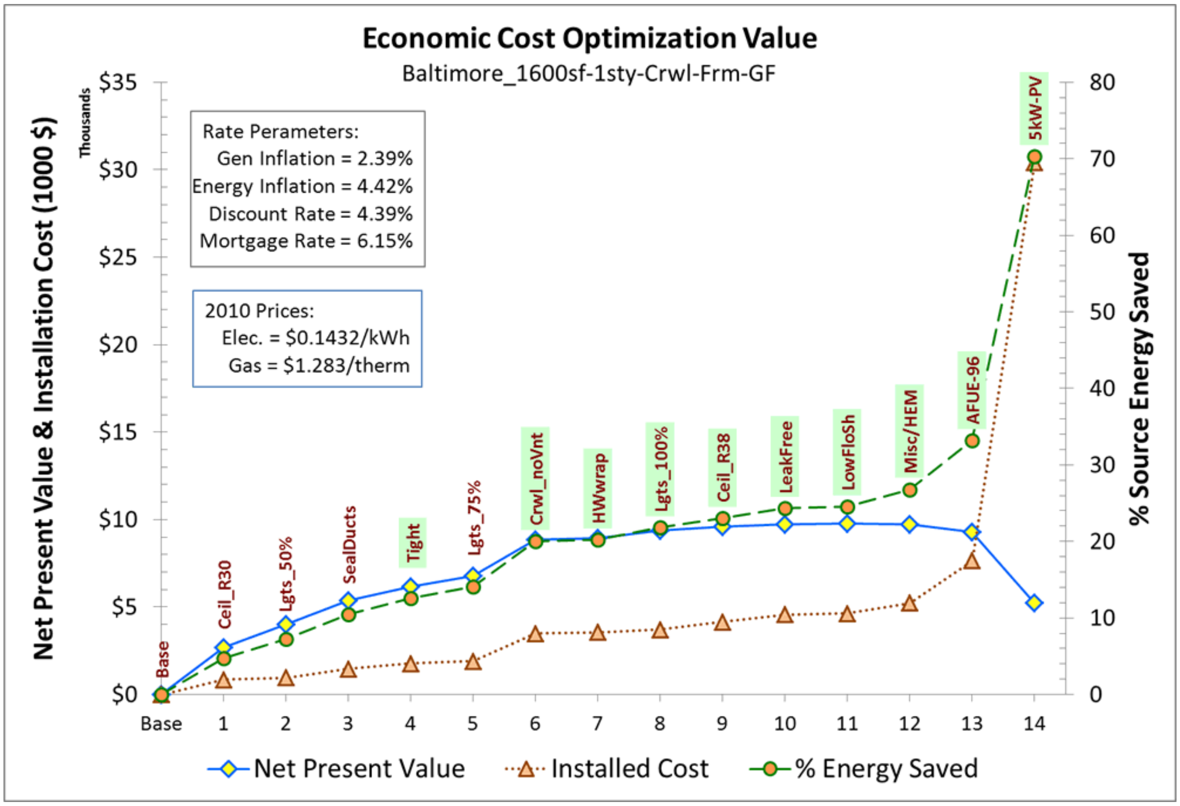
The figures shown on the following pages are in a standard CostOpt format that plots the cumulative investment costs and the cumulative NPV of the investments on the left-hand vertical axis and the cumulative source energy savings percentage on the right-hand axis. Thus, if an individual improvement measure has an SIR greater than unity, cumulative NPV will increase. However, if an individual measure has an SIR less than unity, cumulative NPV will decrease. Therefore, the point at which the NPV is largest is the optimum cost effectiveness from the consumer's perspective. However, often measures come in at the end of the optimization that have an individual measure SIR less than unity but that do not cause the cumulative NPV to drop below zero. These measures are also cost effective from a societal perspective in that they are "paid for" by the earlier highly cost-effective measures. Thus, the neutral cost point from the CostOpt perspective is the line where the cumulative NPV equals zero. Because the optimization method is incremental, a number of measures are selected and then later replaced by higher efficiency measures in the same category. Thus, for ease of understanding, the final selections in each category are highlighted in light green on the plots.

Key to acronyms:

1600sf:	Archetype home size in square feet
1sty:	One-story abov- grade home
SOG:	Slab-on-grade foundation
Crwl:	Crawlspace foundation
Bsmt:	Unconditioned basement foundation
HP:	Electric space and water heating in base archetype
GF:	Natural gas space and water heating in base archetype
7-yr:	Seven year mortgage period (used in Scenarios 2 and 3)
incHVAC:	Incremental costs used for HVAC systems (used in Scenario 3)
ReFi:	Refinance scenario using 4% mortgage interest (used in Scenario 4)


Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1007/kWh
Gas = $1.564/therm
Base
PipeIns
Lgts_50%
SealDucts
Ceil_R30
Tight
HWwrap
Crwl_noVnt
Lgts_75%
Ceil_R38
LowFloSh
Lgts_100%
LeakFree
SEER15HP
TGWH
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-HP
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1007/kWh
Gas = $1.564/therm
Base
Lgts_50%
Ceil_R30
LowFloSh
Lgts_75%
SealDucts
HWwrap
SHW_ICS-HP
Crwl_noVnt
PipeIns
Lgts_100%
Tight
Ceil_R38
Misc/HEM
CrwlW_R10
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
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Net Present Value & Installation Cost (1000 $)
Thousands
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$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
80
70
60
50
40
30
20
10
0
Rate Perameters:
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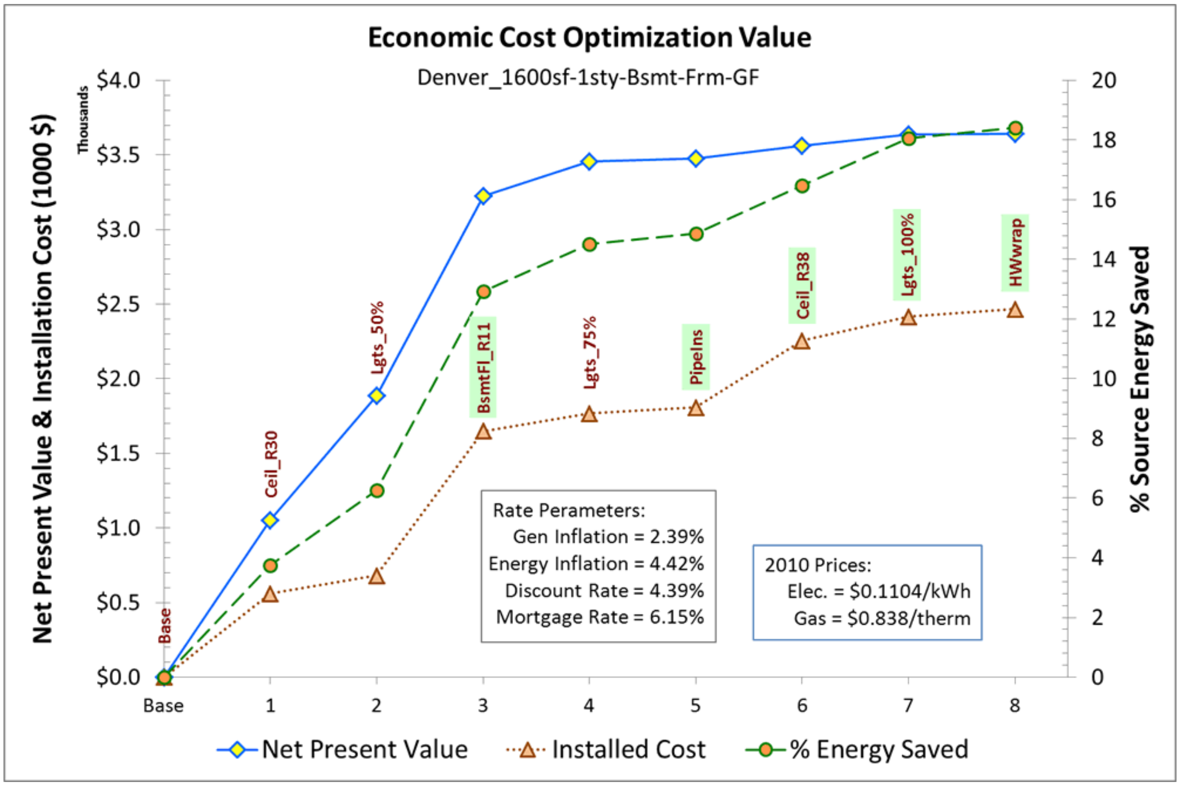
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1432/kWh
Gas = $1.283/therm
Base
Ceil_R30
Lgts_50%
SealDucts
Tight
Lgts_75%
Crwl_noVnt
HWwrap
Lgts_100%
Ceil_R38
LeakFree
LowFloSh
Misc/HEM
AFUE-96
5kW-PV
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved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Net Present Value & Installation Cost (1000 $)
Thousands
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$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
20
18
16
14
12
10
8
6
4
2
0
Base
Ceil_R30
Lgts_50%
BsmtFl_R11
Lgts_75%
PipeIns
Ceil_R38
Lgts_100%
HWwrap
Rate Perameters:
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Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
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Gas = $0.838/therm
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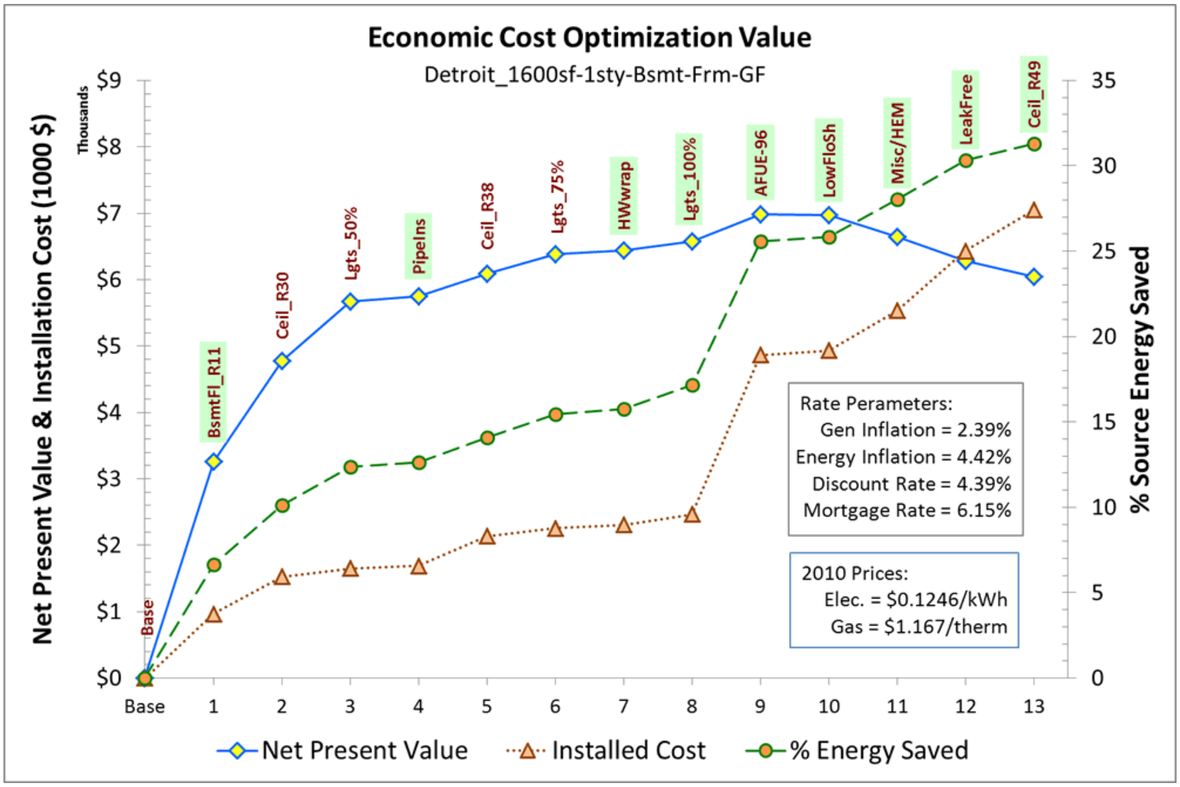
5
6
7
8
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Detroit_1600sf-1sty-Bsmt-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
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$1
$2
$3
$4
$5
$6
$7
$8
$9
% Source Energy Saved
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5
10
15
20
25
30
35
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Base
BsmtFl_R11
Ceil_R30
Lgts_50%
PipeIns
Ceil_R38
Lgts_75%
HWwrap
Lgts_100%
AFUE-96
LowFloSh
Misc/HEM
LeakFree
Ceil_R49
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
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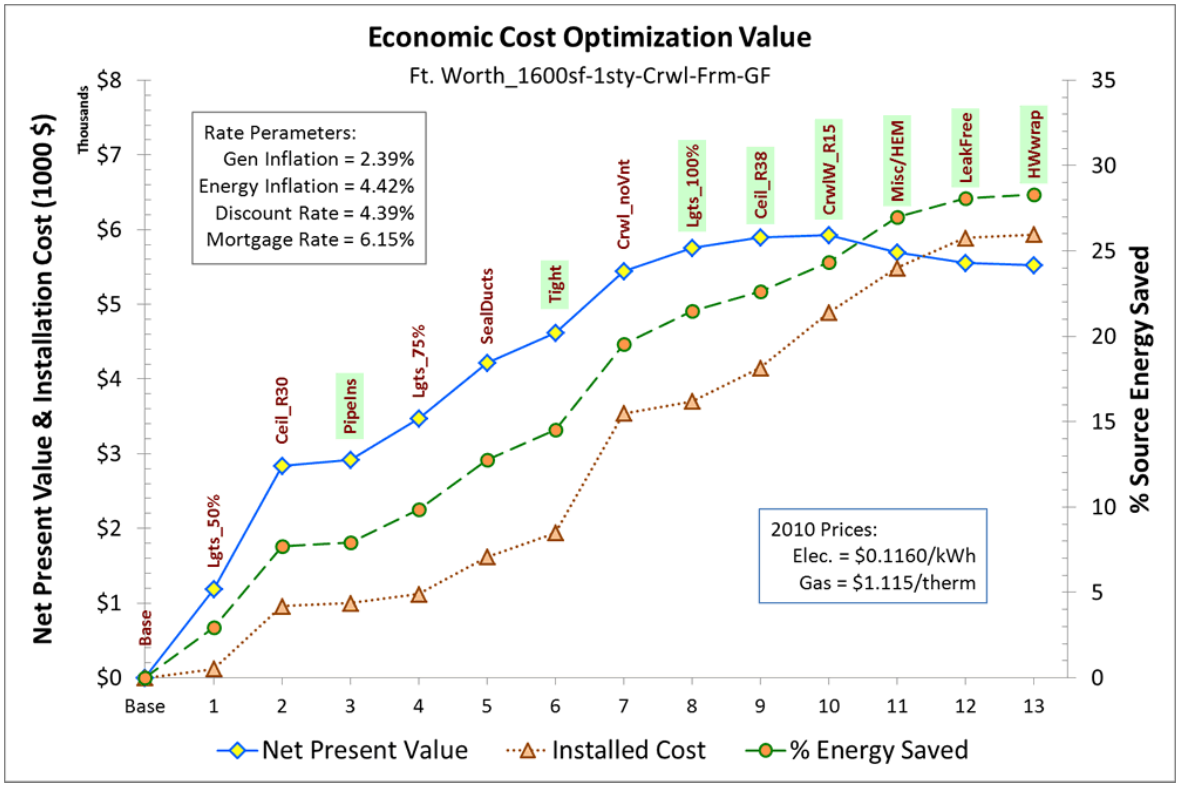
Elec. = $0.1246/kWh
Gas = $1.167/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
$0
$1
$2
$3
$4
$5
$6
$7
$8
% Source Energy Saved
0
5
10
15
20
25
30
35
Base
1
2
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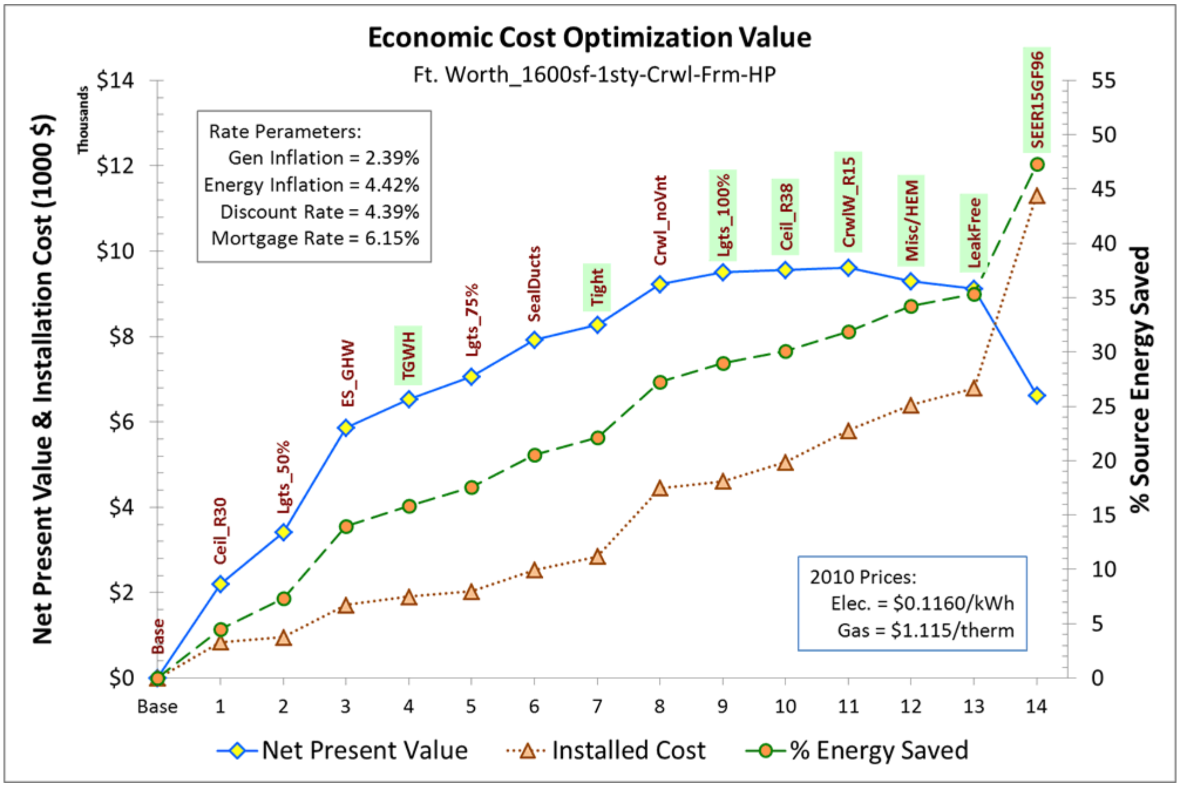
6
7
8
9
10
11
12
13
Base
Lgts_50%
Ceil_R30
PipeIns
Lgts_75%
SealDucts
Tight
Crwl_noVnt
Lgts_100%
Ceil_R38
CrwlW_R15
Misc/HEM
LeakFree
HWwrap
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-HP
Net Present Value & Installation Cost (1000 $)
Thousands
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$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
55
50
45
40
35
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Base
Ceil_R30
Lgts_50%
ES_GHW
TGWH
Lgts_75%
SealDucts
Tight
Crwl_noVnt
Lgts_100%
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CrwlW_R15
Misc/HEM
LeakFree
SEER15GF96
Base
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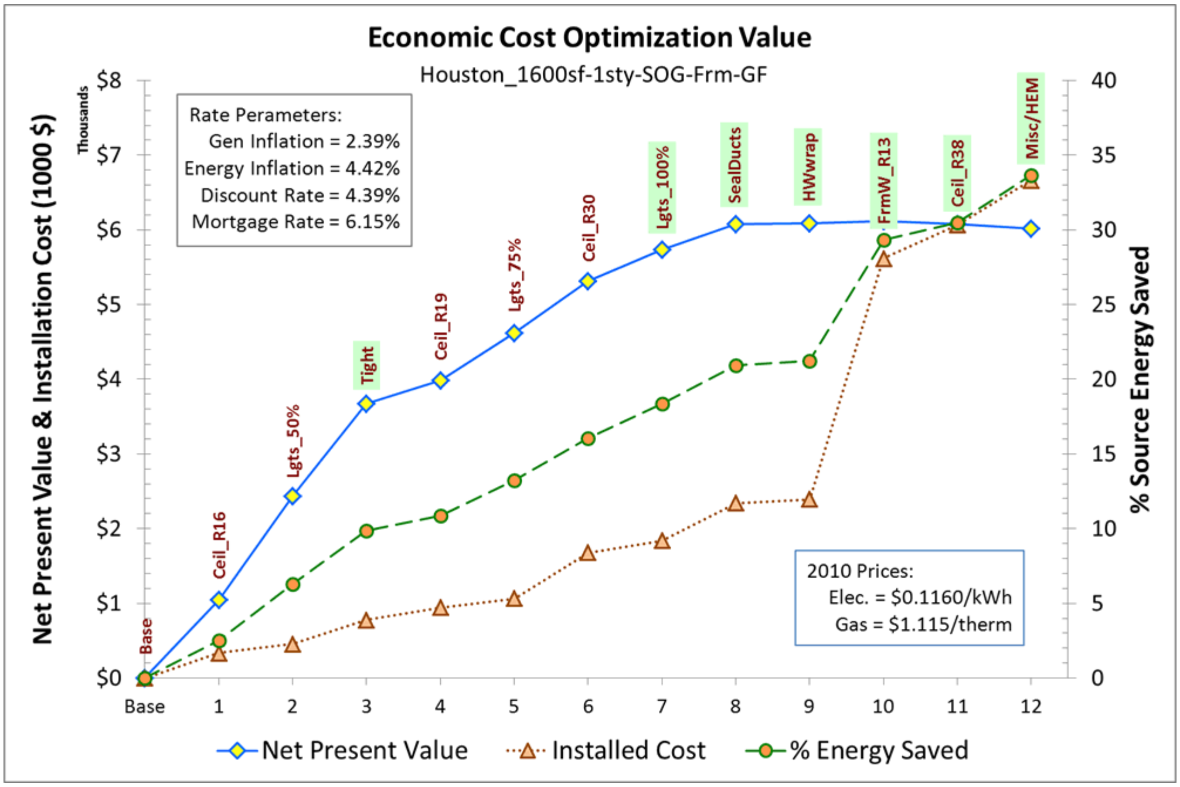
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Houston_1600sf-1sty-SOG-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
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$7
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
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35
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Base
Ceil_R16
Lgts_50%
Tight
Ceil_R19
Lgts_75%
Ceil_R30
Lgts_100%
SealDucts
HWwrap
FrmW_R13
Ceil_R38
Misc/HEM
Base
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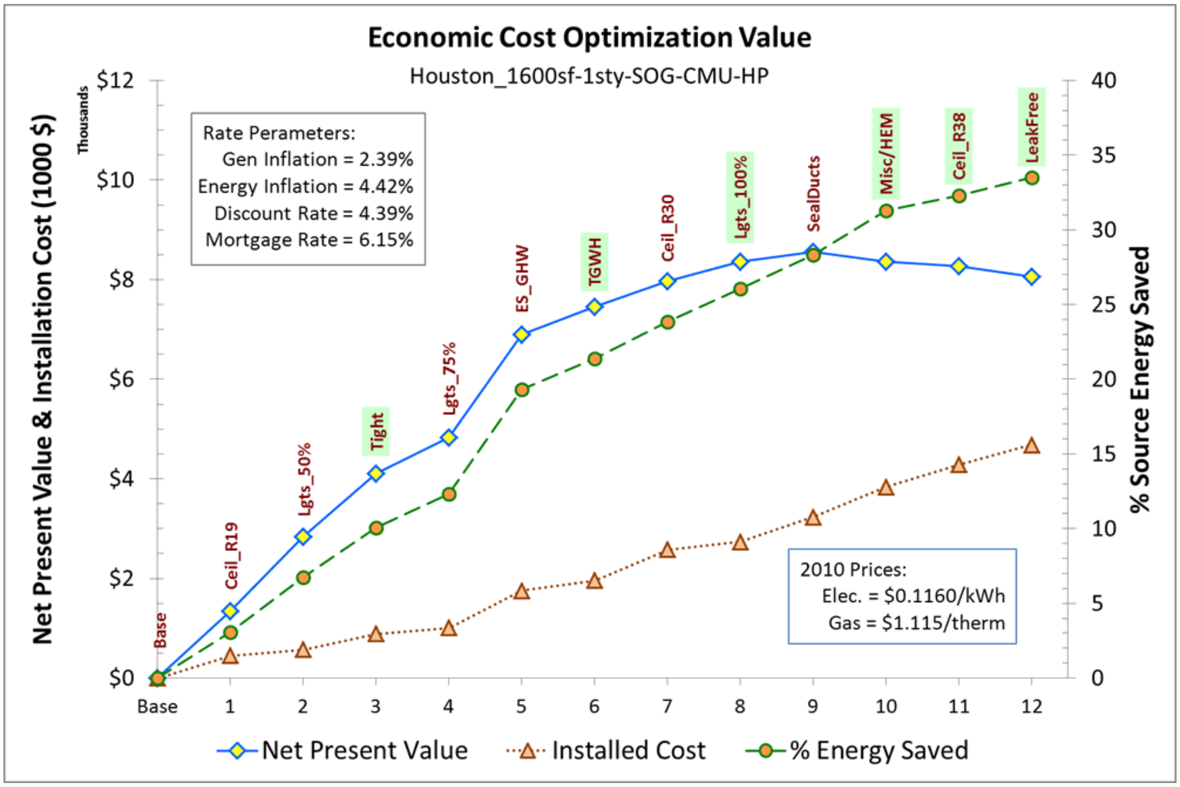
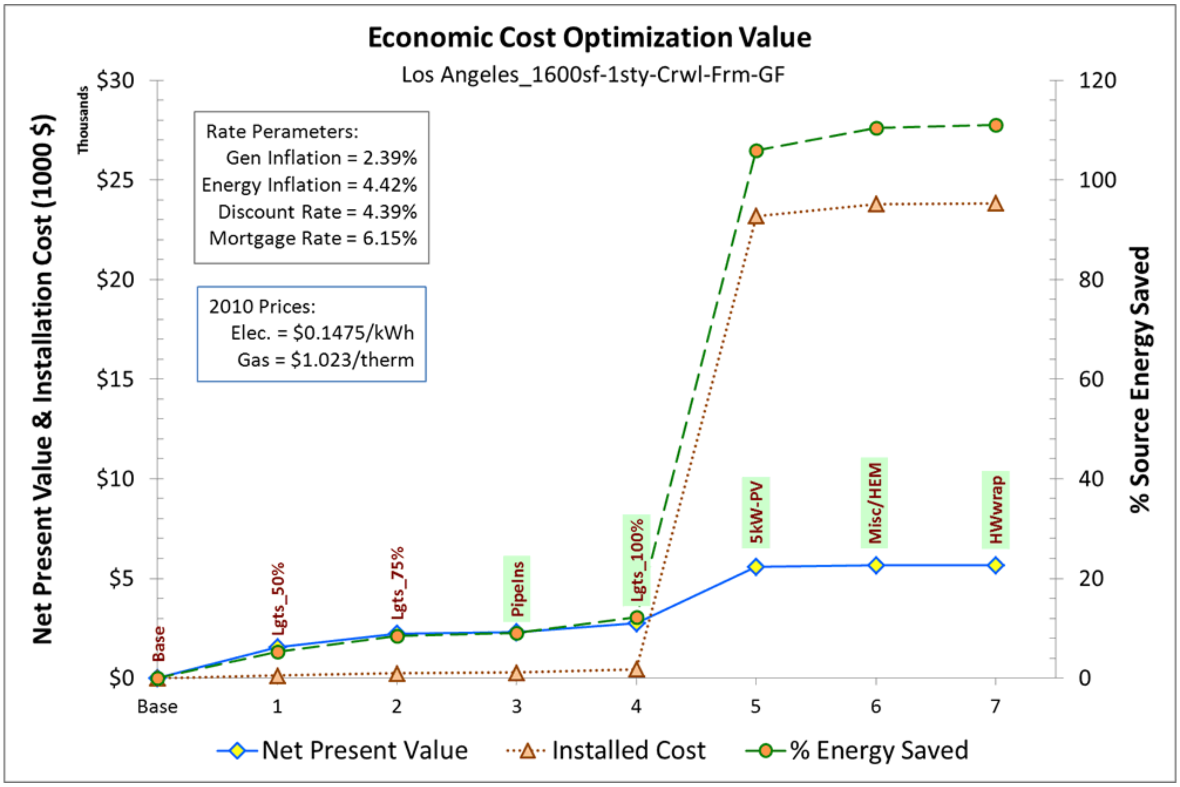
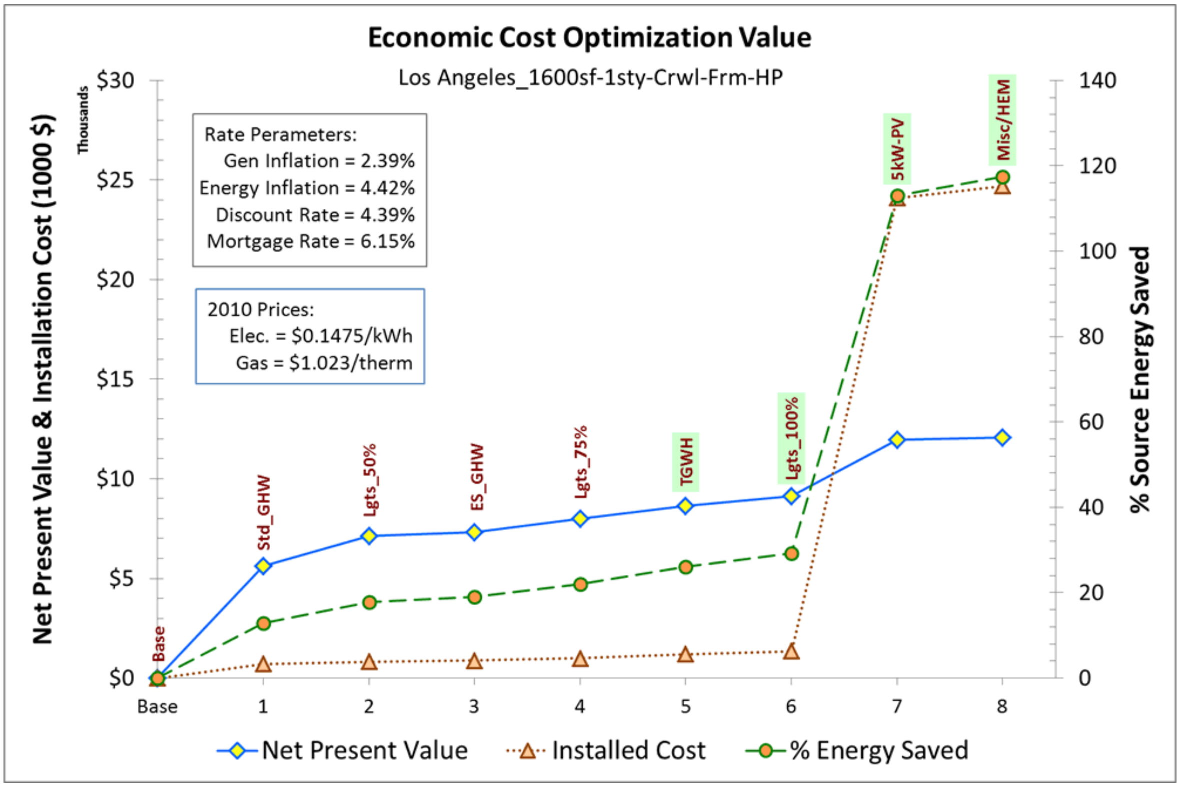
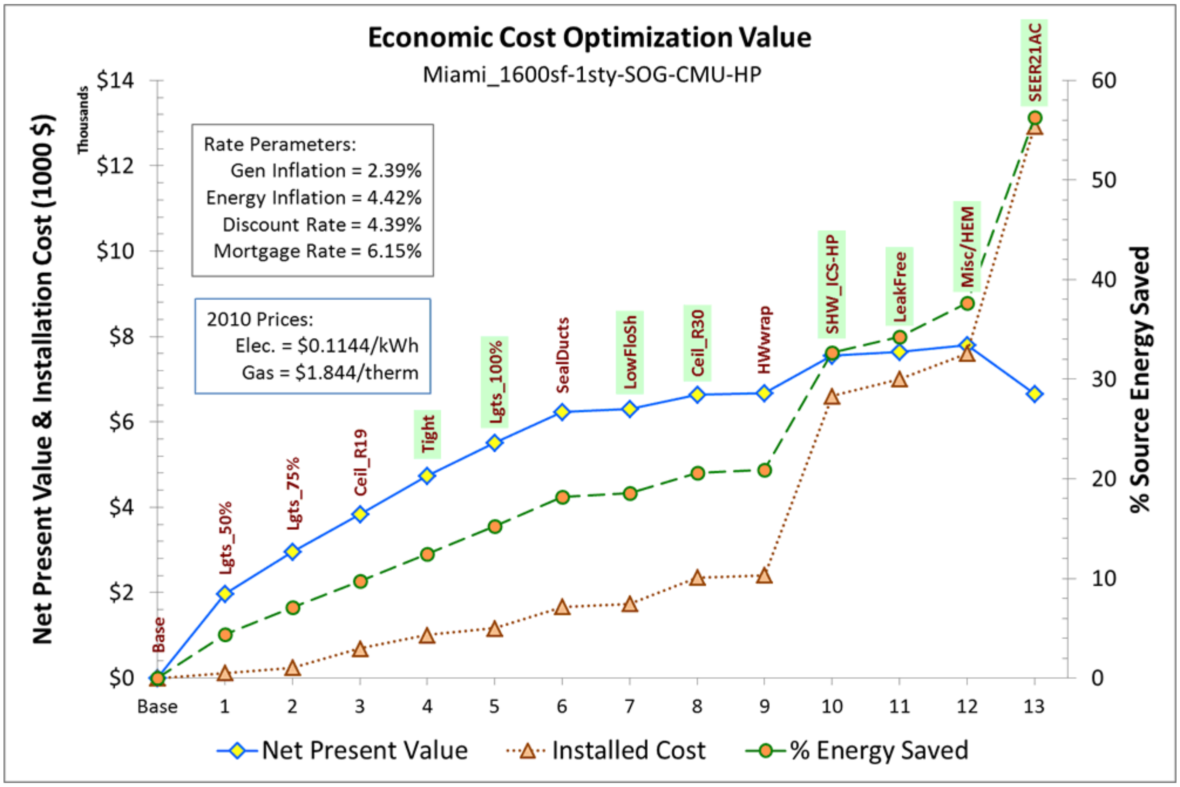
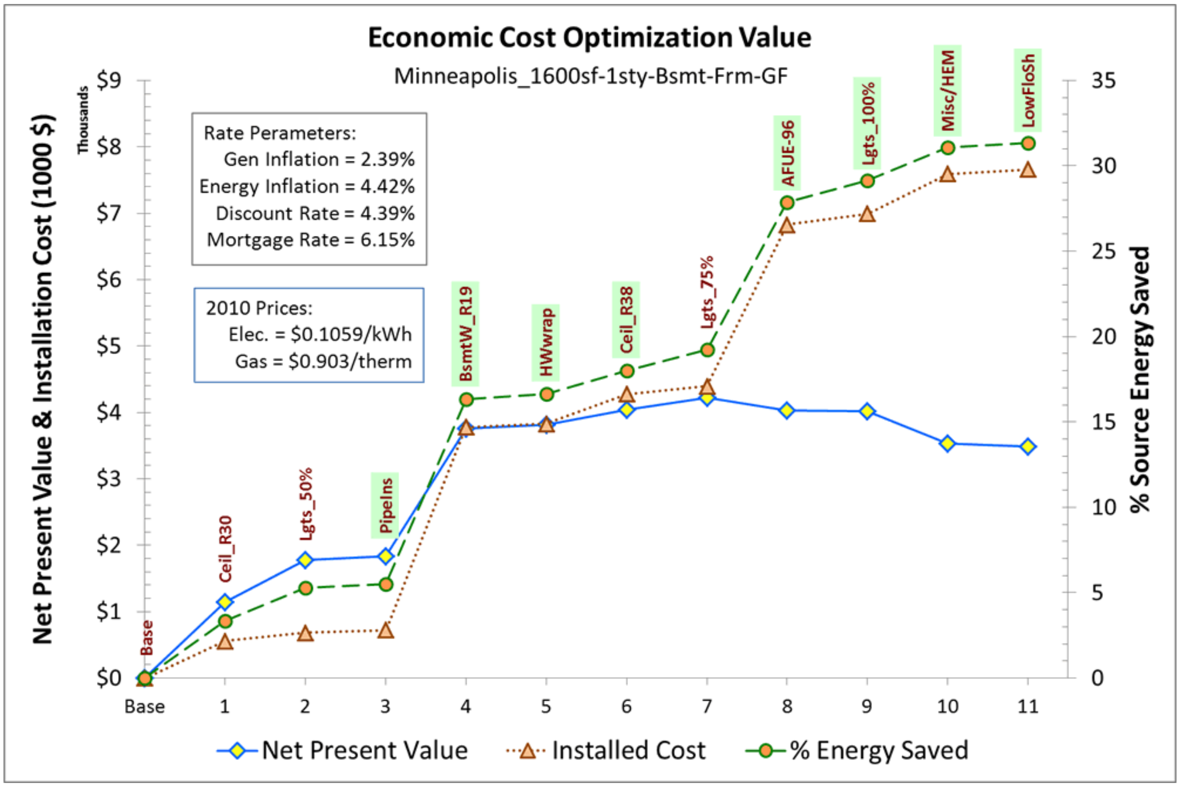
5
6
7
8
9
10
11
12
Net Present Value
Installed Cost
% Energy Saved

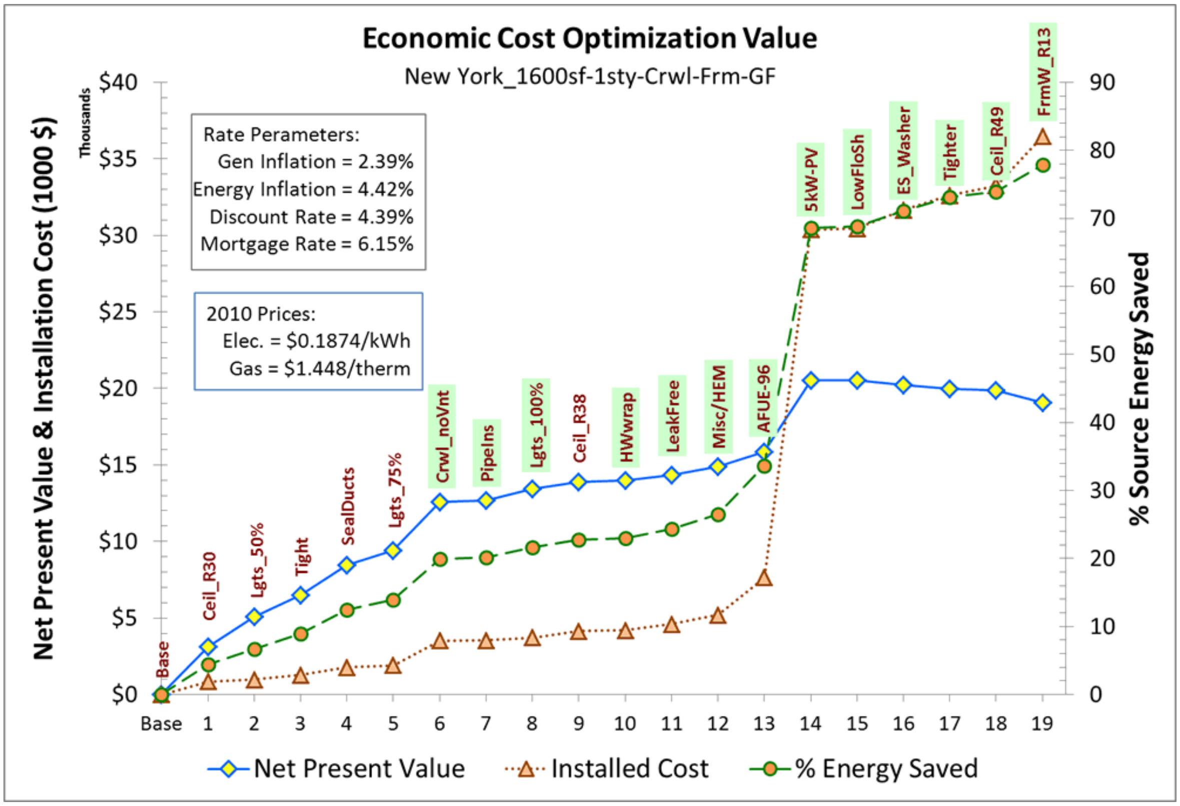

Economic Cost Optimization Value
Houston_1600sf-1sty-SOG-CMU-HP
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value & Installation Cost (1000 $)
Thousands
% Source Energy Saved
$0
$2
$4
$6
$8
$10
$12
0
5
10
15
20
25
30
35
40
Base
1
2
3
4
5
6
7
8
9
10
11
12
Base
Ceil_R19
Lgts_50%
Tight
Lgts_75%
ES_GHW
TGWH
Ceil_R30
Lgts_100%
SealDucts
Misc/HEM
Ceil_R38
LeakFree
Net Present Value
Installed Cost
% Energy Saved

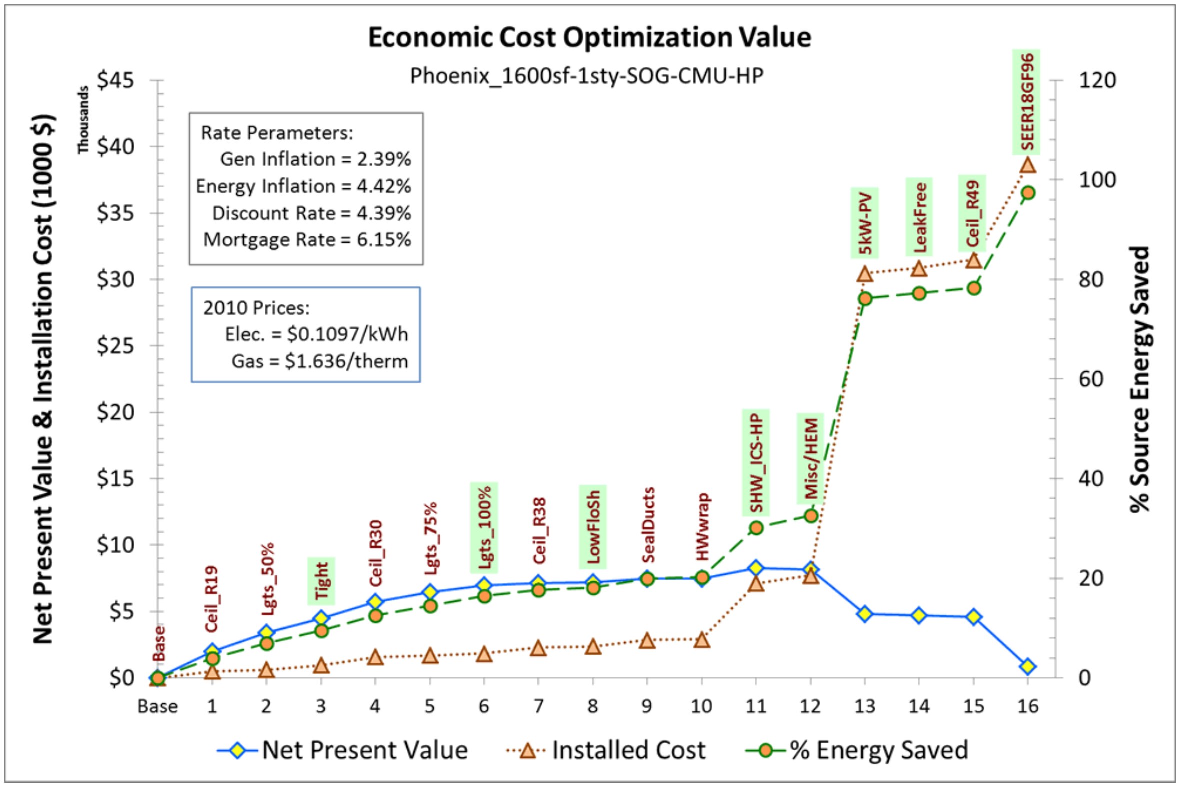

Economic Cost Optimization Value
Los Angeles_1600sf-1sty-Crwl-Frm-GF
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
% Source Energy Saved
$0
$5
$10
$15
$20
$25
$30
0
20
40
60
80
100
120
Base
1
2
3
4
5
6
7
Base
Lgts_50%
Lgts_75%
PipeIns
Lgts_100%
5kW-PV
Misc/HEM
HWwrap
Net Present Value
Installed Cost
% Energy Saved

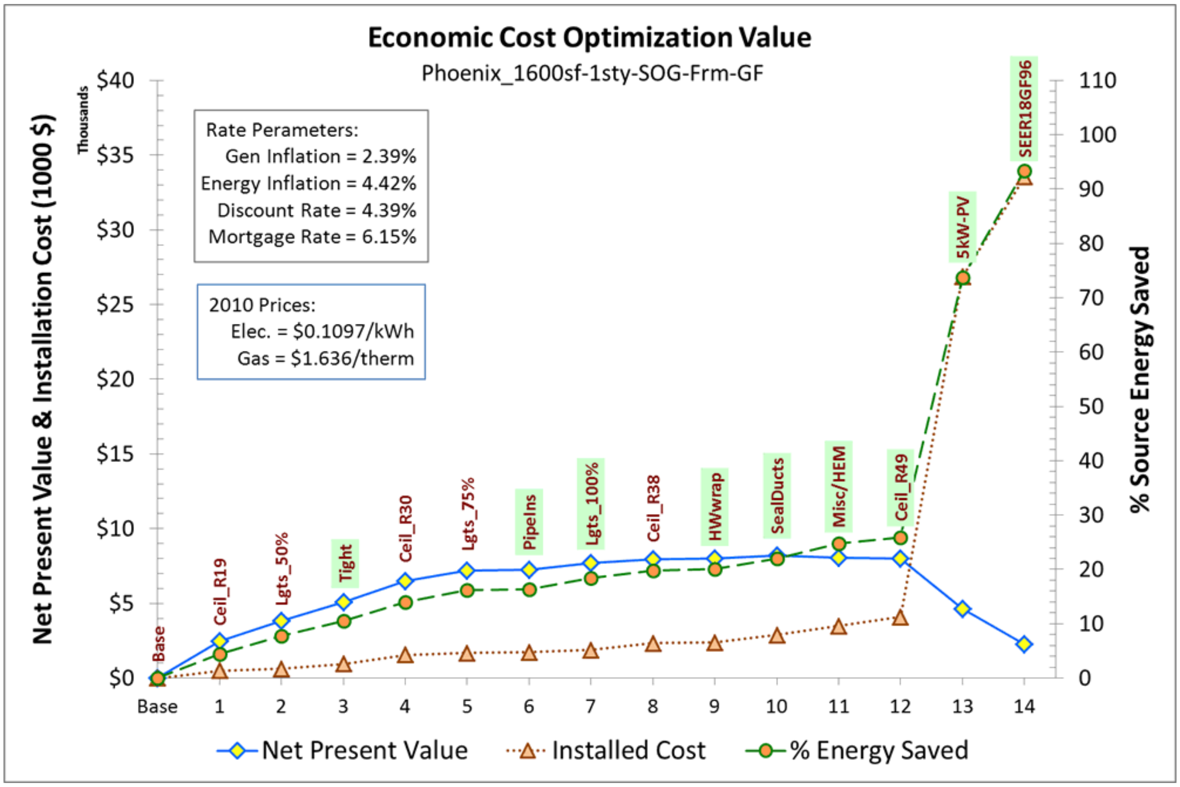

Economic Cost Optimization Value
Los Angeles_1600sf-1sty-Crwl-Frm-HP
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
140
120
100
80
60
40
20
0
Base
1
2
3
4
5
6
7
8
Base
Std_GHW
Lgts_50%
ES_GHW
Lgts_75%
TGWH
Lgts_100%
5kW-PV
Misc/HEM
Net Present Value
Installed Cost
% Energy Saved

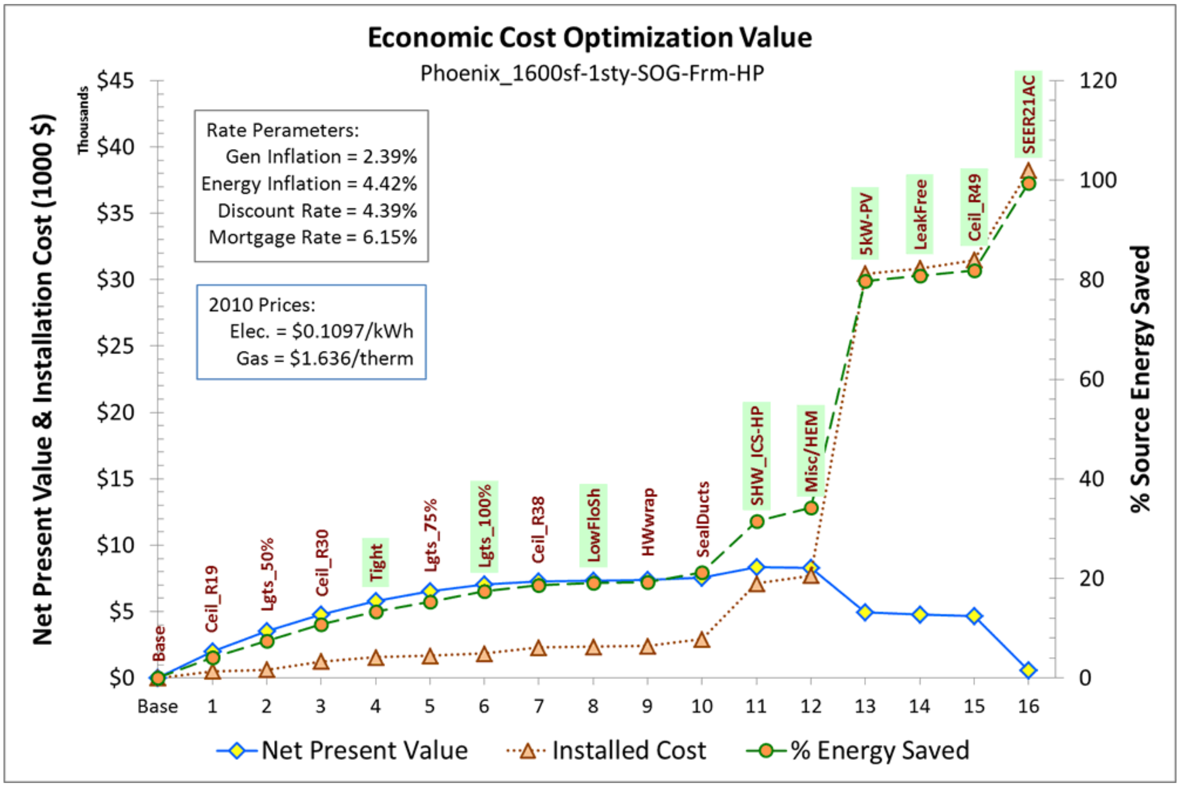

Economic Cost Optimization Value
Miami_1600sf-1sty-SOG-CMU-HP
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1144/kWh
Gas = $1.844/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Base
Lgts_50%
Lgts_75%
Ceil_R19
Tight
Lgts_100%
SealDucts
LowFloSh
Ceil_R30
HWwrap
SHW_ICS-HP
LeakFree
Misc/HEM
SEER21AC
Net Present Value
Installed Cost
% Energy Saved

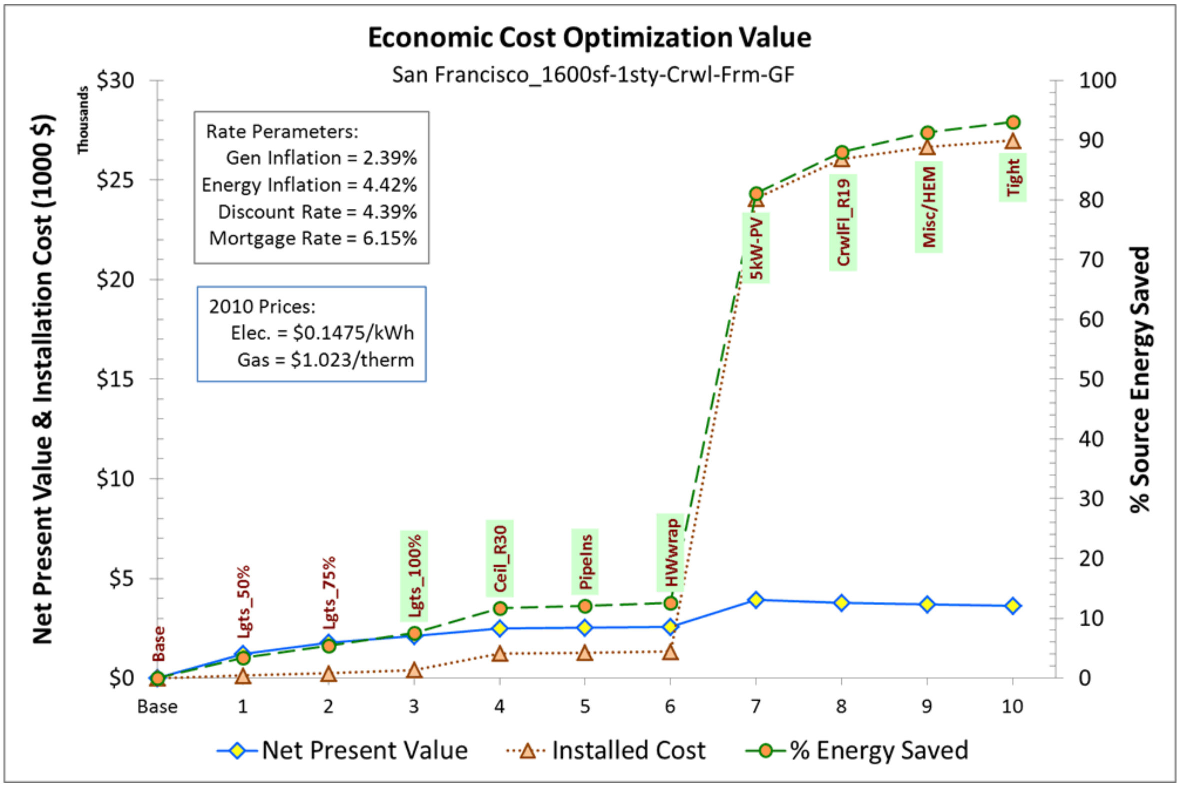

Economic Cost Optimization Value
Minneapolis_1600sf-1sty-Bsmt-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
$0
$1
$2
$3
$4
$5
$6
$7
$8
$9
% Source Energy Saved
0
5
10
15
20
25
30
35
Base
1
2
3
4
5
6
7
8
9
10
11
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1059/kWh
Gas = $0.903/therm
Base
Ceil_R30
Lgts_50%
PipeIns
BsmtW_R19
HWwrap
Ceil_R38
Lgts_75%
AFUE-96
Lgts_100%
Misc/HEM
LowFloSh
Net Present Value
Installed Cost
% Energy Saved

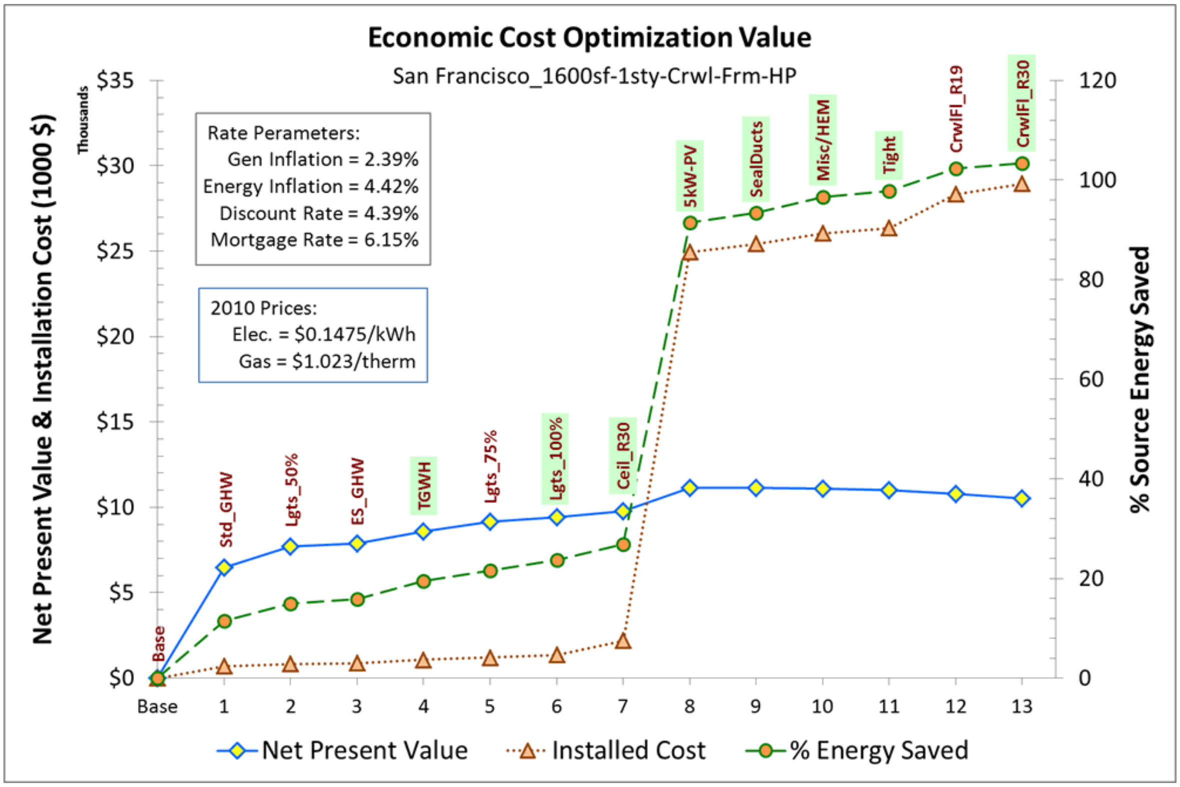

Economic Cost Optimization Value
New York_1600sf-1sty-Crwl-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
$0
$5
$10
$15
$20
$25
$30
$35
$40
% Source Energy Saved
0
10
20
30
40
50
60
70
80
90
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1874/kWh
Gas = $1.448/therm
Base
Ceil_R30
Lgts_50%
Tight
SealDucts
Lgts_75%
Crwl_noVnt
PipeIns
Lgts_100%
Ceil_R38
HWwrap
LeakFree
Misc/HEM
AFUE-96
5kW-PV
LowFloSh
ES_Washer
Tighter
Ceil_R49
FrmW_R13
Net Present Value
Installed Cost
% Energy Saved

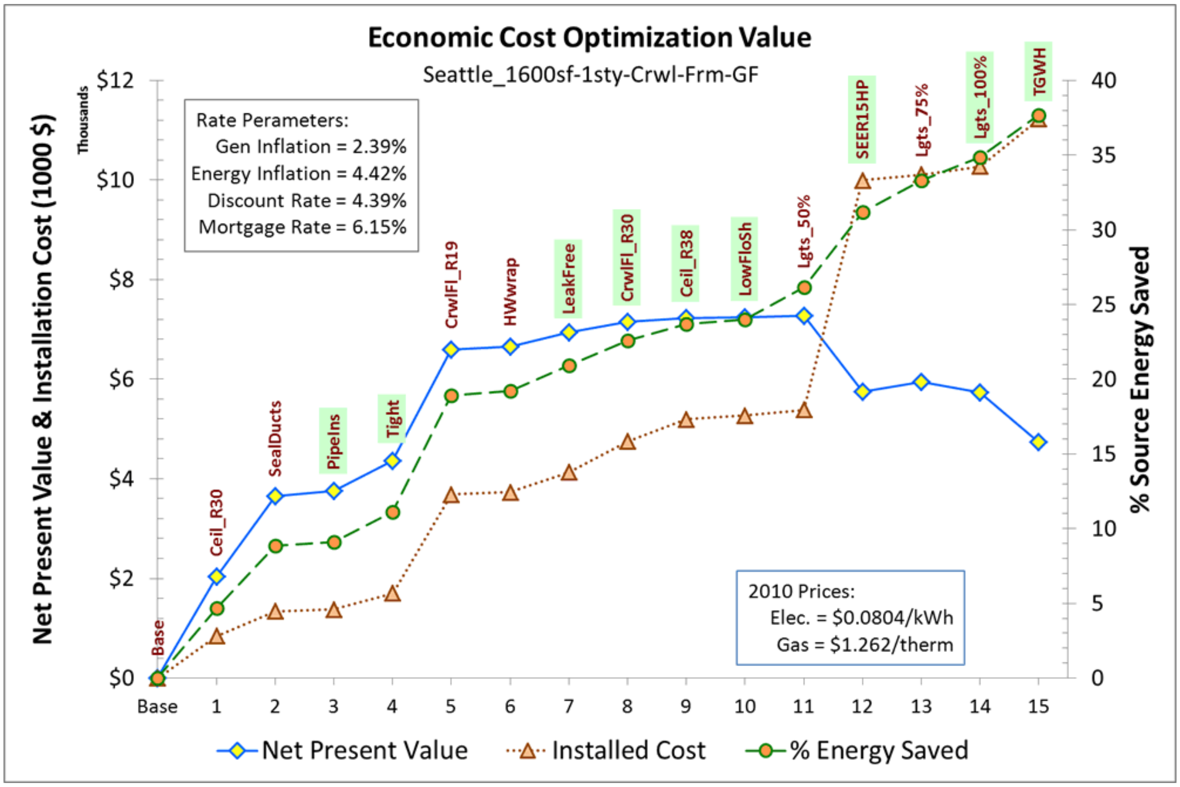

Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-CMU-HP
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Base
Ceil_R19
Lgts_50%
Tight
Ceil_R30
Lgts_75%
Lgts_100%
Ceil_R38
LowFloSh
SealDucts
HWwrap
SHW_ICS-HP
Misc/HEM
5kW-PV
LeakFree
Ceil_R49
SEER18GF96
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Net Present Value
Installed Cost
% Energy Saved

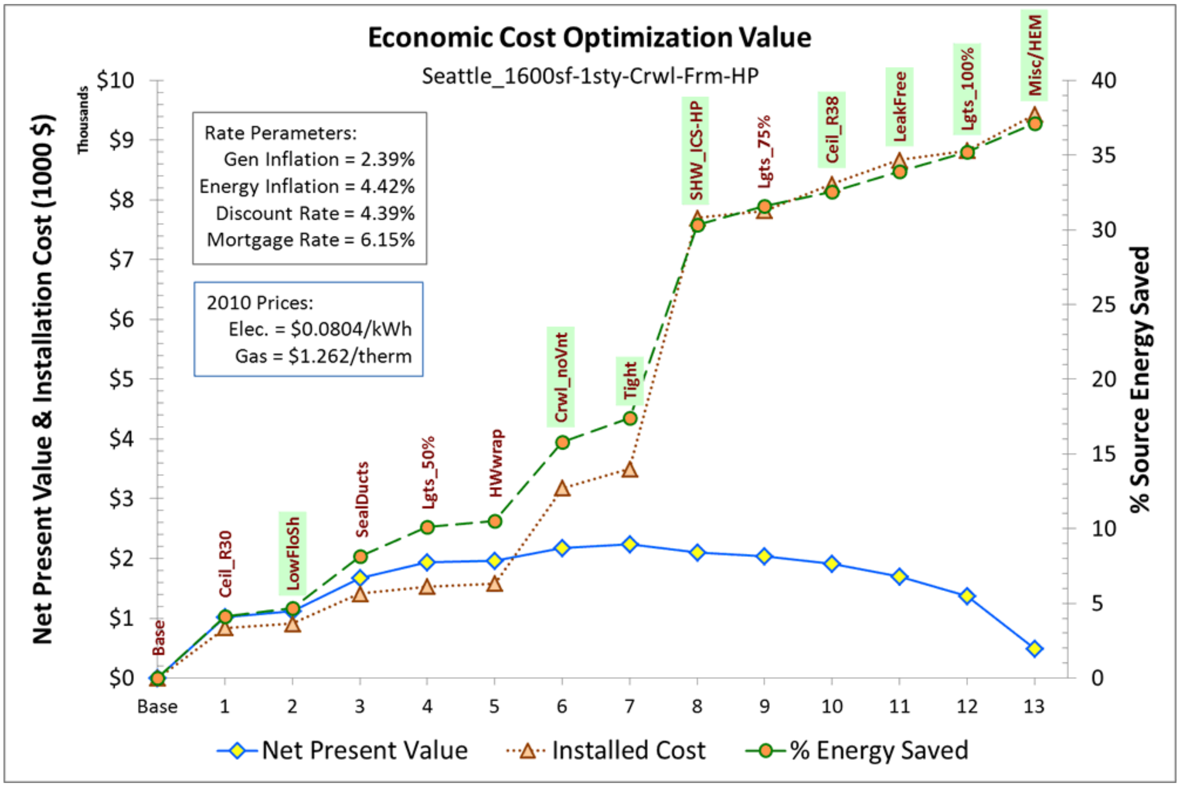

Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-GF
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
110
100
90
80
70
60
50
40
30
20
10
0
Base
Ceil_R19
Lgts_50%
Tight
Ceil_R30
Lgts_75%
PipeIns
Lgts_100%
Ceil_R38
HWwrap
SealDucts
Misc/HEM
Ceil_R49
5kW-PV
SEER18GF96
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-HP
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Base
Ceil_R19
Lgts_50%
Ceil_R30
Tight
Lgts_75%
Lgts_100%
Ceil_R38
LowFloSh
HWwrap
SealDucts
SHW_ICS-HP
Misc/HEM
5kW-PV
LeakFree
Ceil_R49
SEER21AC
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
San Francisco_1600sf-1sty-Crwl-Frm-GF
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Base
Lgts_50%
Lgts_75%
Lgts_100%
Ceil_R30
PipeIns
HWwrap
5kW-PV
CrwlFl_R19
Misc/HEM
Tight
Base
1
2
3
4
5
6
7
8
9
10
Net Present Value
Installed Cost
% Energy Saved

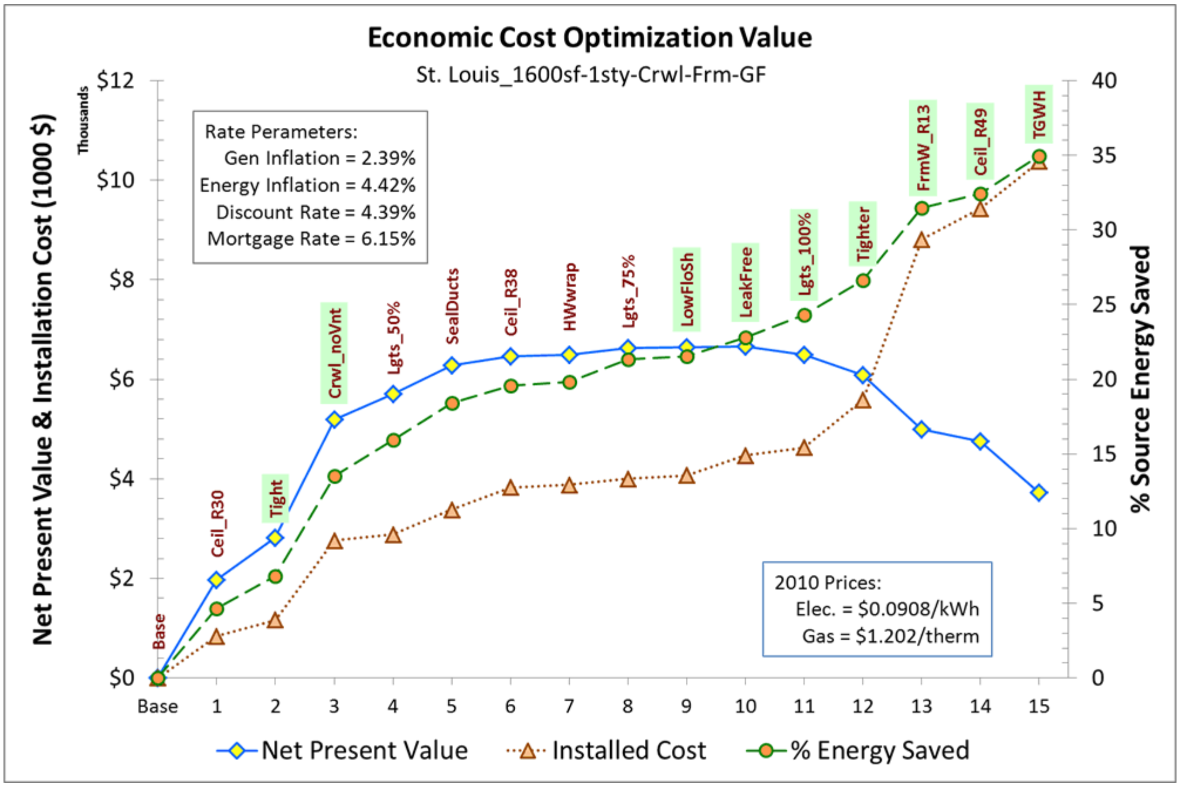

Economic Cost Optimization Value
San Francisco_1600sf-1sty-Crwl-Frm-HP
Net Present Value & Installation Cost (1000 $)
Thousands
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Base
Std_GHW
Lgts_50%
ES_GHW
TGWH
Lgts_75%
Lgts_100%
Ceil_R30
5kW-PV
SealDucts
Misc/HEM
Tight
CrwlFl_R19
CrwlFl_R30
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-GF
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Base
Ceil_R30
SealDucts
PipeIns
Tight
CrwlFl_R19
HWwrap
LeakFree
CrwlFl_R30
Ceil_R38
LowFloSh
Lgts_50%
SEER15HP
Lgts_75%
Lgts_100%
TGWH
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Net Present Value
Installed Cost
% Energy Saved



Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%

2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm



Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%

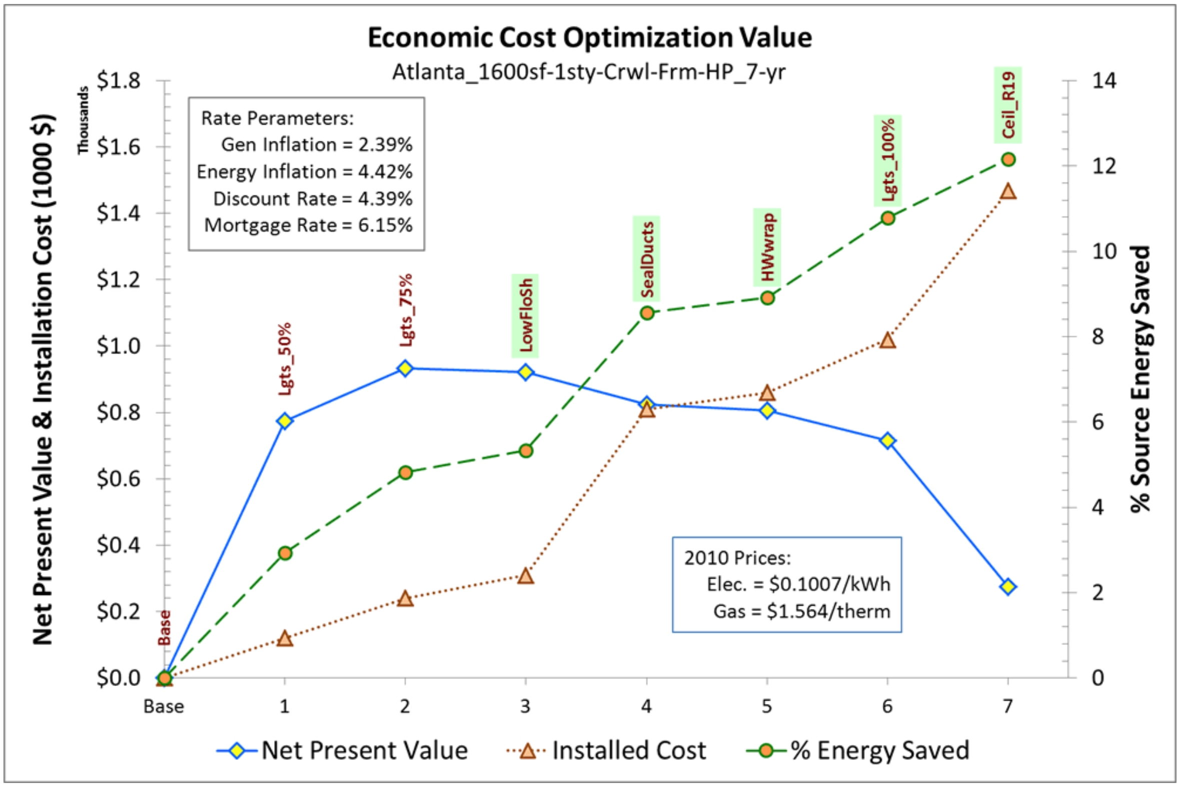
2010 Prices:
Elec. = $0.0908/kWh
Gas = $1.202/therm

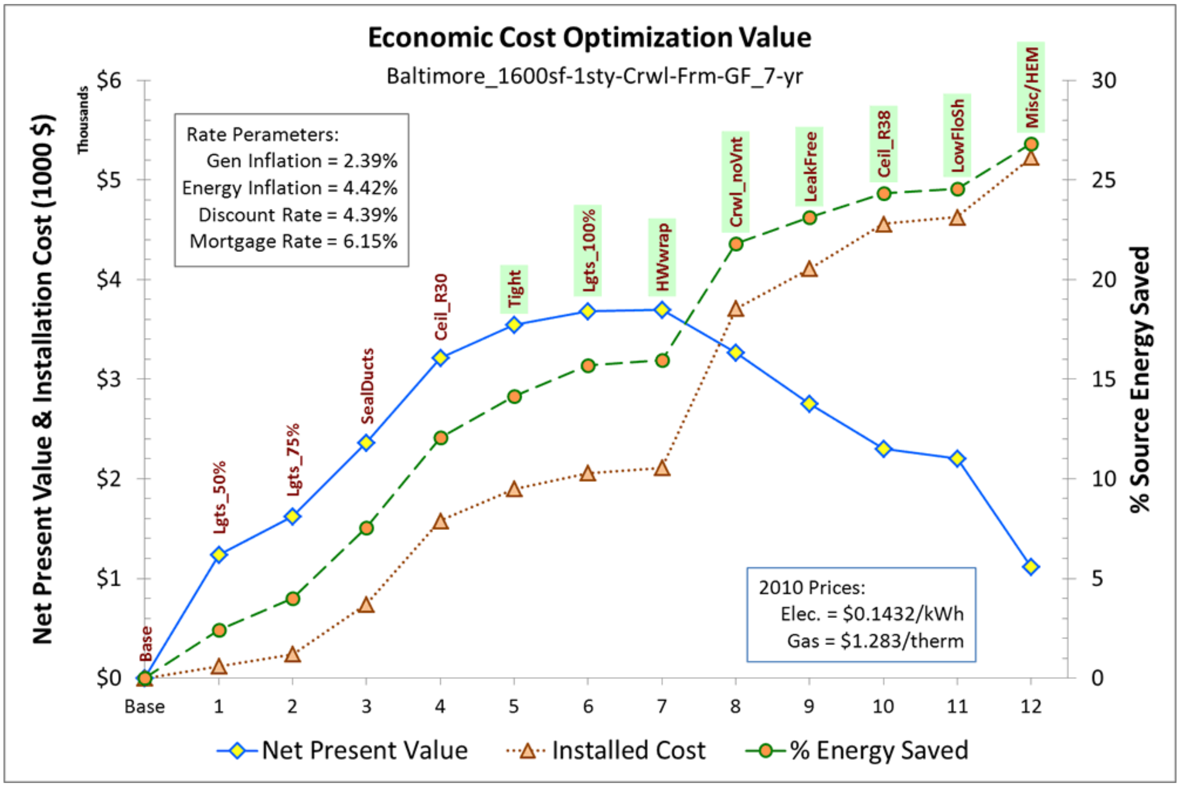
Appendix D. Optimization Scenario 2— Homeowner Financing Home Improvement Loan Model

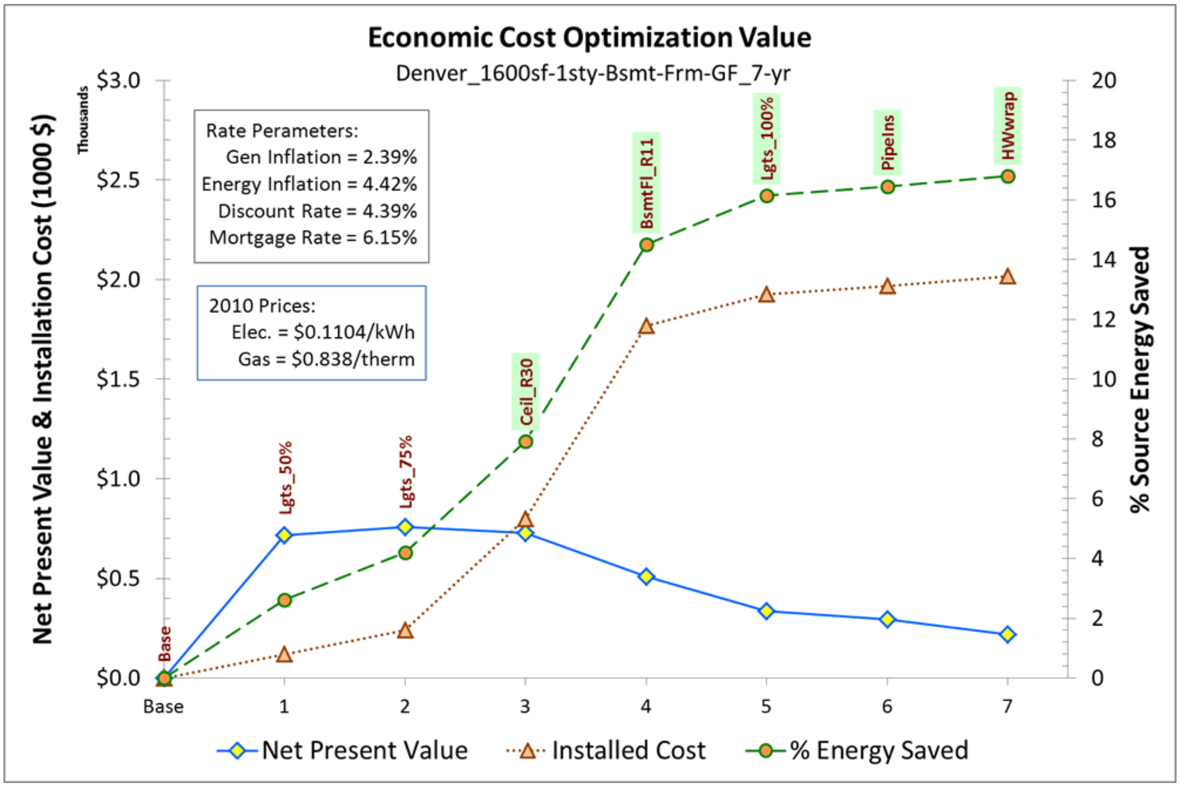
The figures shown on the following pages are in a standard CostOpt format that plots the cumulative investment costs and the cumulative NPV of the investments on the left-hand vertical axis and the cumulative source energy savings percentage on the right-hand axis. Thus, if an individual improvement measure has an SIR greater than unity, cumulative NPV will increase. However, if an individual measure has an SIR less than unity, cumulative NPV will decrease. Therefore, the point at which the NPV is largest is the optimum cost effectiveness from the consumer's perspective. However, often measures come in at the end of the optimization that have an individual measure SIR less than unity but that do not cause the cumulative NPV to drop below zero. These measures are also cost effective from a societal perspective in that they are "paid for" by the earlier highly cost-effective measures. Thus, the neutral cost point from the CostOpt perspective is the line where the cumulative NPV equals zero. Because the optimization method is incremental, a number of measures are selected and then later replaced by higher efficiency measures in the same category. Thus, for ease of understanding, the final selections in each category are highlighted in light green on the plots.

Key to acronyms:

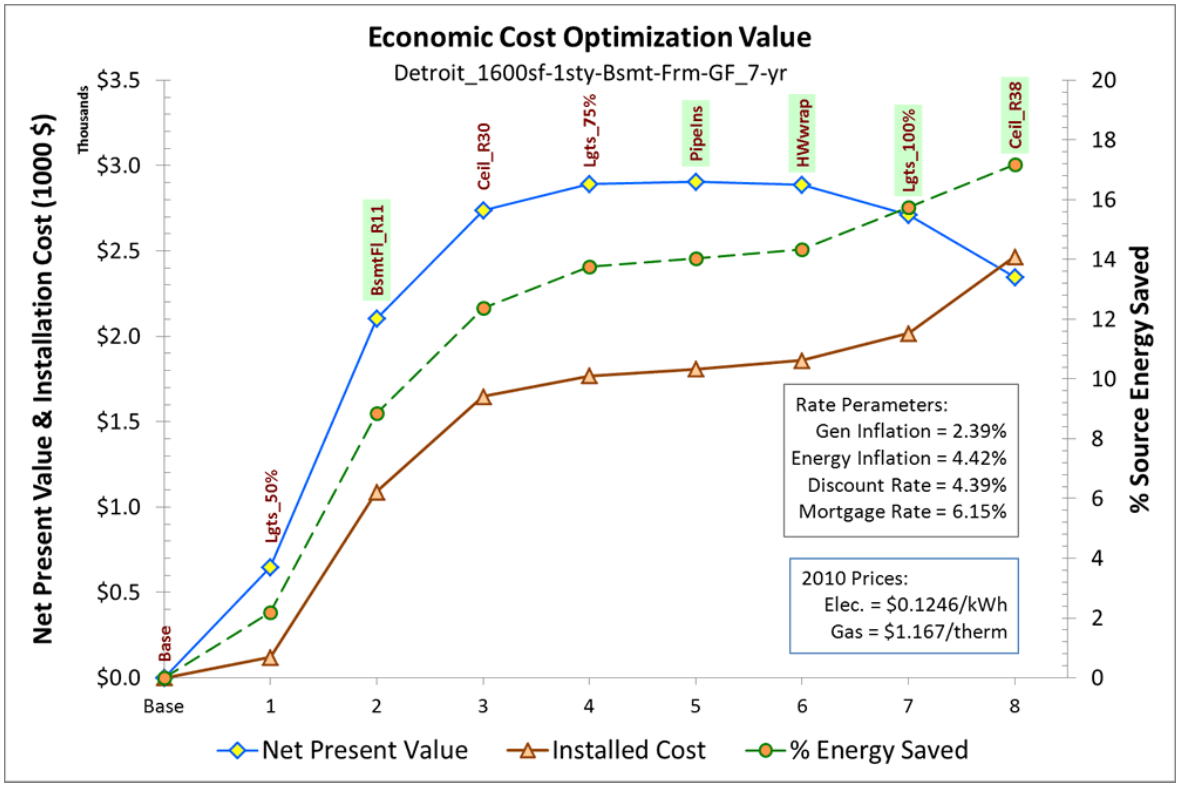
1600sf: Archetype home size in square feet
1sty: One-story above grade home
SOG: Slab-on-grade foundation
Crwl: Crawlspace foundation
Bsmt: Unconditioned basement foundation
HP: Electric space and water heating in base archetype
GF: Natural gas space and water heating in base archetype
7-yr: Seven year mortgage period (used in Scenarios 2 and 3)
incHVAC: Incremental costs used for HVAC systems (used in Scenario 3)
ReFi: Refinance scenario using 4% mortgage interest (used in Scenario 4)


Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-HP_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1007/kWh
Gas = $1.564/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$1.8
$1.6
$1.4
$1.2
$1.0
$0.8
$0.6
$0.4
$0.2
$0.0
% Source Energy Saved
14
12
10
8
6
4
2
0
Base
1
2
3
4
5
6
7
Base
Lgts_50%
Lgts_75%
LowFloSh
SealDucts
HWwrap
Lgts_100%
Ceil_R19
Net Present Value
Installed Cost
% Energy Saved

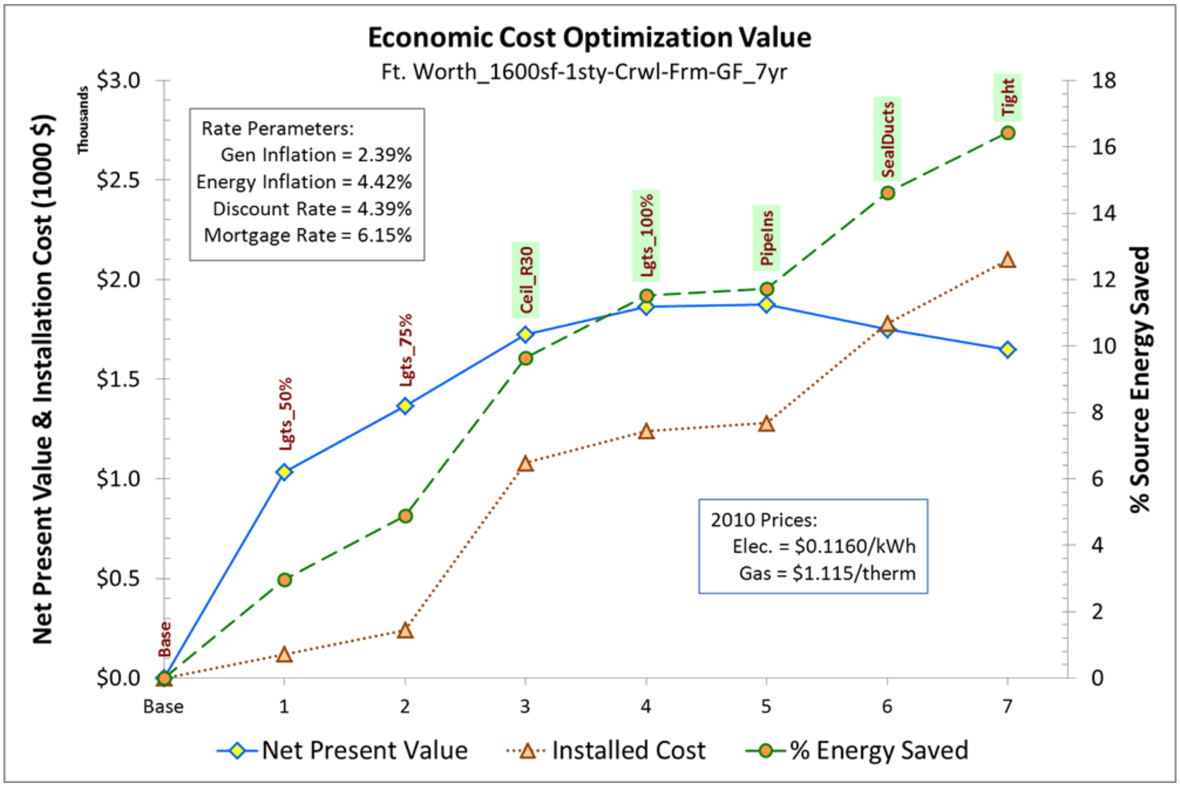

Economic Cost Optimization Value
Baltimore_1600sf-1sty-Crwl-Frm-GF_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1432/kWh
Gas = $1.283/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
Base
Lgts_50%
Lgts_75%
SealDucts
Ceil_R30
Tight
Lgts_100%
HWwrap
Crwl_noVnt
LeakFree
Ceil_R38
LowFloSh
Misc/HEM
Net Present Value
Installed Cost
% Energy Saved

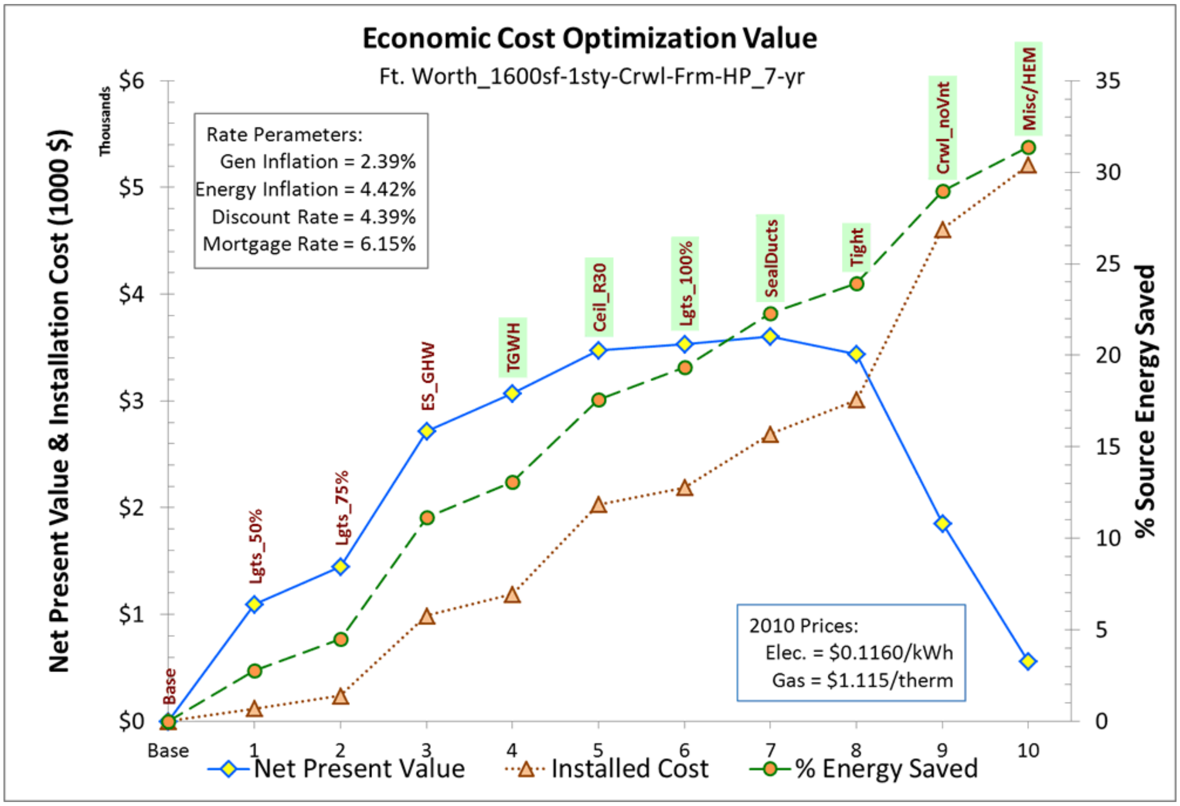


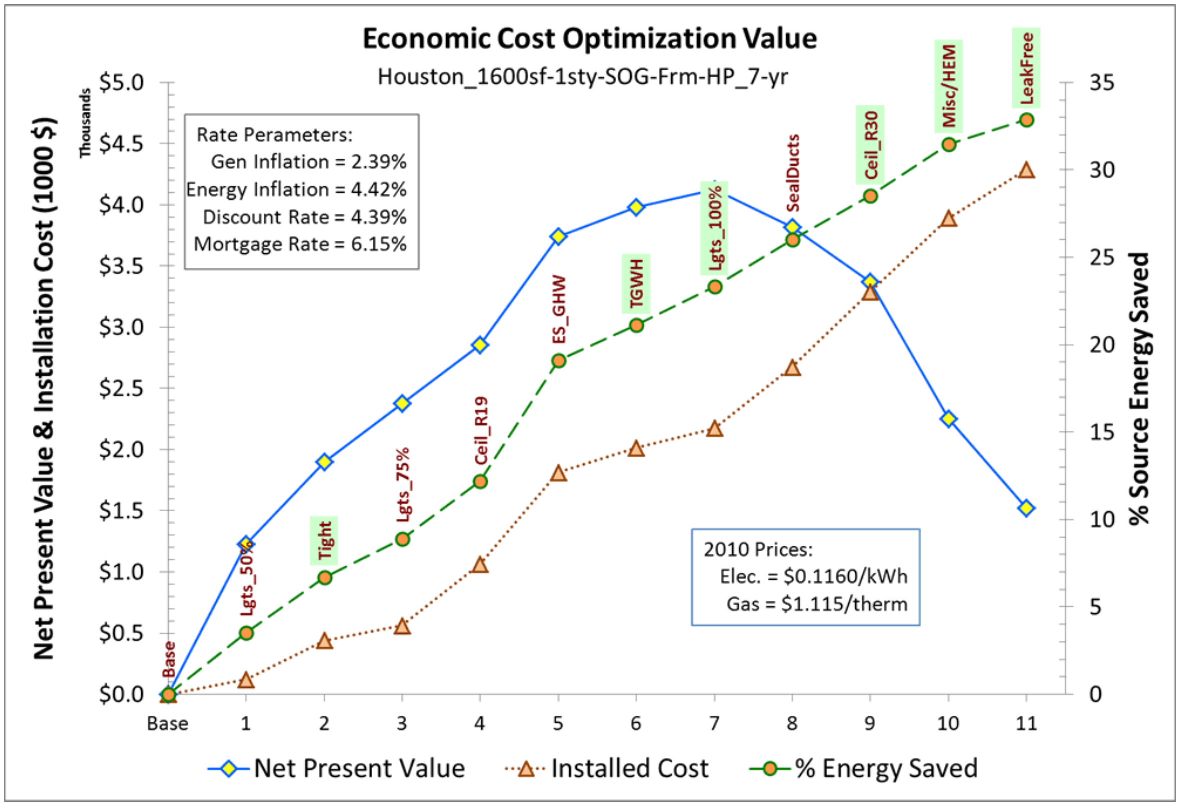
Economic Cost Optimization Value
Denver_1600sf-1sty-Bsmt-Frm-GF_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1104/kWh
Gas = $0.838/therm
Net Present Value & Installation Cost (1000 $)
Thousands
% Source Energy Saved
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
20
18
16
14
12
10
8
6
4
2
0
Base
1
2
3
4
5
6
7
Base
Lgts_50%
Lgts_75%
Ceil_R30
BsmtFl_R11
Lgts_100%
PipeIns
HWwrap
Net Present Value
Installed Cost
% Energy Saved

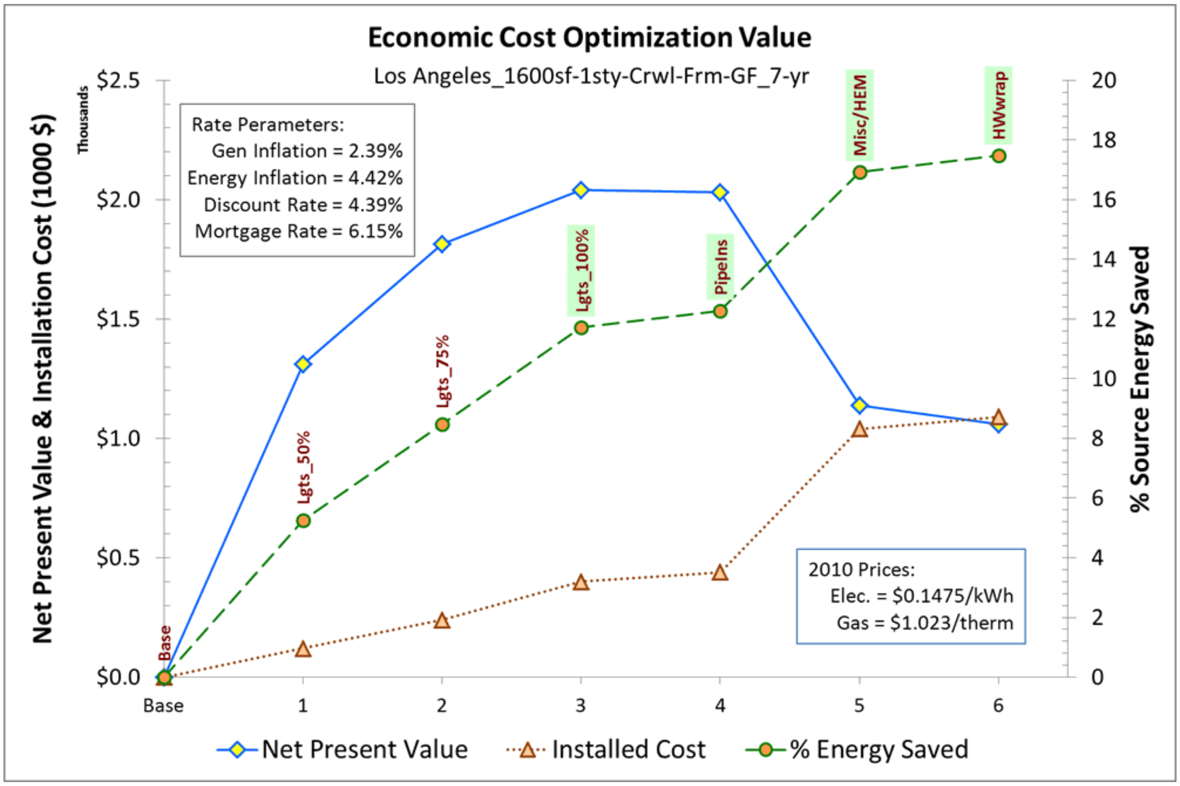


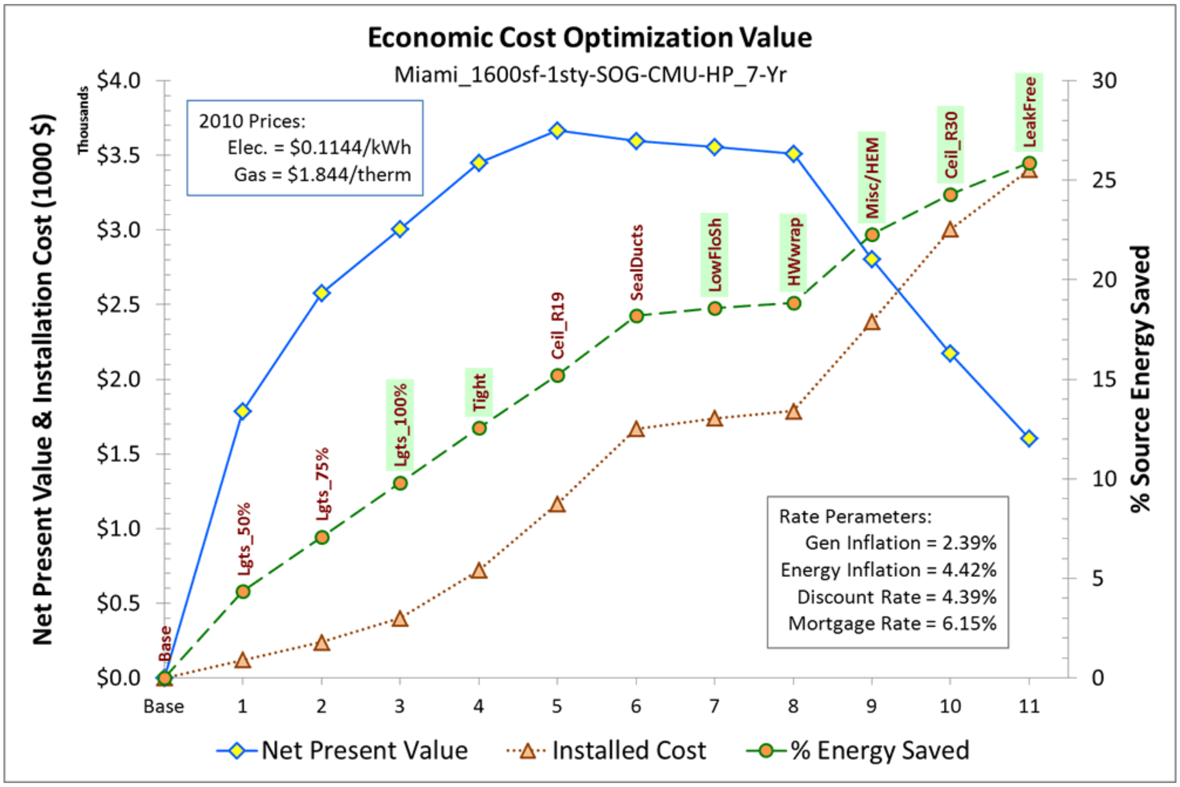
Economic Cost Optimization Value
Detroit_1600sf-1sty-Bsmt-Frm-GF_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1246/kWh
Gas = $1.167/therm
Net Present Value & Installation Cost (1000 $)
Thousands
% Source Energy Saved
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
20
18
16
14
12
10
8
6
4
2
0
Base
1
2
3
4
5
6
7
8
Base
Lgts_50%
BsmtFl_R11
Ceil_R30
Lgts_75%
PipeIns
HWwrap
Lgts_100%
Ceil_R38
Net Present Value
Installed Cost
% Energy Saved

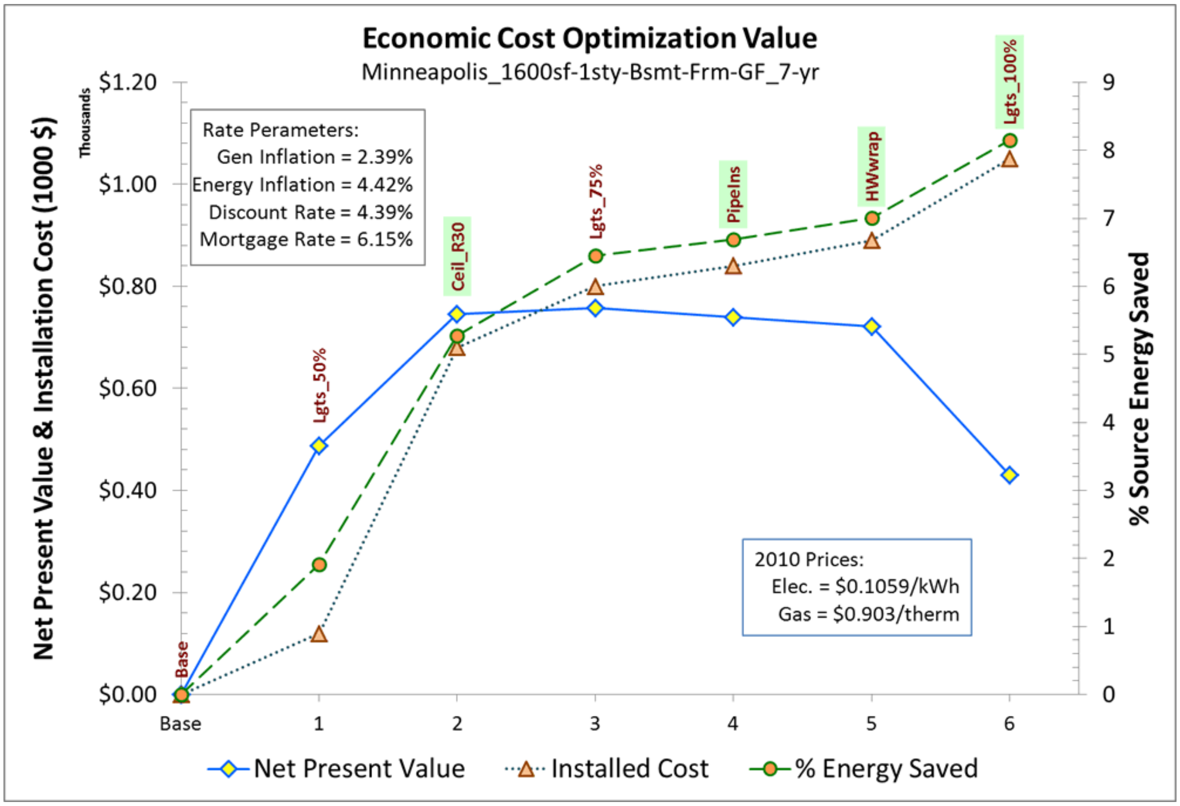

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-GF_7yr
Net Present Value & Installation Cost (1000 $)
Thousands
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
18
16
14
12
10
8
6
4
2
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Base
Lgts_50%
Lgts_75%
Ceil_R30
Lgts_100%
PipeIns
SealDucts
Tight
Base
1
2
3
4
5
6
7
Net Present Value
Installed Cost
% Energy Saved

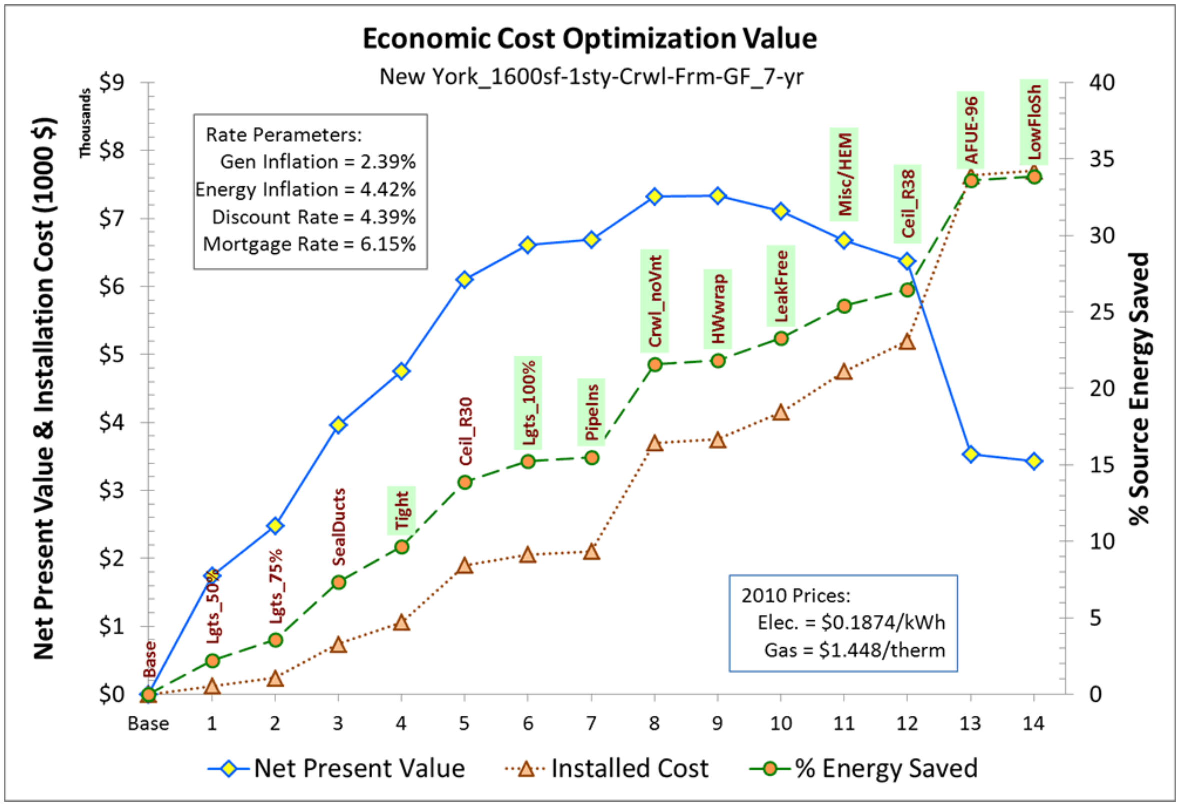

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-HP_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
35
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Base
Lgts_50%
Lgts_75%
ES_GHW
TGWH
Ceil_R30
Lgts_100%
SealDucts
Tight
Crwl_noVnt
Misc/HEM
Base
1
2
3
4
5
6
7
8
9
10
Net Present Value
Installed Cost
% Energy Saved

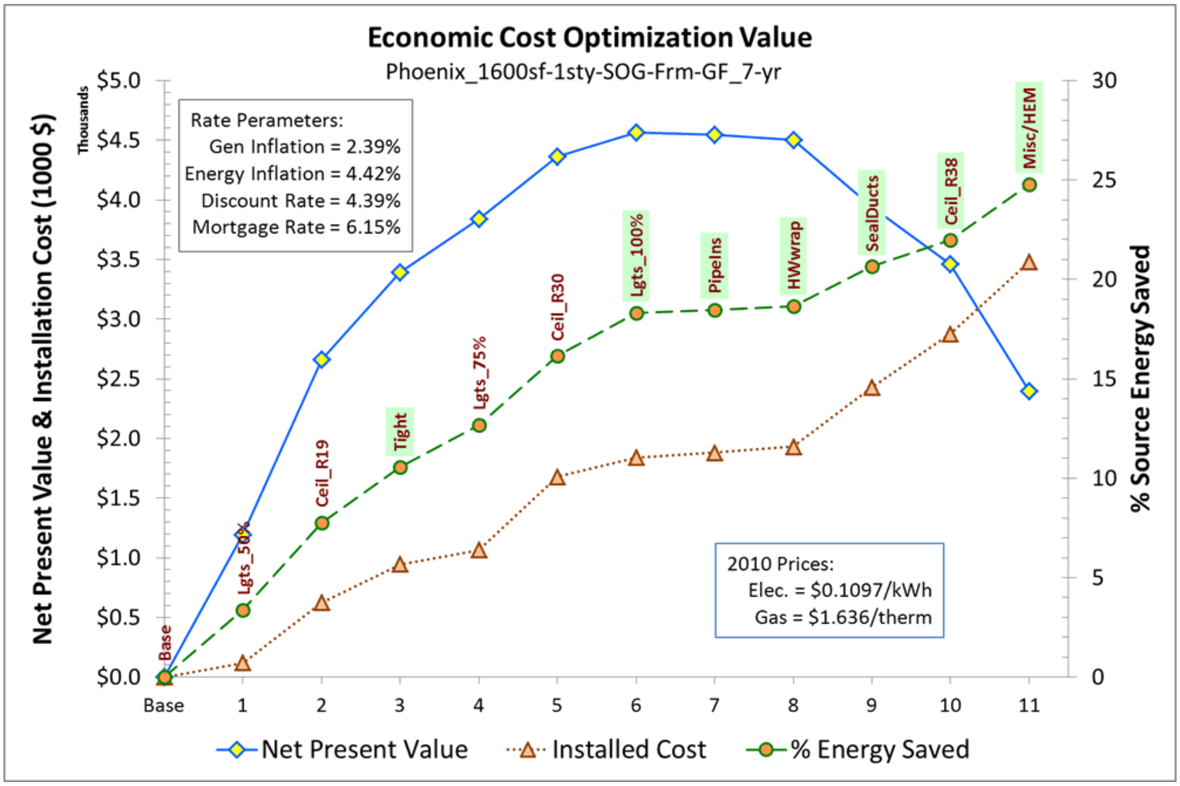

Economic Cost Optimization Value
Houston_1600sf-1sty-SOG-Frm-HP_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$5.0
$4.5
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Base
Lgts_50%
Tight
Lgts_75%
Ceil_R19
ES_GHW
TGWH
Lgts_100%
SealDucts
Ceil_R30
Misc/HEM
LeakFree
Net Present Value
Installed Cost
% Energy Saved

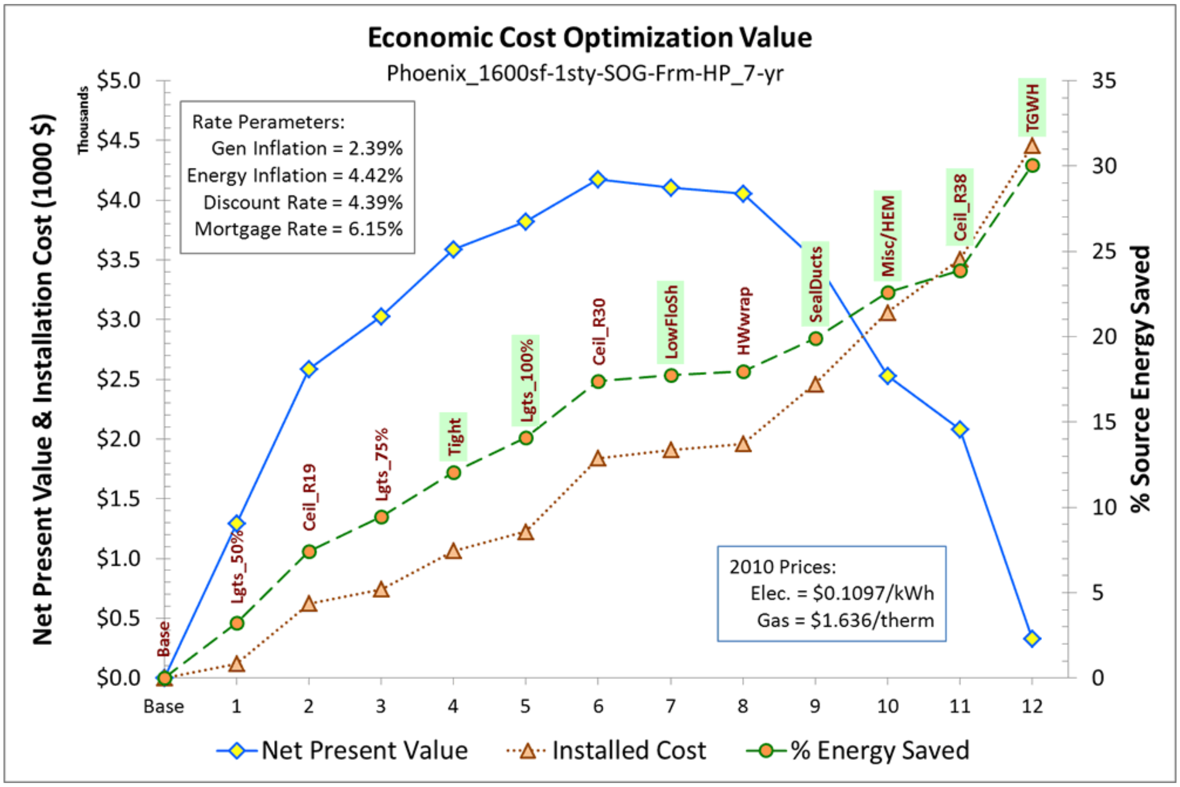

Economic Cost Optimization Value
Los Angeles_1600sf-1sty-Crwl-Frm-GF_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
20
18
16
14
12
10
8
6
4
2
0
Base
1
2
3
4
5
6
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Base
Lgts_50%
Lgts_75%
Lgts_100%
PipeIns
Misc/HEM
HWwrap
Net Present Value
Installed Cost
% Energy Saved

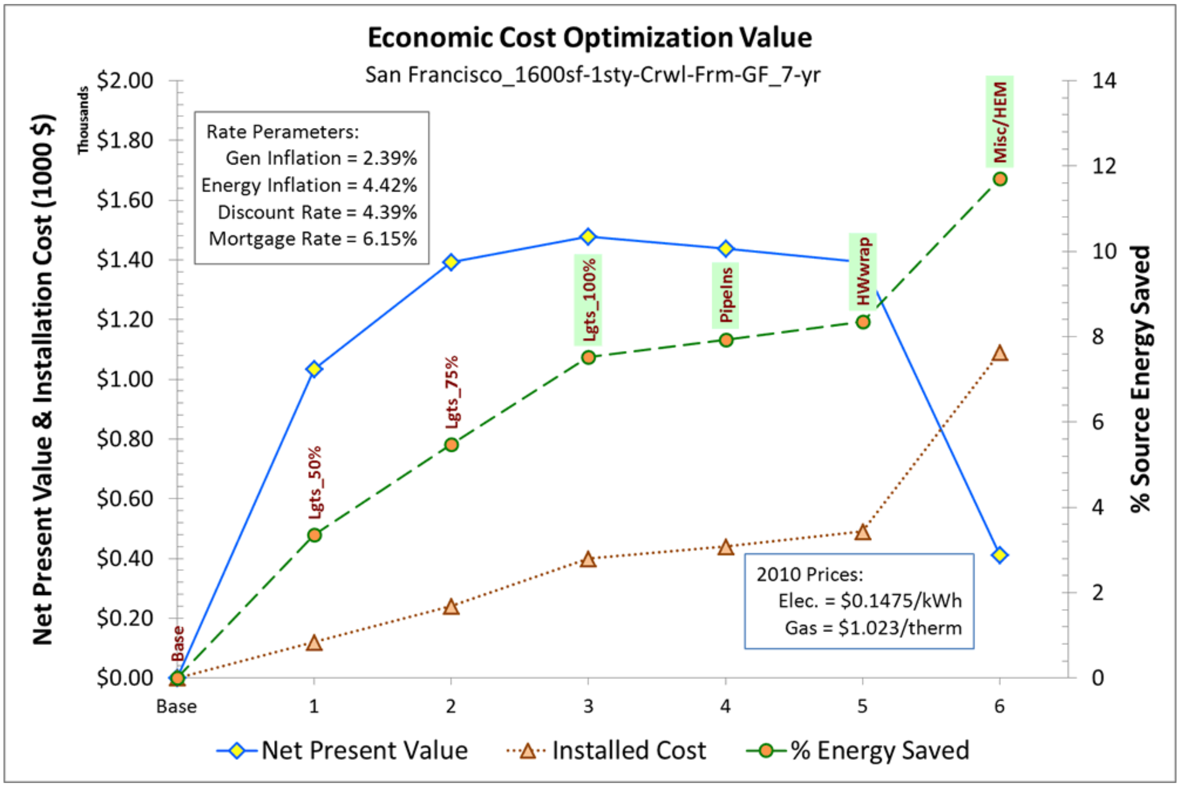

Economic Cost Optimization Value
Miami_1600sf-1sty-SOG-CMU-HP_7-Yr
Thousands
Net Present Value & Installation Cost (1000 $)
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
2010 Prices:
Elec. = $0.1144/kWh
Gas = $1.844/therm
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
Base
Lgts_50%
Lgts_75%
Lgts_100%
Tight
Ceil_R19
SealDucts
LowFloSh
HWwrap
Misc/HEM
Ceil_R30
LeakFree
Net Present Value
Installed Cost
% Energy Saved

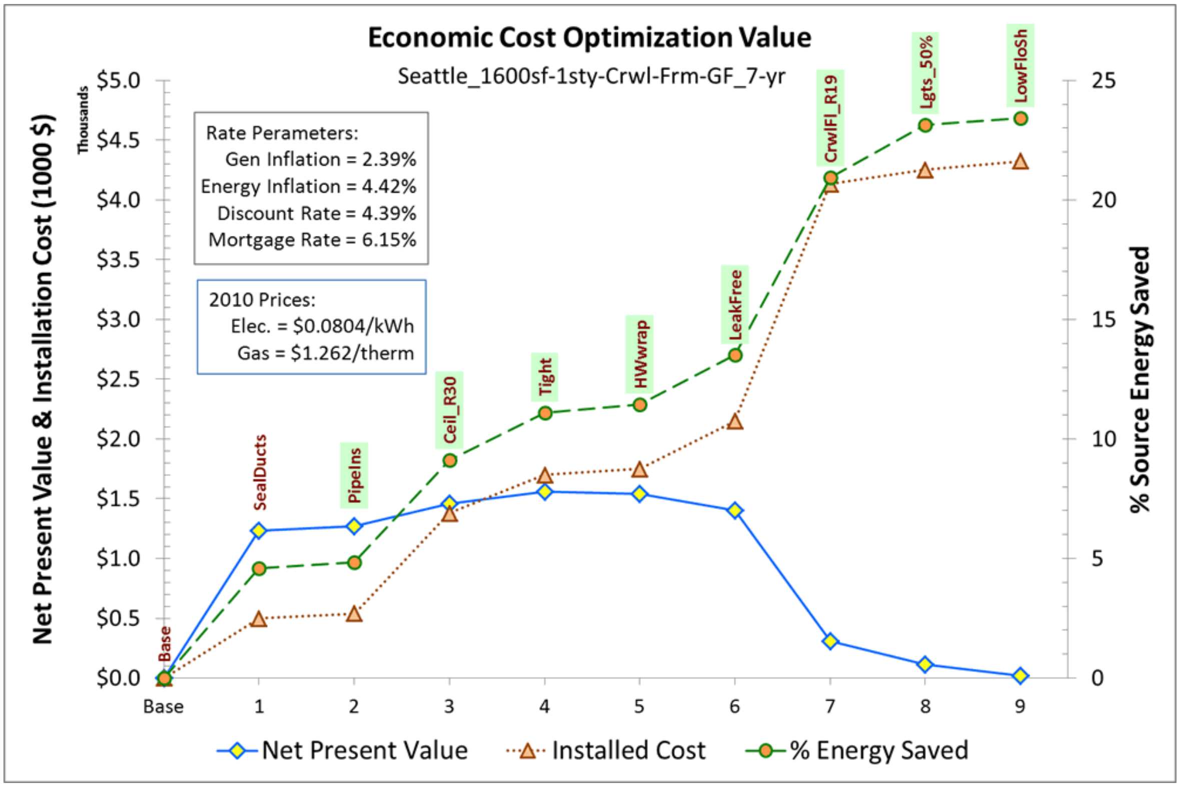

Economic Cost Optimization Value
Minneapolis_1600sf-1sty-Bsmt-Frm-GF_7-yr
Thousands
Net Present Value & Installation Cost (1000 $)
$1.20
$1.00
$0.80
$0.60
$0.40
$0.20
$0.00
% Source Energy Saved
9
8
7
6
5
4
3
2
1
0
Base
1
2
3
4
5
6
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1059/kWh
Gas = $0.903/therm
Base
Lgts_50%
Ceil_R30
Lgts_75%
PipeIns
HWwrap
Lgts_100%
Net Present Value
Installed Cost
% Energy Saved

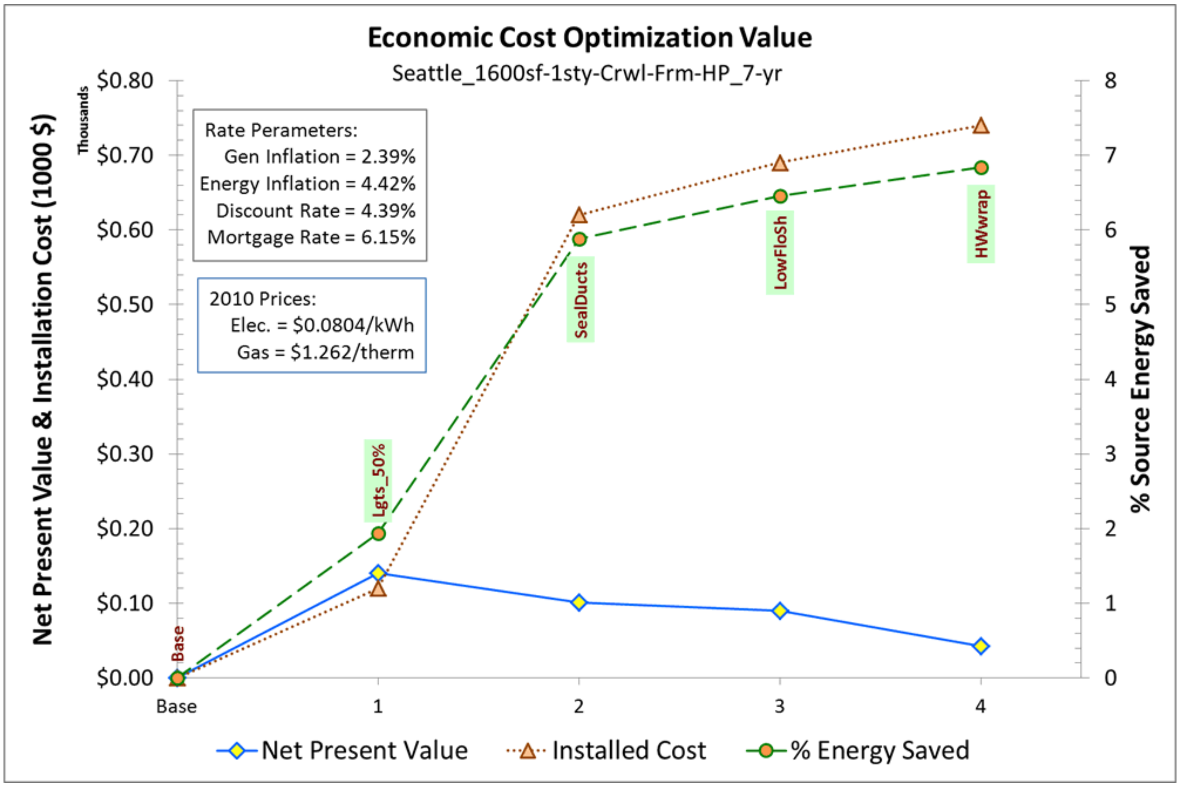

Economic Cost Optimization Value
New York_1600sf-1sty-Crwl-Frm-GF_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$9
$8
$7
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1874/kWh
Gas = $1.448/therm
Base
Lgts_50%
Lgts_75%
SealDucts
Tight
Ceil_R30
Lgts_100%
PipeIns
Crwl_noVnt
HWwrap
LeakFree
Misc/HEM
Ceil_R38
AFUE-96
LowFloSh
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved

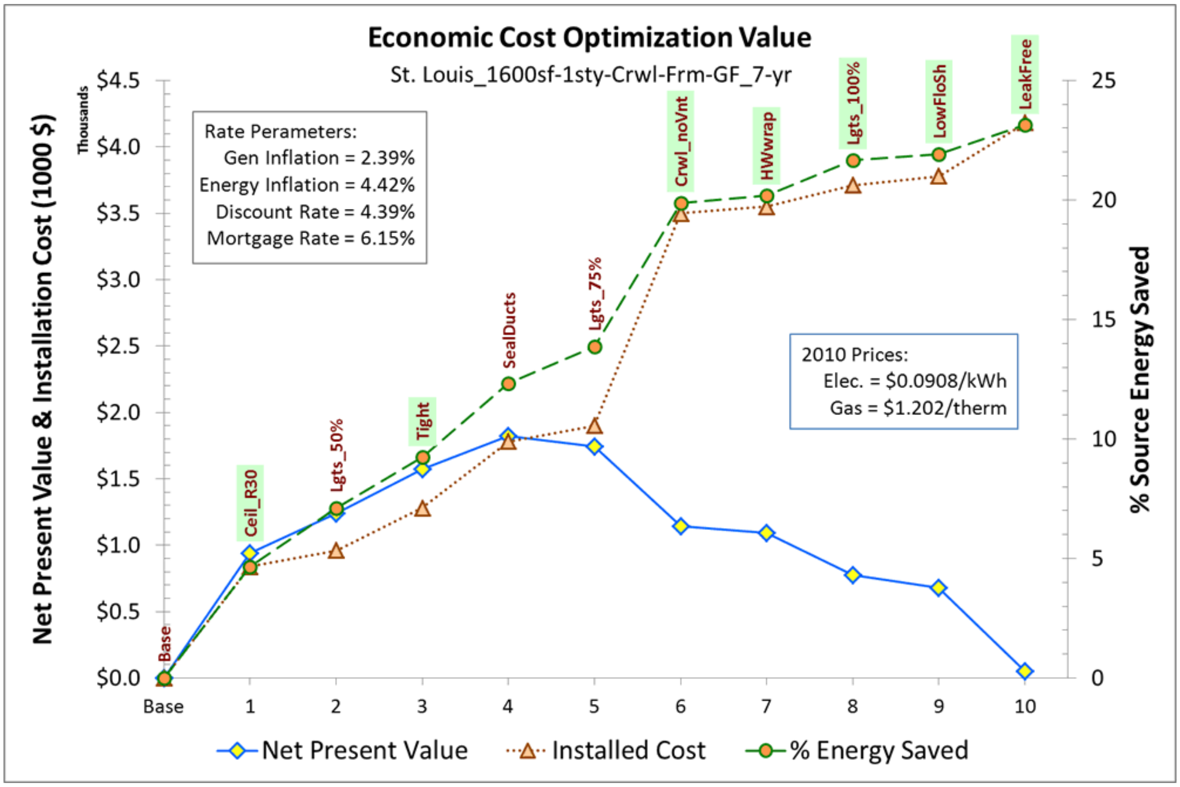

Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-GF_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$5.0
$4.5
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
30
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Base
Lgts_50%
Ceil_R19
Tight
Lgts_75%
Ceil_R30
Lgts_100%
PipeIns
HWwrap
SealDucts
Ceil_R38
Misc/HEM
Base
1
2
3
4
5
6
7
8
9
10
11
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-HP_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$5.0
$4.5
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
Base
Lgts_50%
Ceil_R19
Lgts_75%
Tight
Lgts_100%
Ceil_R30
LowFloSh
HWwrap
SealDucts
Misc/HEM
Ceil_R38
TGWH
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
San Francisco_1600sf-1sty-Crwl-Frm-GF_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$2.00
$1.80
$1.60
$1.40
$1.20
$1.00
$0.80
$0.60
$0.40
$0.20
$0.00
% Source Energy Saved
14
12
10
8
6
4
2
0
Base
1
2
3
4
5
6
Base
Lgts_50%
Lgts_75%
Lgts_100%
PipeIns
HWwrap
Misc/HEM
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-GF_7-yr
Thousands
Net Present Value & Installation Cost (1000 $)
$5.0
$4.5
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
25
20
15
10
5
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Base
SealDucts
PipeIns
Ceil_R30
Tight
HWwrap
LeakFree
CrwlFl_R19
Lgts_50%
LowFloSh
Base
1
2
3
4
5
6
7
8
9
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-HP_7-yr
Thousands
Net Present Value & Installation Cost (1000 $)
$0.80
$0.70
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
% Source Energy Saved
8
7
6
5
4
3
2
1
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Base
Lgts_50%
SealDucts
LowFloSh
HWwrap
Base
1
2
3
4
Net Present Value
Installed Cost
% Energy Saved

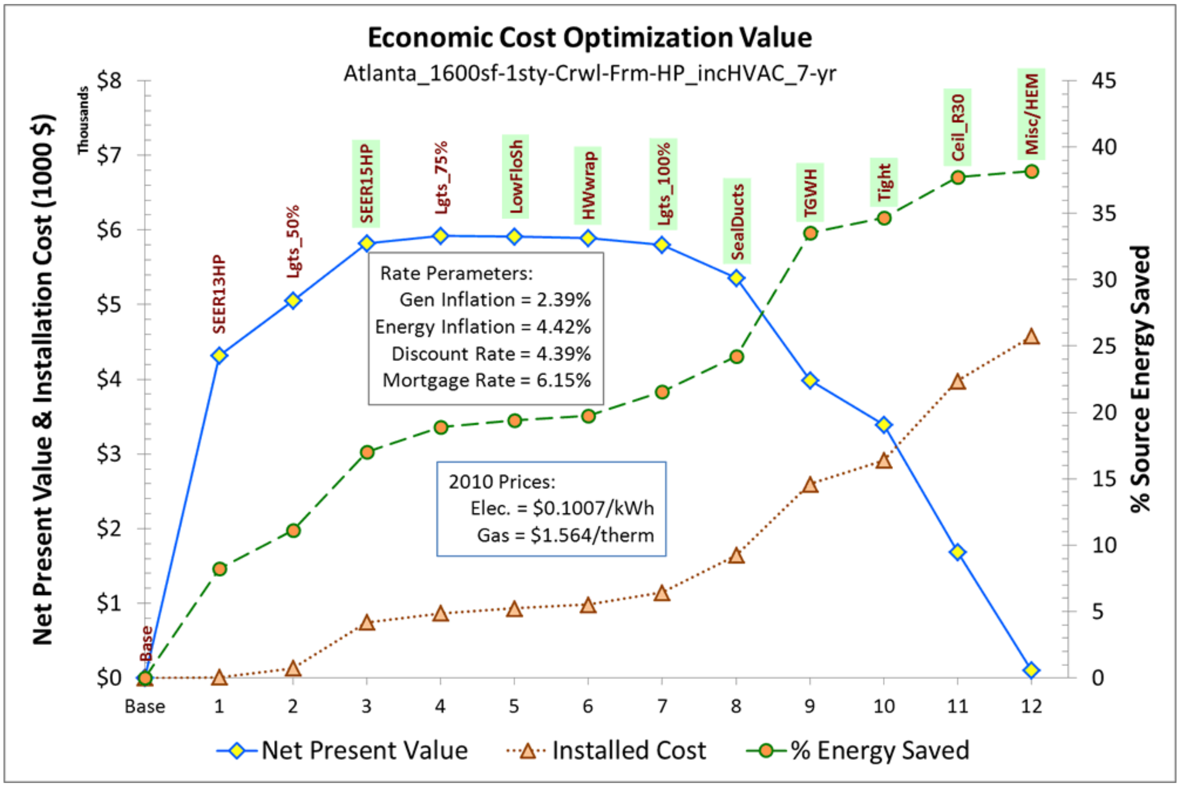

Economic Cost Optimization Value
St. Louis_1600sf-1sty-Crwl-Frm-GF_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$4.5
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
Base
Ceil_R30
Lgts_50%
Tight
SealDucts
Lgts_75%
Crwl_noVnt
HWwrap
Lgts_100%
LowFloSh
LeakFree
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0908/kWh
Gas = $1.202/therm
Net Present Value
Installed Cost
% Energy Saved

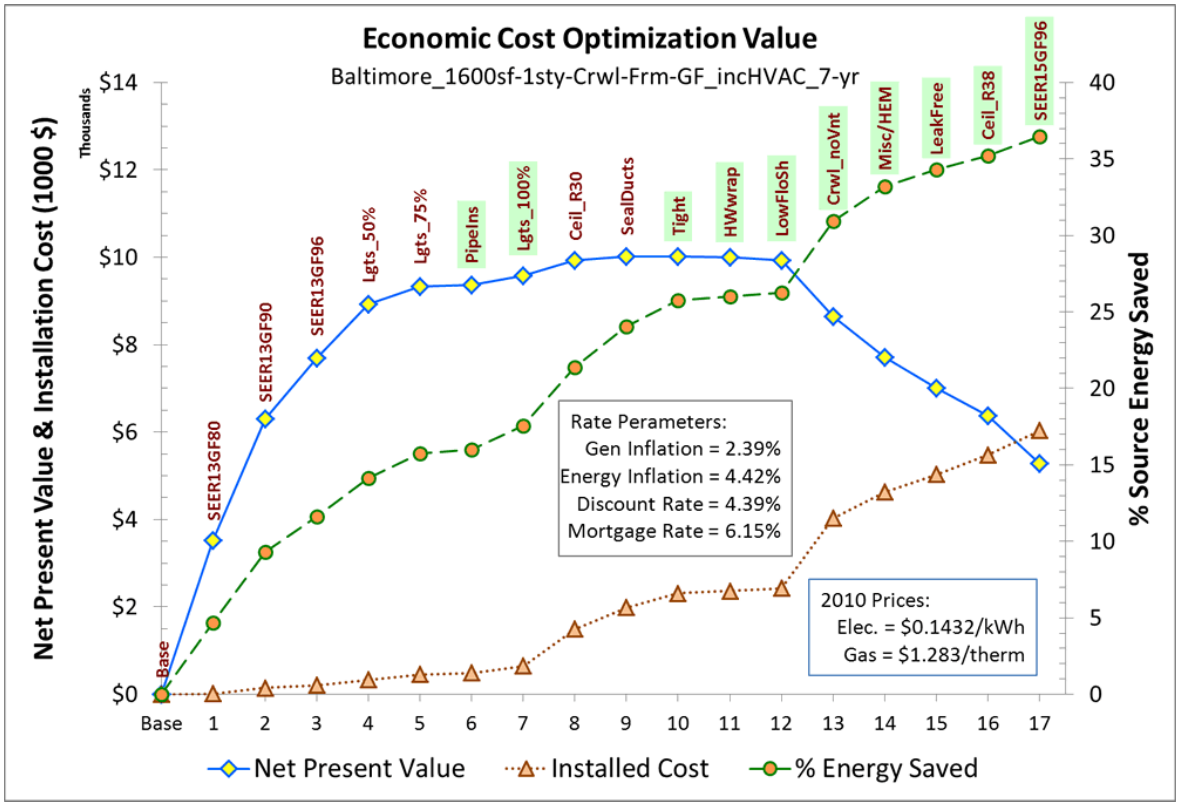
Appendix E. Optimization Scenario 3—HVAC Contractor Financing Business Model

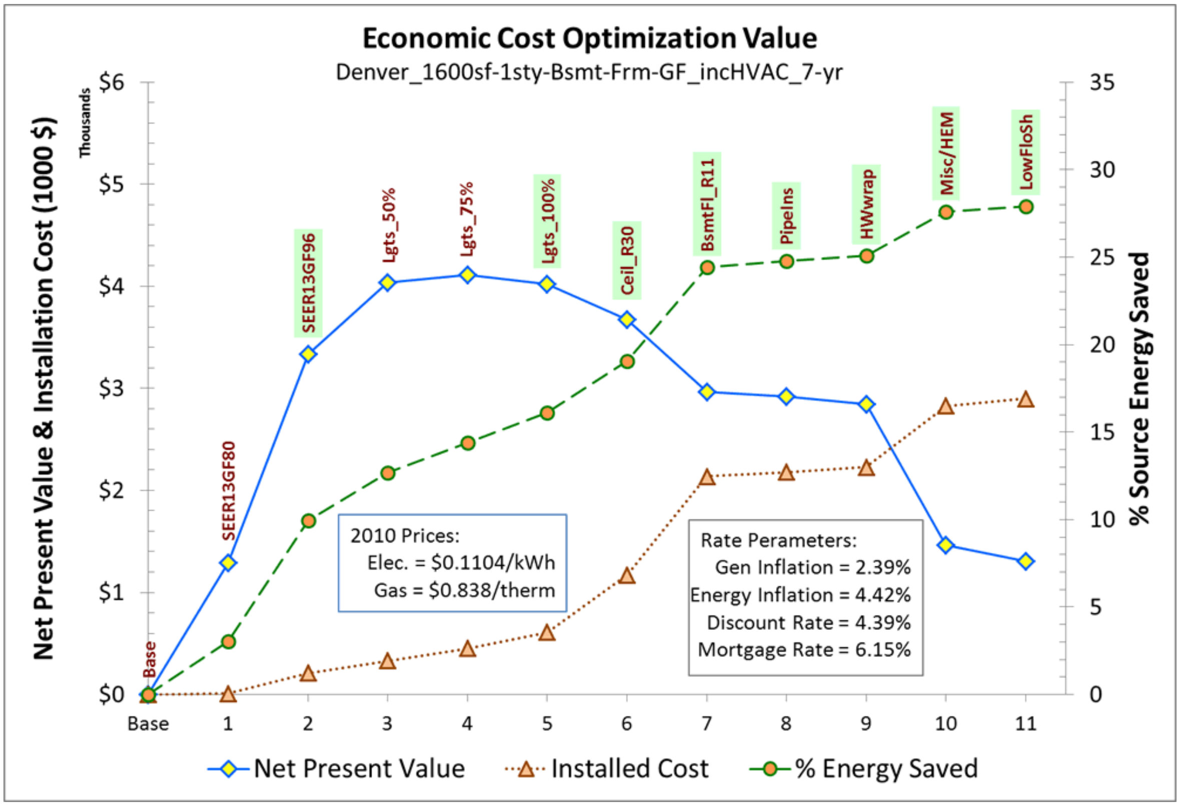
The figures shown on the following pages are in a standard CostOpt format that plots the cumulative investment costs and the cumulative NPV of the investments on the left-hand vertical axis and the cumulative source energy savings percentage on the right-hand axis. Thus, if an individual improvement measure has an SIR greater than unity, cumulative NPV will increase. However, if an individual measure has an SIR less than unity, cumulative NPV will decrease. Therefore, the point at which the NPV is largest is the optimum cost effectiveness from the consumer's perspective. However, often measures come in at the end of the optimization that have an individual measure SIR less than unity but that do not cause the cumulative NPV to drop below zero. These measures are also cost effective from a societal perspective in that they are "paid for" by the earlier highly cost-effective measures. Thus, the neutral cost point from the CostOpt perspective is the line where the cumulative NPV equals zero. Because the optimization method is incremental, a number of measures are selected and then later replaced by higher efficiency measures in the same category. Thus, for ease of understanding, the final selections in each category are highlighted in light green on the plots.

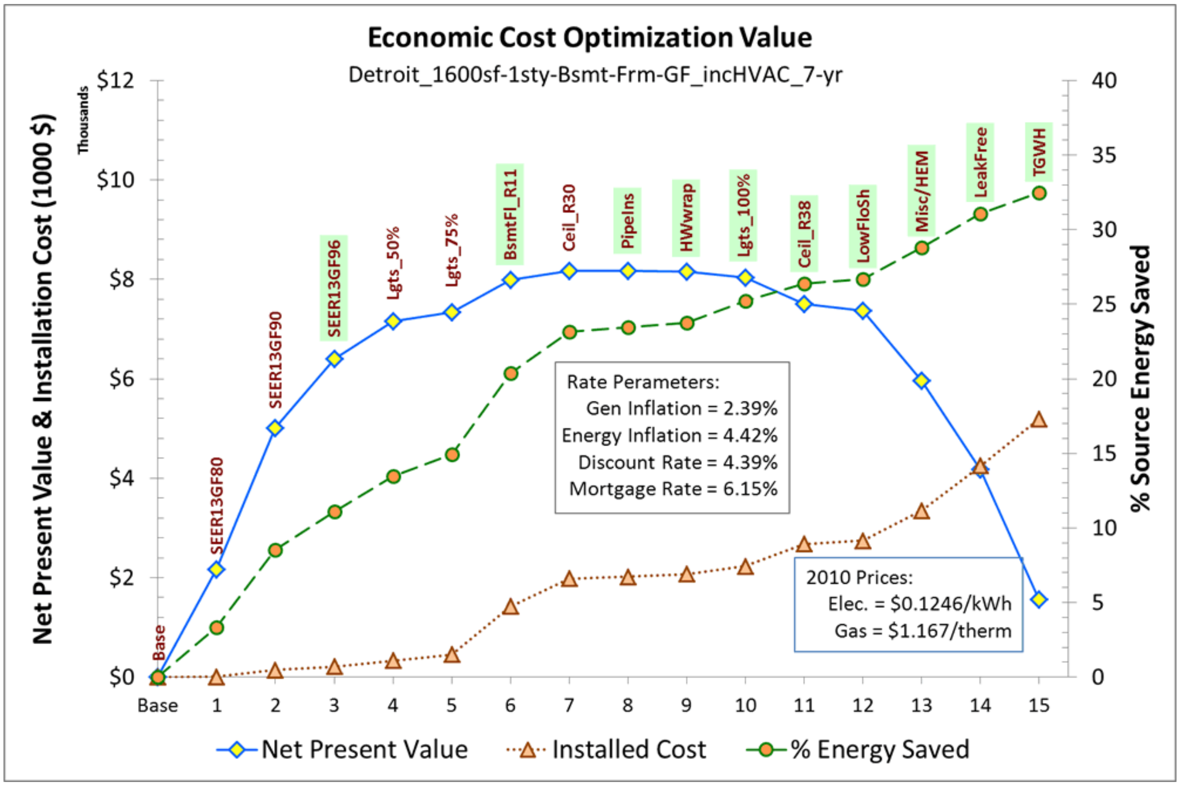
Key to acronyms:

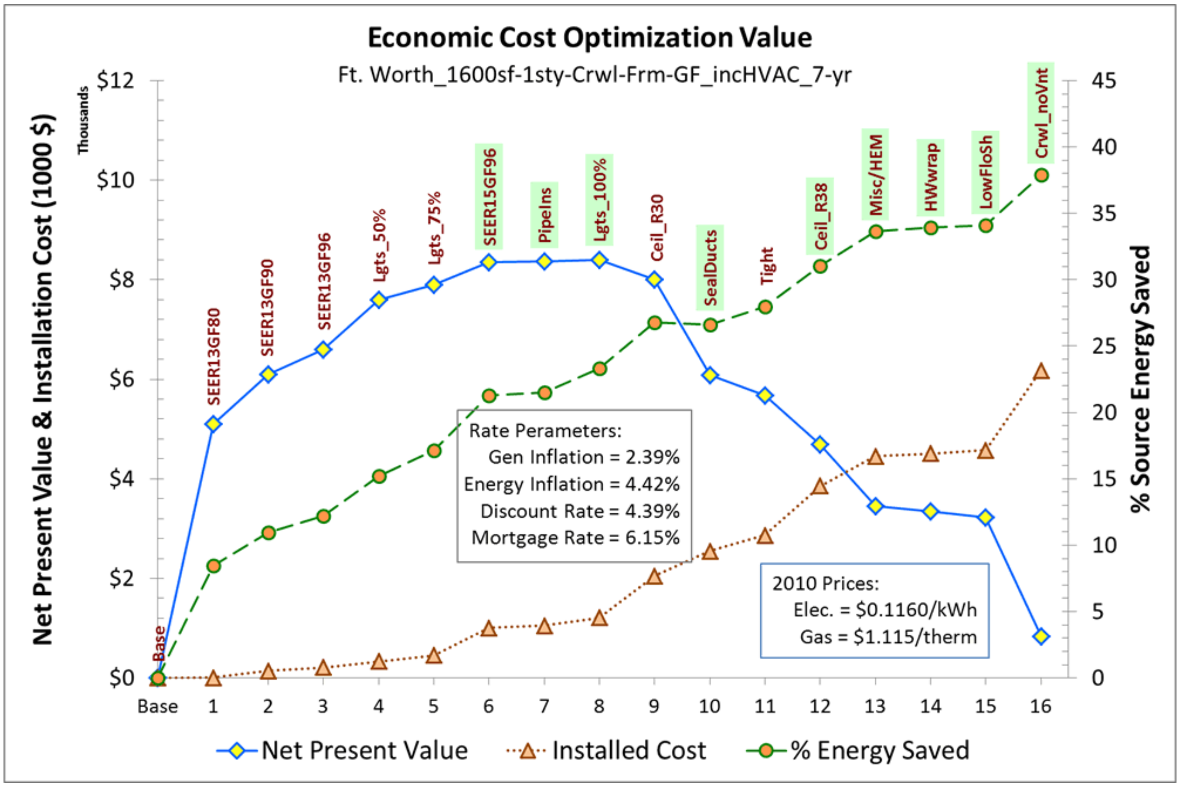
1600sf:	Archetype home size in square feet
1sty:	One-story above grade home
SOG:	Slab-on-grade foundation
Crwl:	Crawlspace foundation
Bsmt:	Unconditioned basement foundation
HP:	Electric space and water heating in base archetype
GF:	Natural gas space and water heating in base archetype
7-yr:	Seven year mortgage period (used in Scenarios 2 and 3)
incHVAC:	Incremental costs used for HVAC systems (used in Scenario 3)
ReFi:	Refinance scenario using 4% mortgage interest (used in Scenario 4)

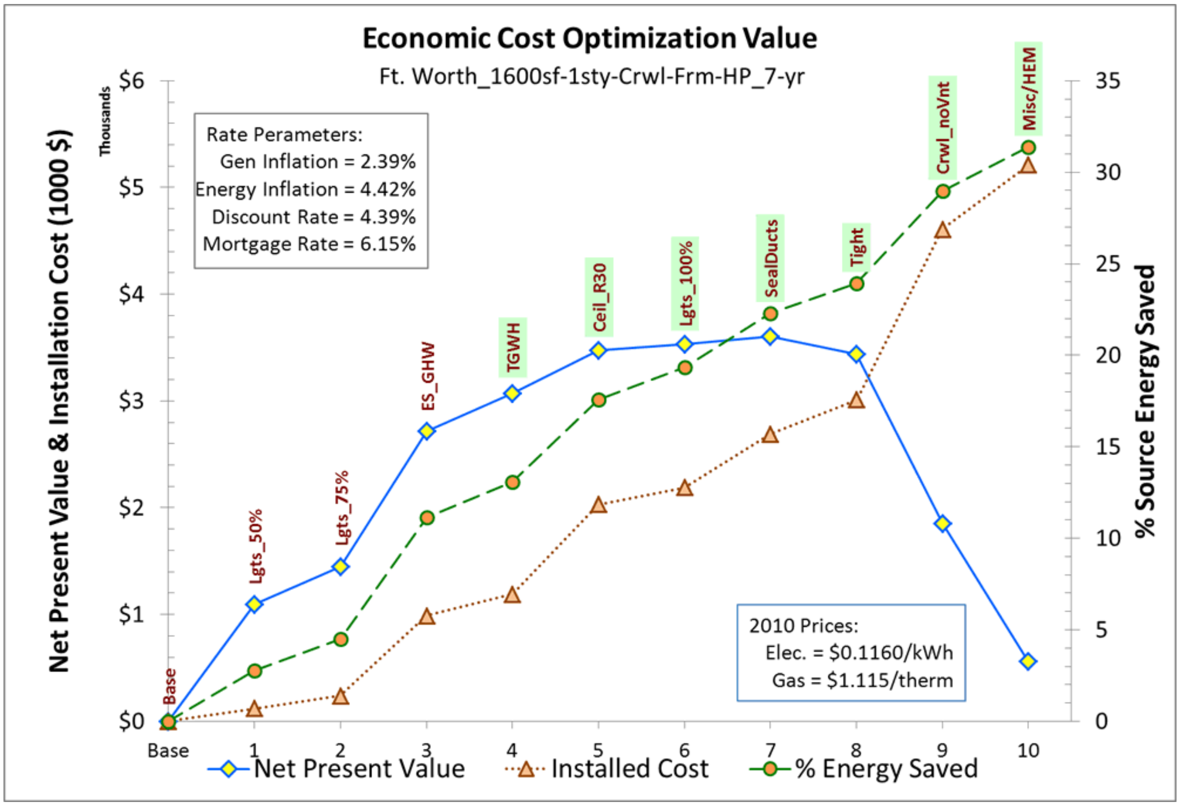

Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-HP_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$8
$7
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
Base
SEER13HP
Lgts_50%
SEER15HP
Lgts_75%
LowFloSh
HWwrap
Lgts_100%
SealDucts
TGWH
Tight
Ceil_R30
Misc/HEM
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1007/kWh
Gas = $1.564/therm
Net Present Value
Installed Cost
% Energy Saved

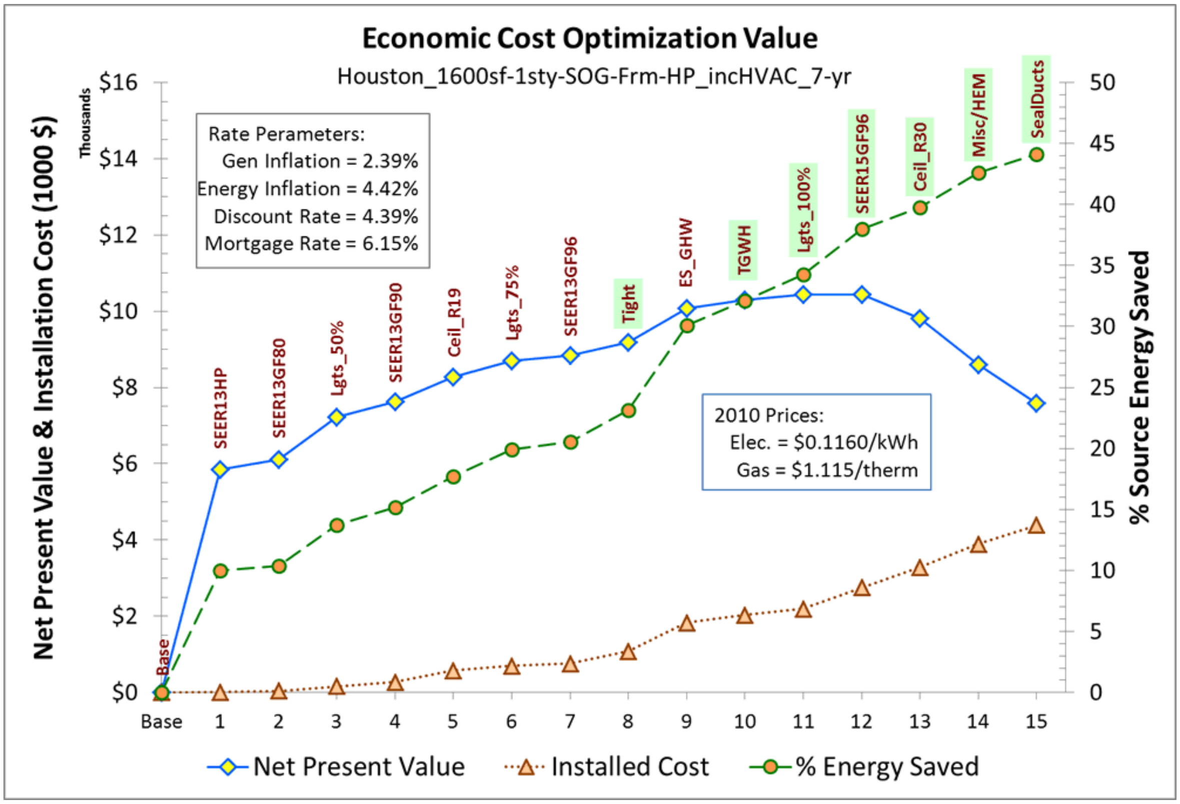

Economic Cost Optimization Value
Baltimore_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Base
SEER13GF80
SEER13GF90
SEER13GF96
Lgts_50%
Lgts_75%
PipeIns
Lgts_100%
Ceil_R30
SealDucts
Tight
HWwrap
LowFloSh
Crwl_noVnt
Misc/HEM
LeakFree
Ceil_R38
SEER15GF96
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1432/kWh
Gas = $1.283/therm
Net Present Value
Installed Cost
% Energy Saved

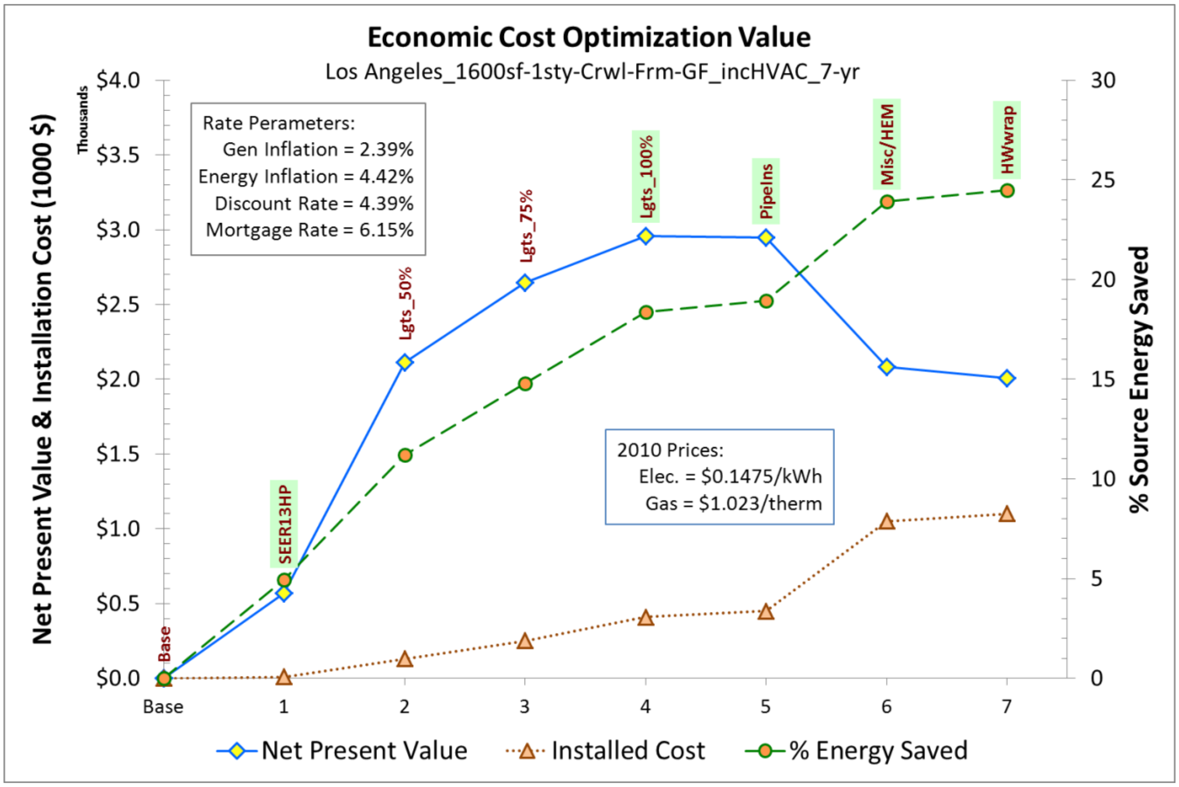

Economic Cost Optimization Value
Denver_1600sf-1sty-Bsmt-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
Base
SEER13GF80
SEER13GF96
Lgts_50%
Lgts_75%
Lgts_100%
Ceil_R30
BsmtFl_R11
PipeIns
HWwrap
Misc/HEM
LowFloSh
2010 Prices:
Elec. = $0.1104/kWh
Gas = $0.838/therm
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
Net Present Value
Installed Cost
% Energy Saved

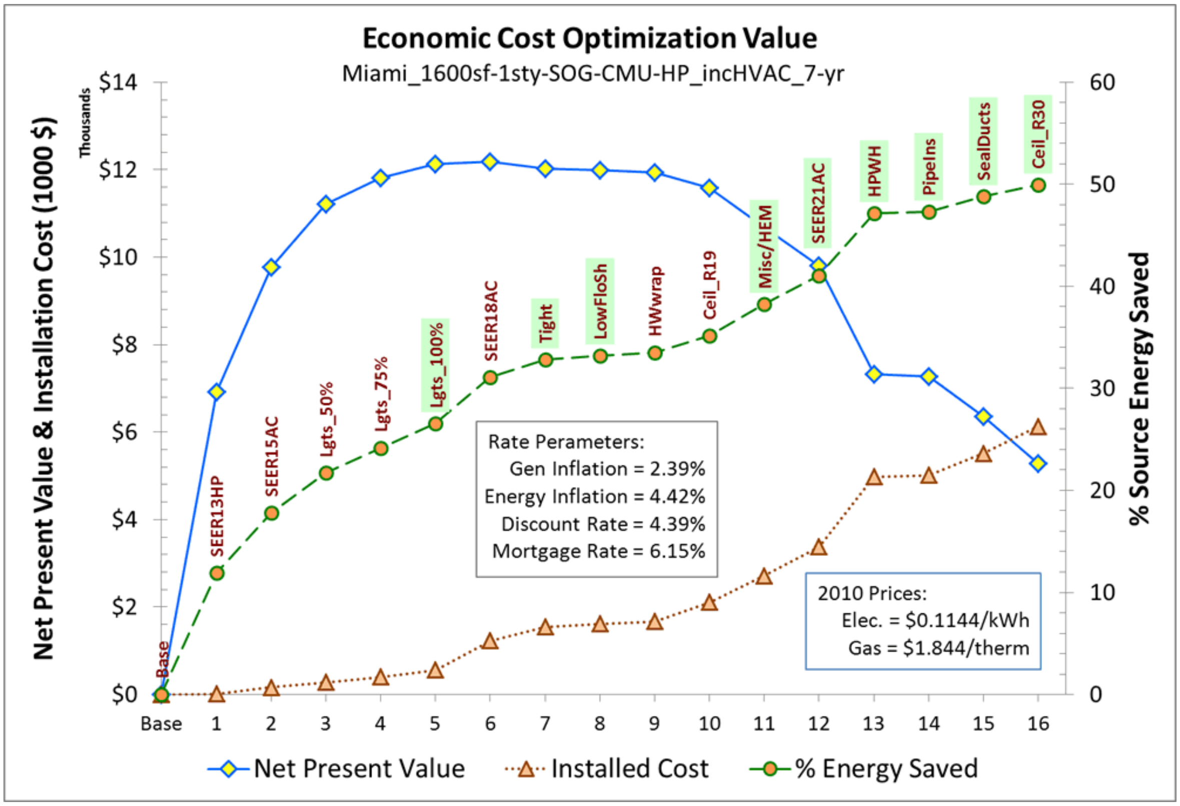

Economic Cost Optimization Value
Detroit_1600sf-1sty-Bsmt-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Base
SEER13GF80
SEER13GF90
SEER13GF96
Lgts_50%
Lgts_75%
BsmtFl_R11
Ceil_R30
PipeIns
HWwrap
Lgts_100%
Ceil_R38
LowFloSh
Misc/HEM
LeakFree
TGWH
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1246/kWh
Gas = $1.167/therm
Net Present Value
Installed Cost
% Energy Saved

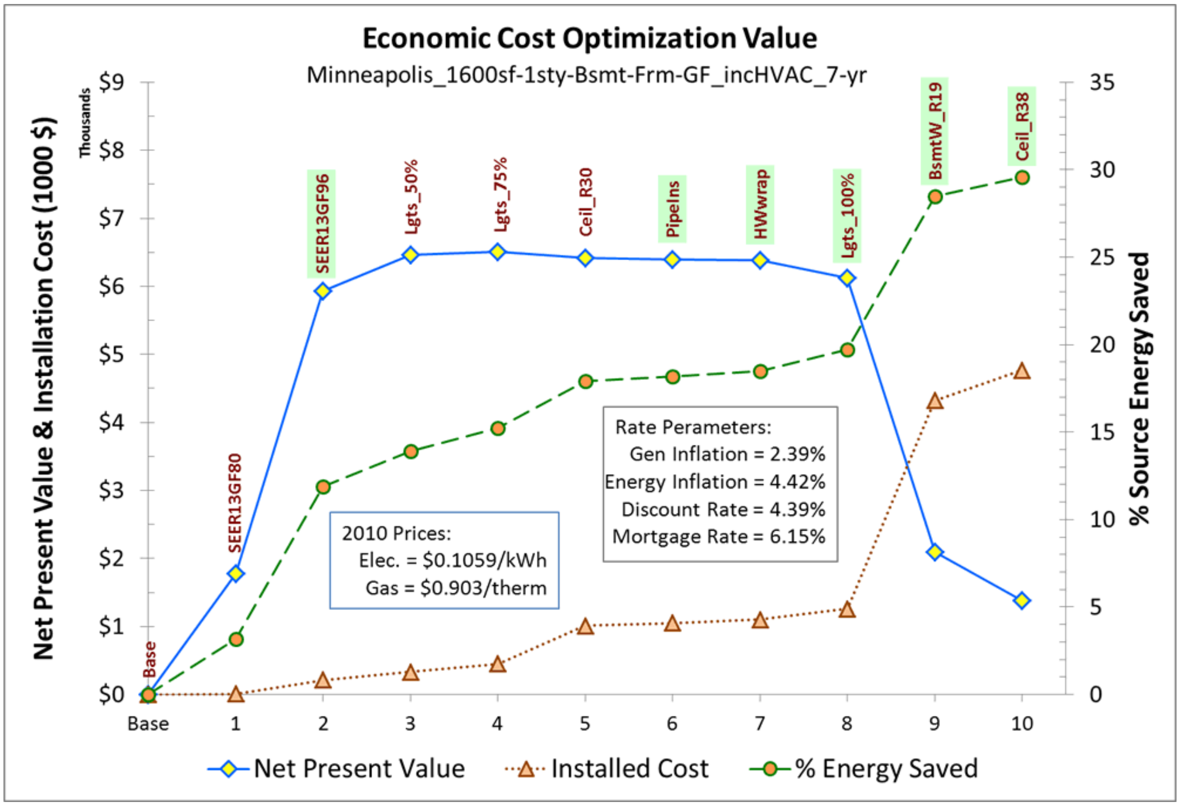

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Base
SEER13GF80
SEER13GF90
SEER13GF96
Lgts_50%
Lgts_75%
SEER15GF96
PipeIns
Lgts_100%
Ceil_R30
SealDucts
Tight
Ceil_R38
Misc/HEM
HWwrap
LowFloSh
Crwl_noVnt
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value
Installed Cost
% Energy Saved

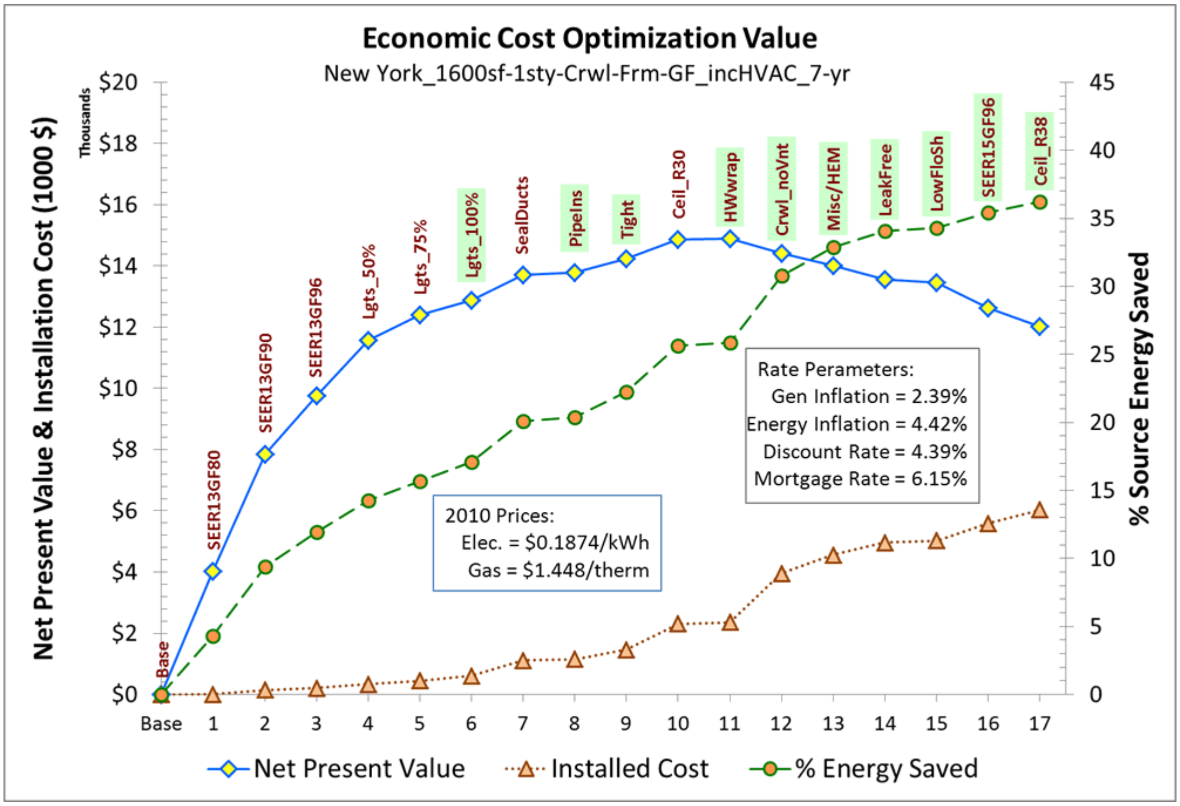

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-HP_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
Base
Lgts_50%
Lgts_75%
ES_GHW
TGWH
Ceil_R30
Lgts_100%
SealDucts
Tight
Crwl_noVnt
Misc/HEM
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value
Installed Cost
% Energy Saved

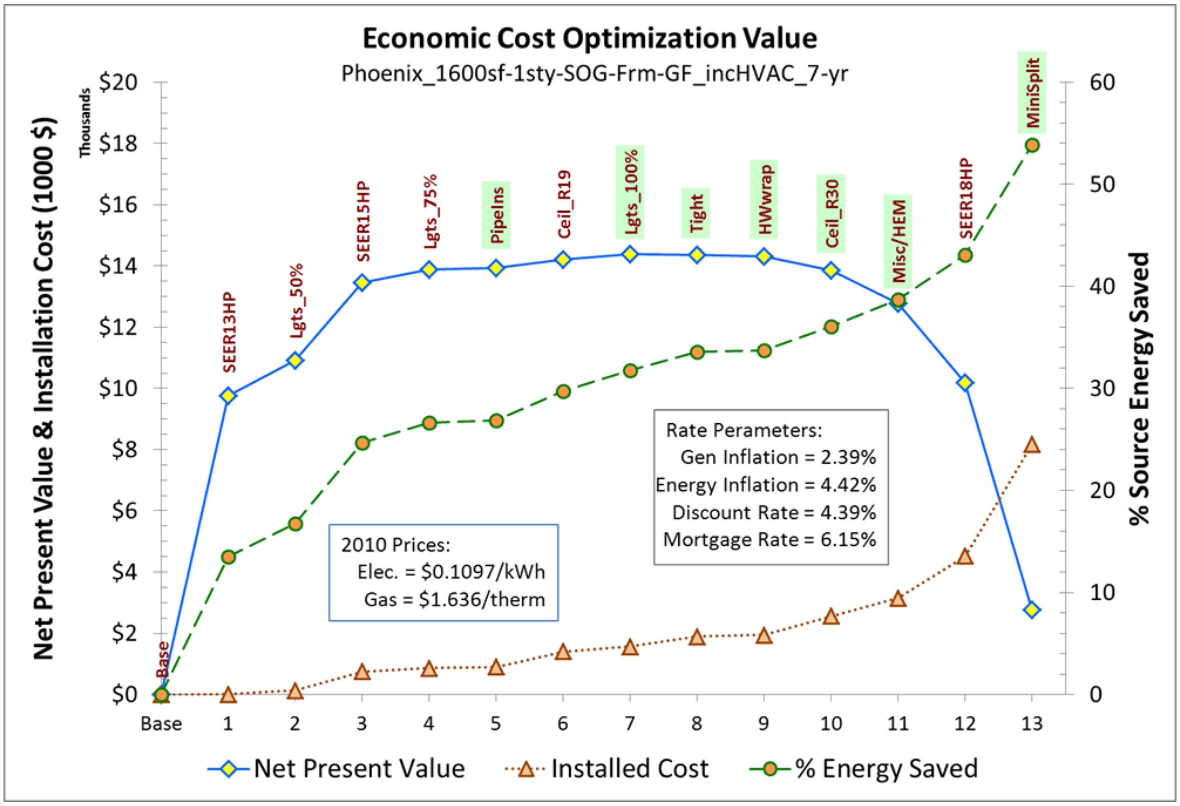

Economic Cost Optimization Value
Houston_1600sf-1sty-SOG-Frm-HP_incHVAC_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$16
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
50
45
40
35
30
25
20
15
10
5
0
Base
SEER13HP
SEER13GF80
Lgts_50%
SEER13GF90
Ceil_R19
Lgts_75%
SEER13GF96
Tight
ES_GHW
TGWH
Lgts_100%
SEER15GF96
Ceil_R30
Misc/HEM
SealDucts
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Net Present Value
Installed Cost
% Energy Saved

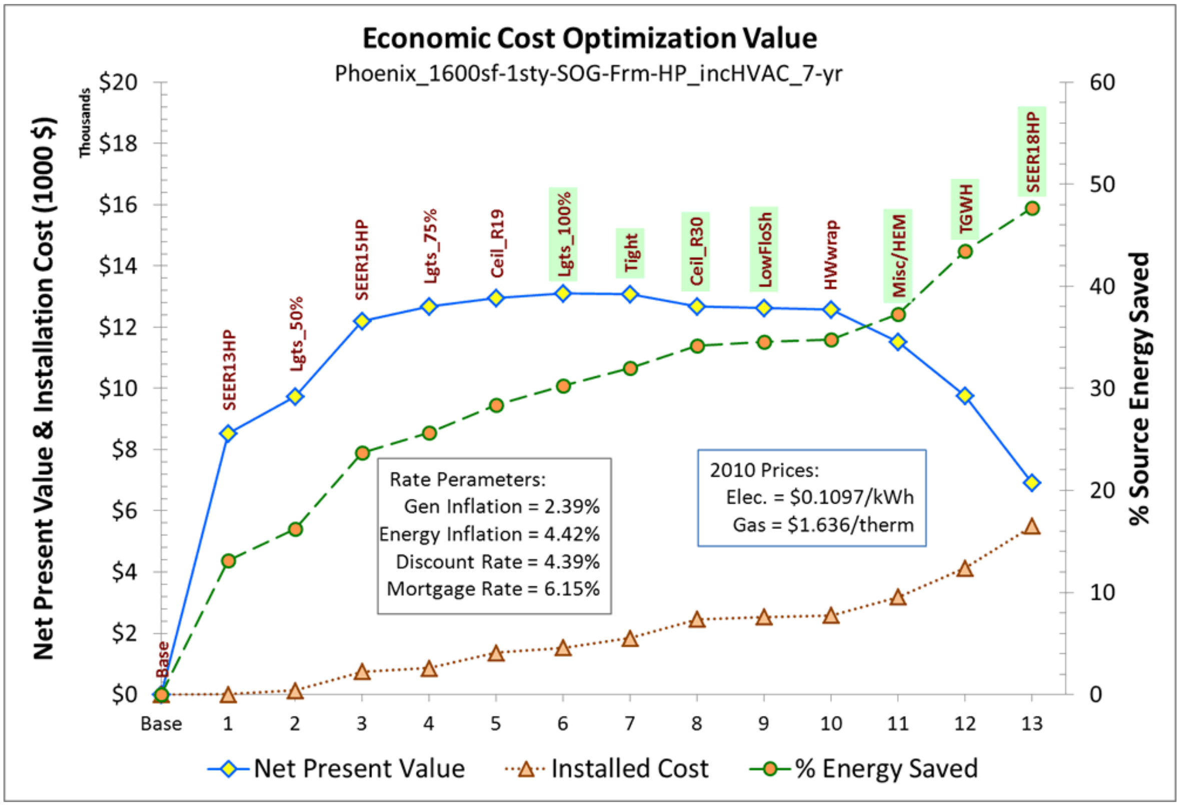

Economic Cost Optimization Value
Los Angeles_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$4.0
$3.5
$3.0
$2.5
$2.0
$1.5
$1.0
$0.5
$0.0
% Source Energy Saved
30
25
20
15
10
5
0
Base
SEER13HP
Lgts_50%
Lgts_75%
Lgts_100%
PipeIns
Misc/HEM
HWwrap
Base
1
2
3
4
5
6
7
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Miami_1600sf-1sty-SOG-CMU-HP_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Base
SEER13HP
SEER15AC
Lgts_50%
Lgts_75%
Lgts_100%
SEER18AC
Tight
LowFloSh
HWwrap
Ceil_R19
Misc/HEM
SEER21AC
HPWH
PipeIns
SealDucts
Ceil_R30
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1144/kWh
Gas = $1.844/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Minneapolis_1600sf-1sty-Bsmt-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$9
$8
$7
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
Base
SEER13GF80
SEER13GF96
Lgts_50%
Lgts_75%
Ceil_R30
PipeIns
HWwrap
Lgts_100%
BsmtW_R19
Ceil_R38
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1059/kWh
Gas = $0.903/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
New York_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$20
$18
$16
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Base
SEER13GF80
SEER13GF90
SEER13GF96
Lgts_50%
Lgts_75%
Lgts_100%
SealDucts
PipeIns
Tight
Ceil_R30
HWwrap
Crwl_noVnt
Misc/HEM
LeakFree
LowFloSh
SEER15GF96
Ceil_R38
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1874/kWh
Gas = $1.448/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$20
$18
$16
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Base
SEER13HP
Lgts_50%
SEER15HP
Lgts_75%
PipeIns
Ceil_R19
Lgts_100%
Tight
HWwrap
Ceil_R30
Misc/HEM
SEER18HP
MiniSplit
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value
Installed Cost
% Energy Saved

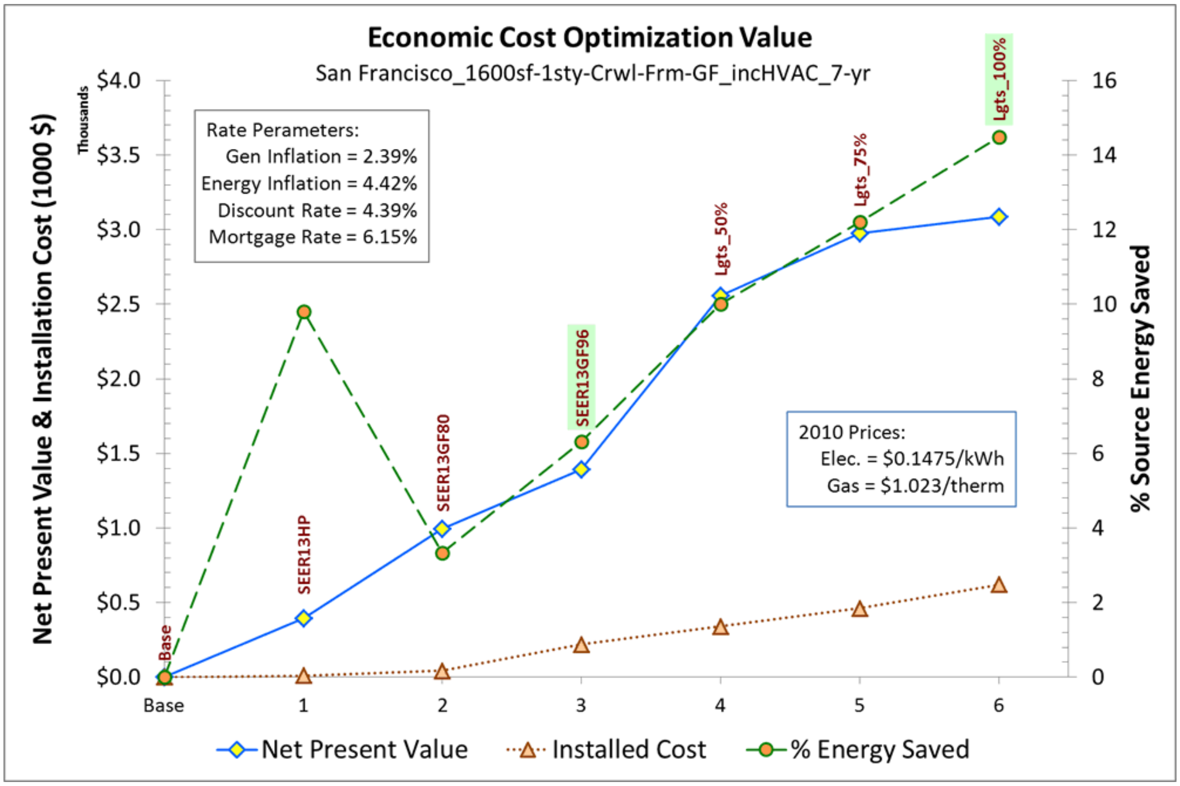


Economic Cost Optimization Value

Phoenix_1600sf-1sty-SOG-Frm-HP_incHVAC_7-yr

Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%

2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm

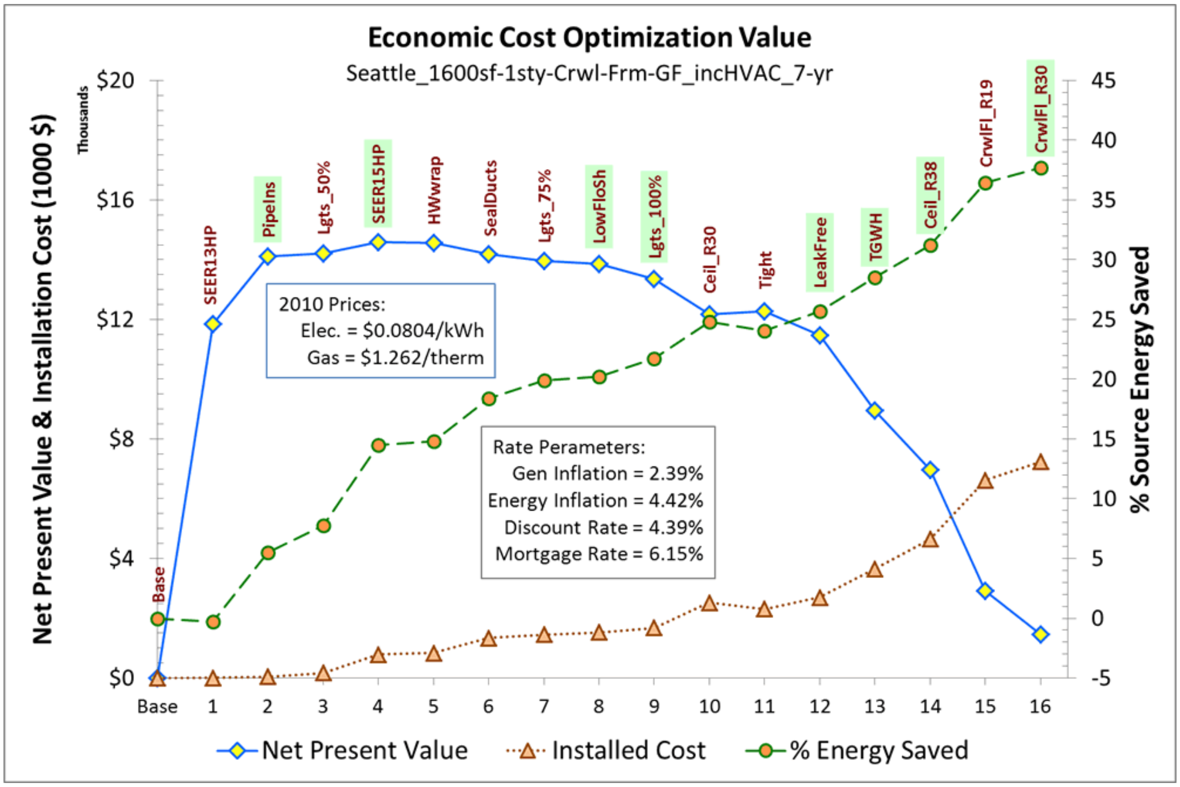


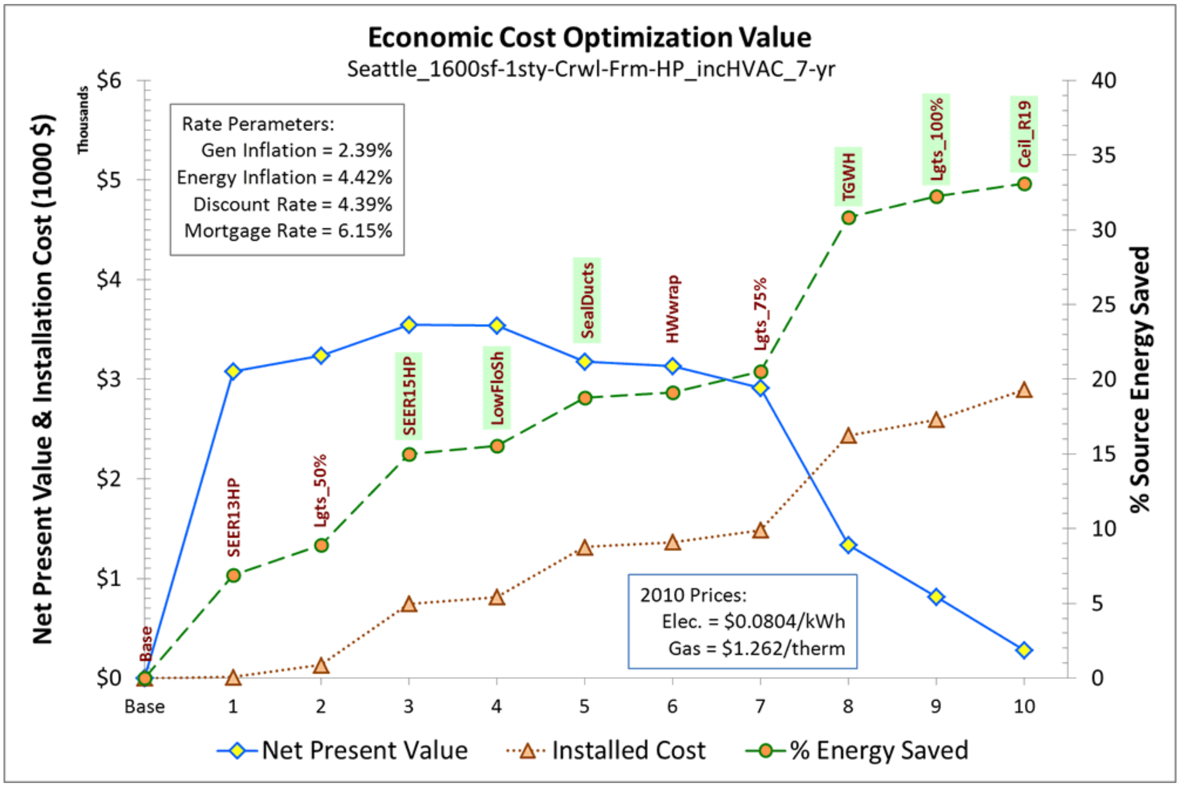
Economic Cost Optimization Value

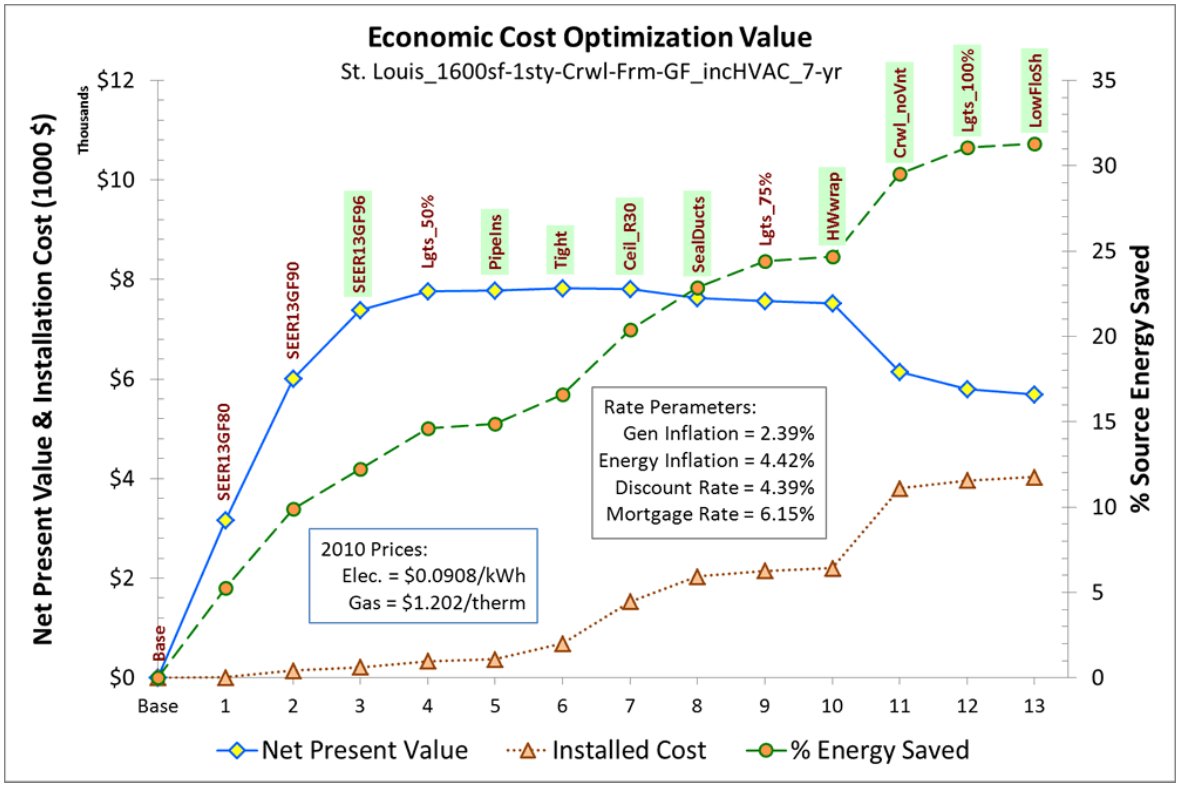
San Francisco_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr

Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%

2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$20
$16
$12
$8
$4
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
-5
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Base
SEER13HP
PipeIns
Lgts_50%
SEER15HP
HWwrap
SealDucts
Lgts_75%
LowFloSh
Lgts_100%
Ceil_R30
Tight
LeakFree
TGWH
Ceil_R38
CrwlFl_R19
CrwlFl_R30
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-HP_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
Base
SEER13HP
Lgts_50%
SEER15HP
LowFloSh
SealDucts
HWwrap
Lgts_75%
TGWH
Lgts_100%
Ceil_R19
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Net Present Value
Installed Cost
% Energy Saved

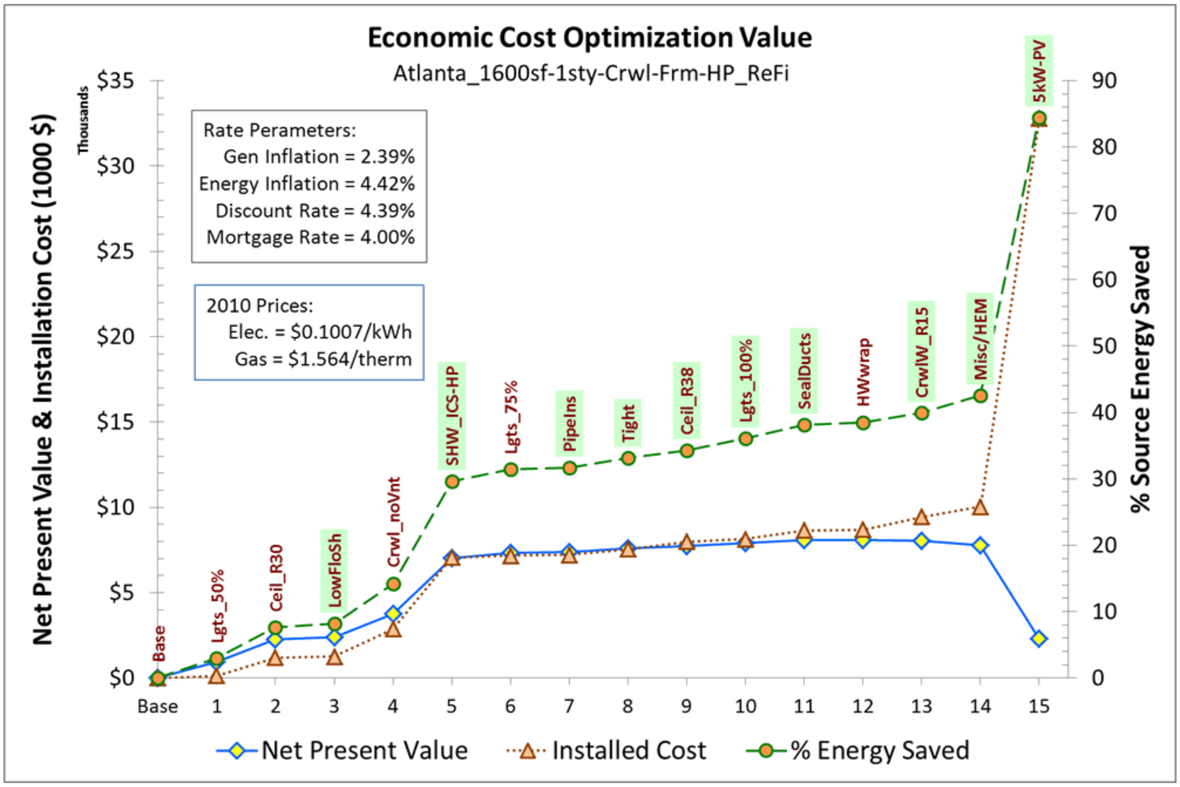

Economic Cost Optimization Value
St. Louis_1600sf-1sty-Crwl-Frm-GF_incHVAC_7-yr
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Base
SEER13GF80
SEER13GF90
SEER13GF96
Lgts_50%
PipeIns
Tight
Ceil_R30
SealDucts
Lgts_75%
HWwrap
Crwl_noVnt
Lgts_100%
LowFloSh
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0908/kWh
Gas = $1.202/therm
Net Present Value
Installed Cost
% Energy Saved

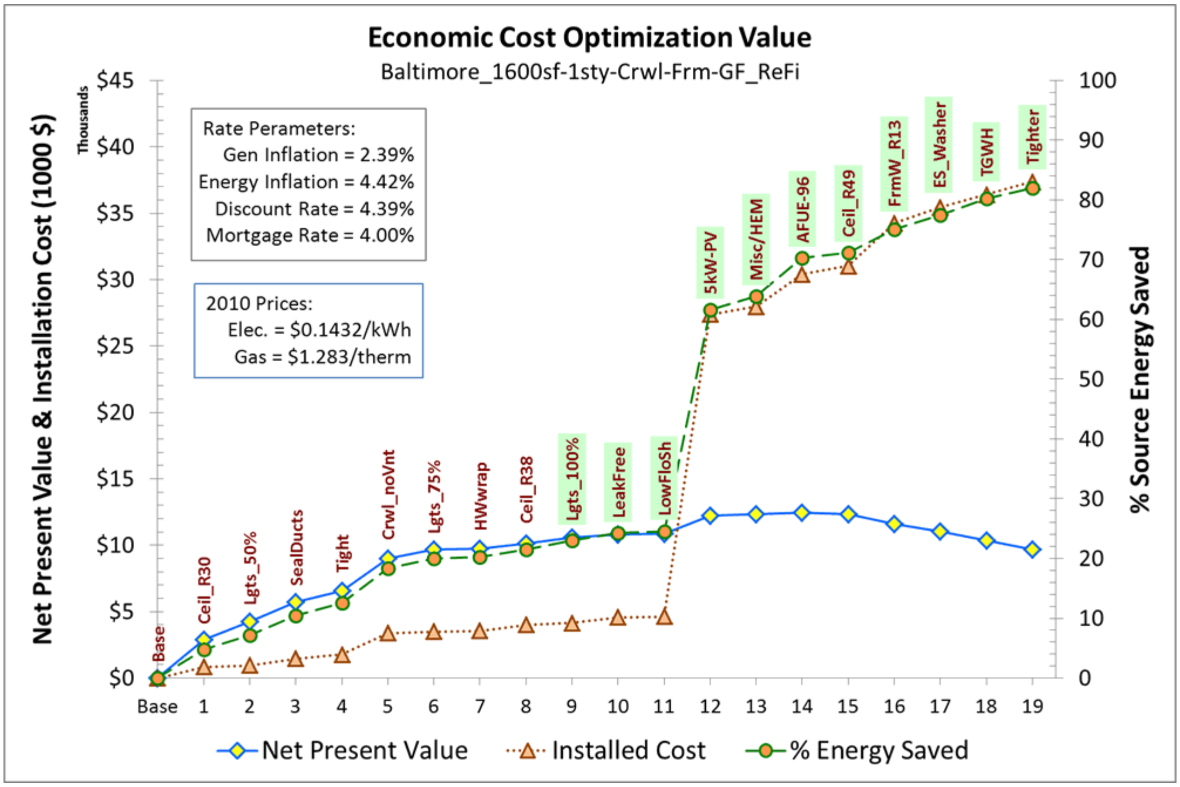
Appendix F. Optimization Scenario 4—Home Remodel/Refinance

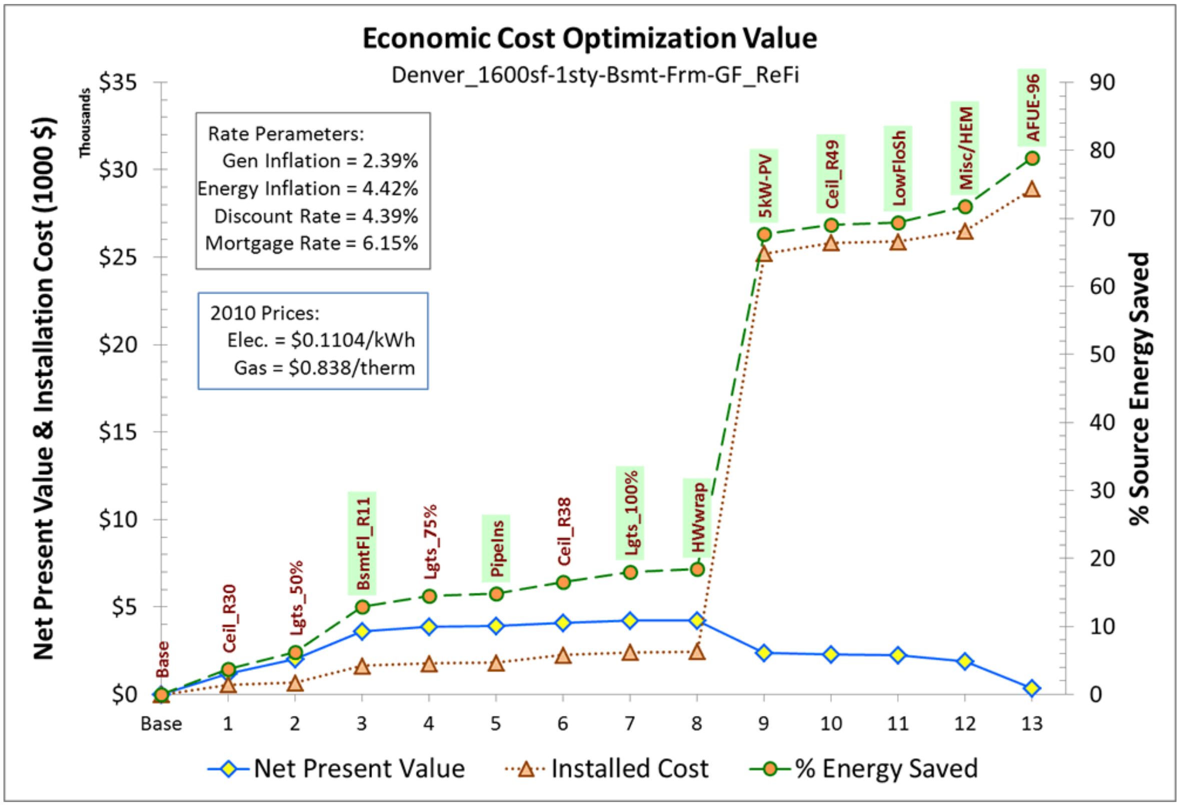
The figures shown on the following pages are in a standard *CostOpt* format that plots the cumulative investment costs and the cumulative Net Present Value (NPV) of the investments on the left-hand vertical axis and the cumulative source energy savings percentage on the right-hand axis. Thus, if an individual improvement measure has a Saving-to-Investment Ratio (SIR) greater than unity, cumulative NPV will increase. However, if an individual measure has an SIR less than unity, cumulative NPV will decrease. Therefore, the point at which the NPV is largest is the optimum cost effectiveness from the consumer's perspective. However, often there are measures that come in at the end of the optimization which have an individual measure SIR less than unity but which do not cause the cumulative NPV to drop below zero. These measures are also cost effective from a societal perspective in that they are "paid for" by the earlier highly cost effective measures. Thus, the neutral cost point from the *CostOpt* perspective is the line where the cumulative NPV equals zero. Since the optimization method is incremental there also are a number of measures that are selected and then later replaced by measures in the same category with greater levels of efficiency. Thus, for ease of understanding, the final selections in each category are highlighted in light green on the plots.

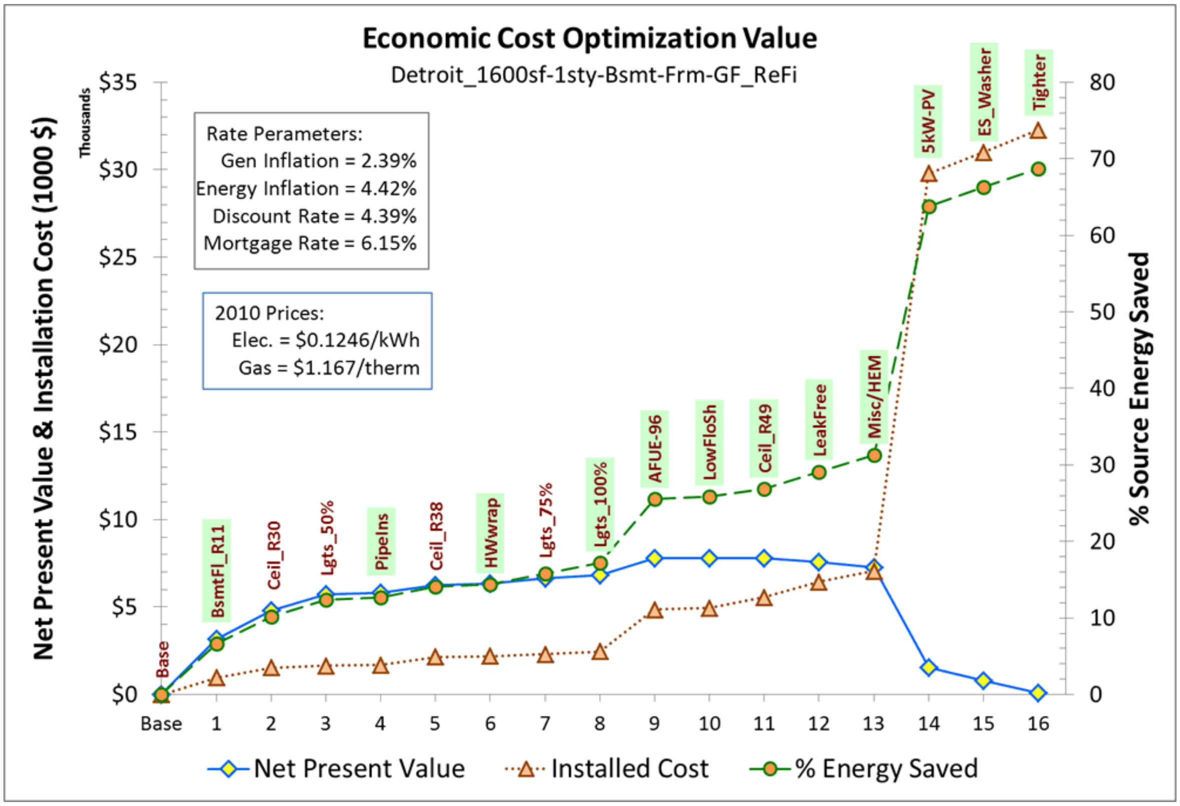
Key to acronyms:

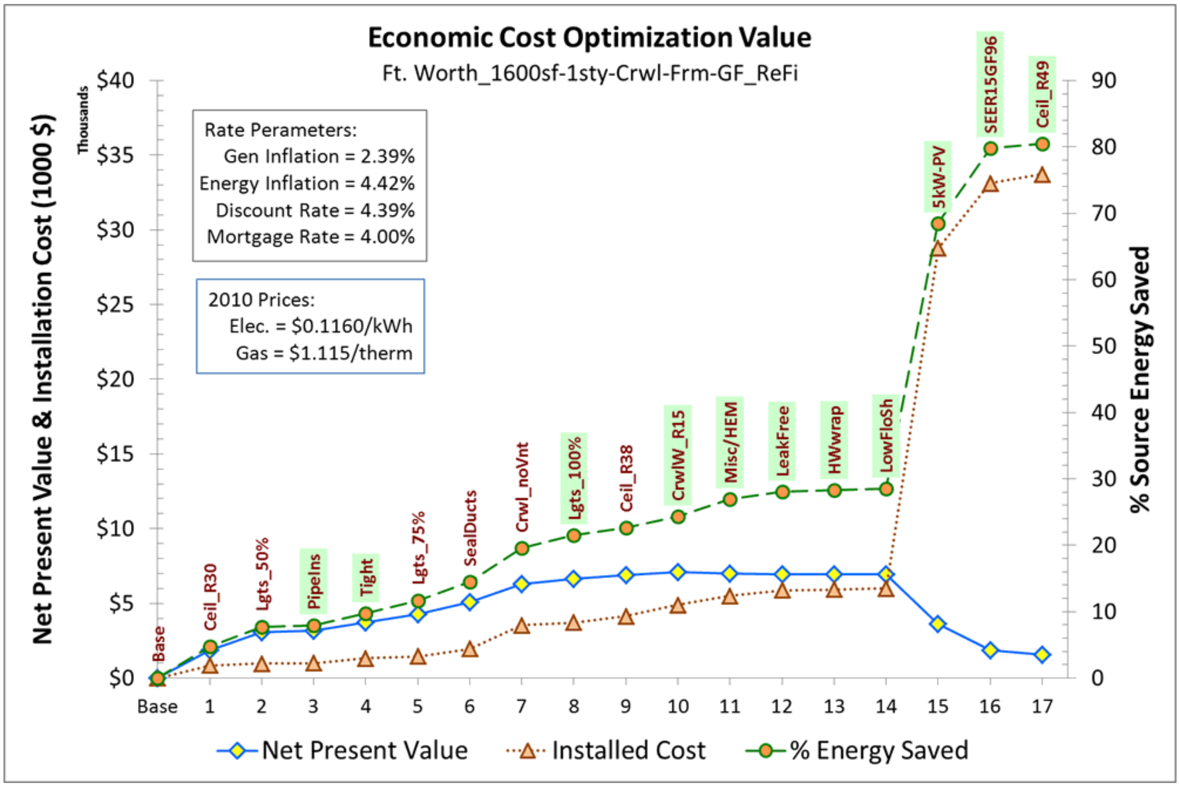
1600sf: Archetype home size in square feet
1sty: One-story above grade home
SOG: Slab-on-grade foundation
Crwl: Crawlspace foundation
Bsmt: Unconditioned basement foundation
HP: Electric space and water heating in base archetype
GF: Natural gas space and water heating in base archetype
7-yr: Seven year mortgage period (used in Scenarios 2 and 3)
incHVAC: Incremental costs used for HVAC systems (used in Scenario 3)
ReFi: Refinance scenario using 4% mortgage interest (used in Scenario 4)

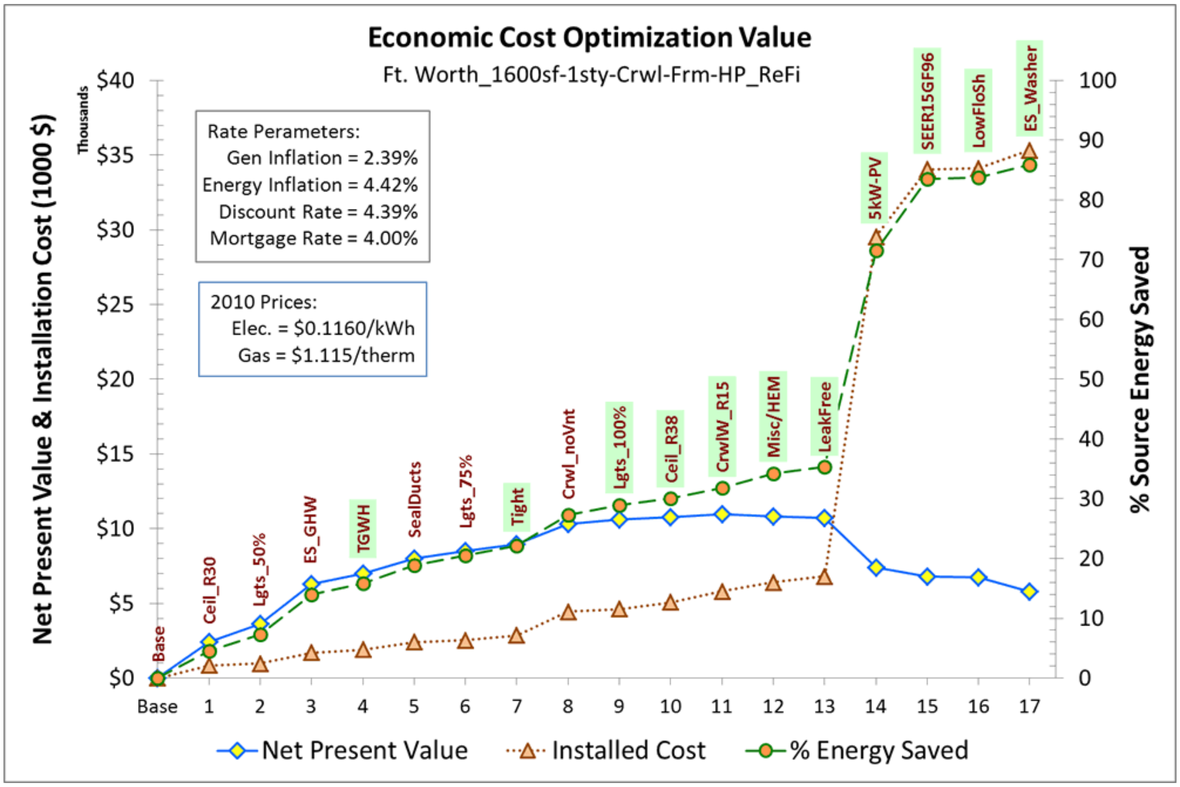

Economic Cost Optimization Value
Atlanta_1600sf-1sty-Crwl-Frm-HP_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1007/kWh
Gas = $1.564/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
90
80
70
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Base
Lgts_50%
Ceil_R30
LowFloSh
Crwl_noVnt
SHW_ICS-HP
Lgts_75%
PipeIns
Tight
Ceil_R38
Lgts_100%
SealDucts
HWwrap
CrwlW_R15
Misc/HEM
5kW-PV
Net Present Value
Installed Cost
% Energy Saved

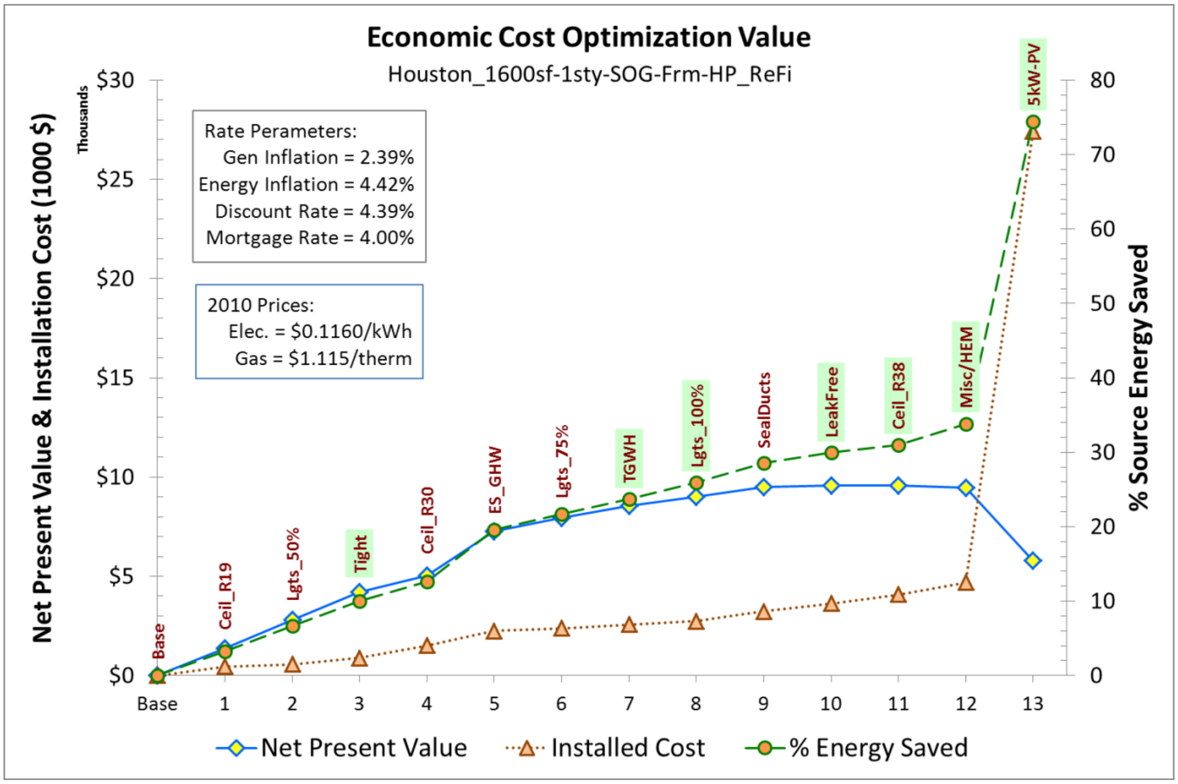

Economic Cost Optimization Value
Baltimore_1600sf-1sty-Crwl-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1432/kWh
Gas = $1.283/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Base
Ceil_R30
Lgts_50%
SealDucts
Tight
Crwl_noVnt
Lgts_75%
HWwrap
Ceil_R38
Lgts_100%
LeakFree
LowFloSh
5kW-PV
Misc/HEM
AFUE-96
Ceil_R49
FrmW_R13
ES_Washer
TGWH
Tighter
Net Present Value
Installed Cost
% Energy Saved

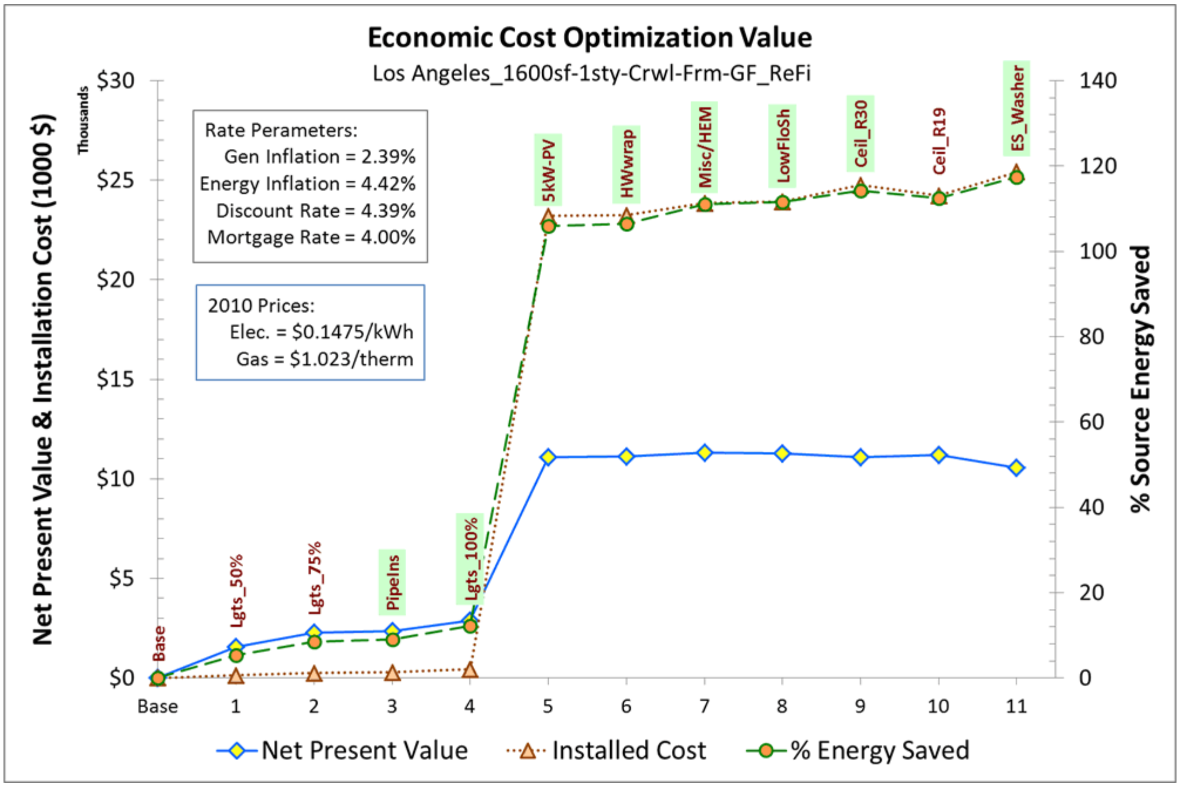

Economic Cost Optimization Value
Denver_1600sf-1sty-Bsmt-Frm-GF_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
90
80
70
60
50
40
30
20
10
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1104/kWh
Gas = $0.838/therm
Base
Ceil_R30
Lgts_50%
BsmtFl_R11
Lgts_75%
PipeIns
Ceil_R38
Lgts_100%
HWwrap
5kW-PV
Ceil_R49
LowFloSh
Misc/HEM
AFUE-96
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Net Present Value
Installed Cost
% Energy Saved

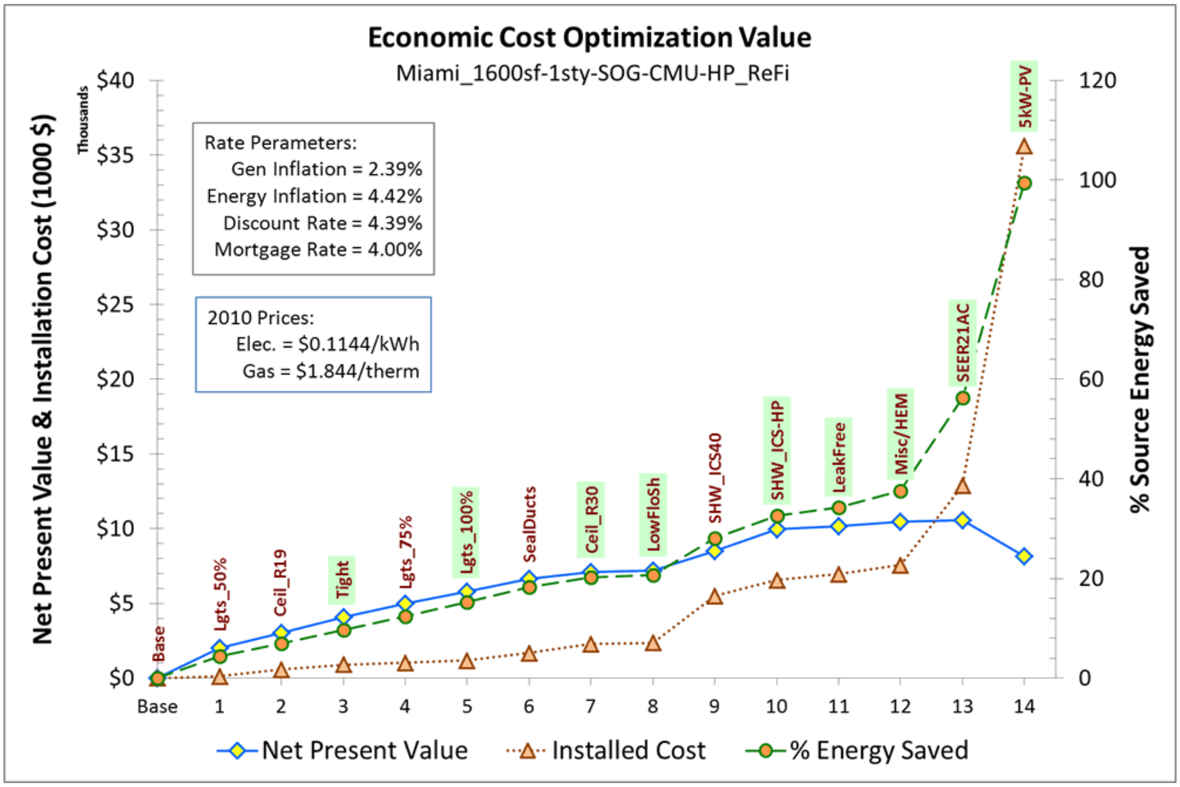

Economic Cost Optimization Value
Detroit_1600sf-1sty-Bsmt-Frm-GF_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
80
70
60
50
40
30
20
10
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.1246/kWh
Gas = $1.167/therm
Base
BsmtFl_R11
Ceil_R30
Lgts_50%
PipeIns
Ceil_R38
HWwrap
Lgts_75%
Lgts_100%
AFUE-96
LowFloSh
Ceil_R49
LeakFree
Misc/HEM
5kW-PV
ES_Washer
Tighter
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Net Present Value
Installed Cost
% Energy Saved

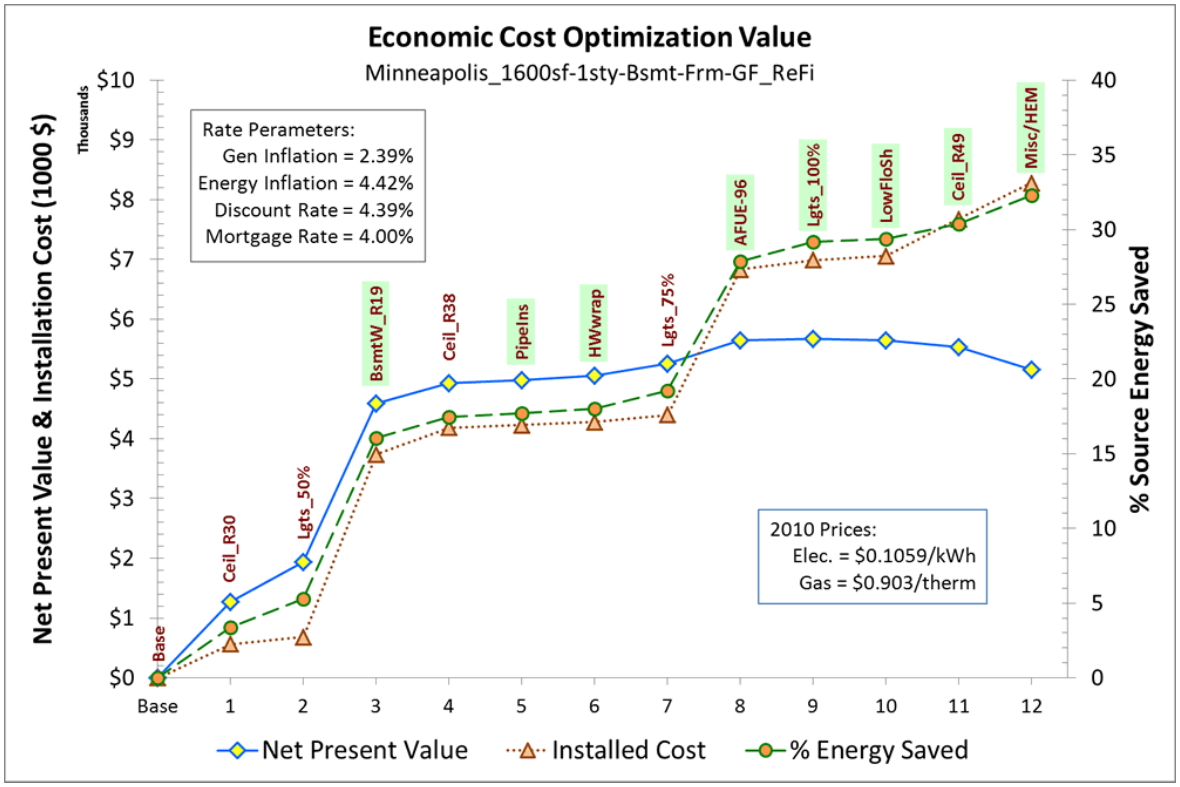

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
90
80
70
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Base
Ceil_R30
Lgts_50%
PipeIns
Tight
Lgts_75%
SealDucts
Crwl_noVnt
Lgts_100%
Ceil_R38
CrwlW_R15
Misc/HEM
LeakFree
HWwrap
LowFloSh
5kW-PV
SEER15GF96
Ceil_R49
Net Present Value
Installed Cost
% Energy Saved

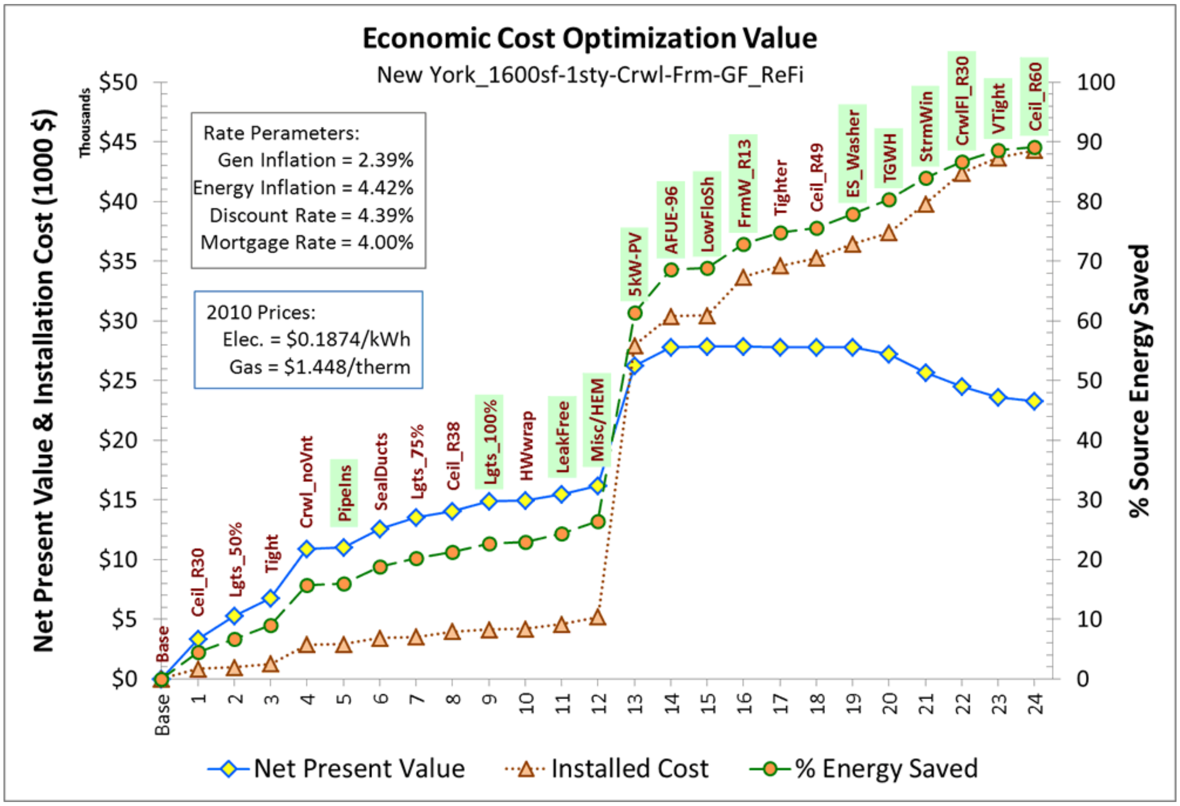

Economic Cost Optimization Value
Ft. Worth_1600sf-1sty-Crwl-Frm-HP_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Base
Ceil_R30
Lgts_50%
ES_GHW
TGWH
SealDucts
Lgts_75%
Tight
Crwl_noVnt
Lgts_100%
Ceil_R38
CrwlW_R15
Misc/HEM
LeakFree
5kW-PV
SEER15GF96
LowFloSh
ES_Washer
Net Present Value
Installed Cost
% Energy Saved

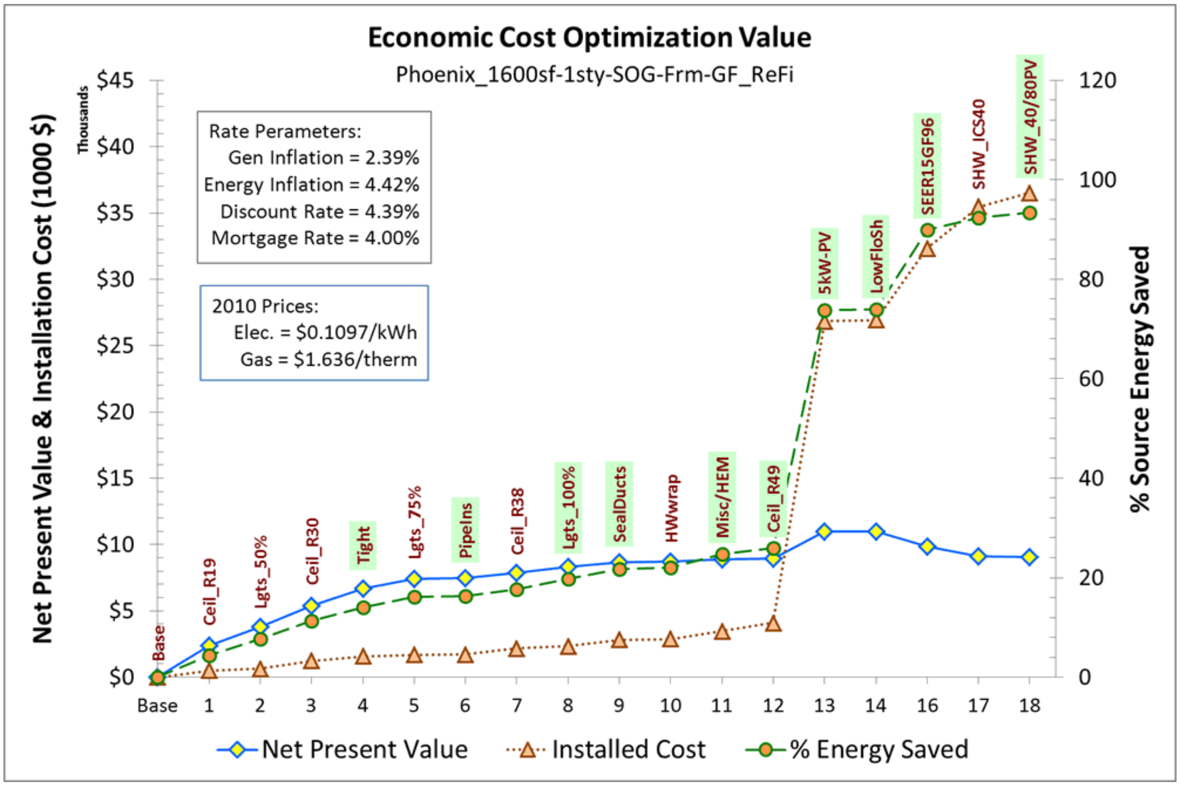

Economic Cost Optimization Value
Houston_1600sf-1sty-SOG-Frm-HP_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1160/kWh
Gas = $1.115/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
80
70
60
50
40
30
20
10
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
Base
Ceil_R19
Lgts_50%
Tight
Ceil_R30
ES_GHW
Lgts_75%
TGWH
Lgts_100%
SealDucts
LeakFree
Ceil_R38
Misc/HEM
5kW-PV
Net Present Value
Installed Cost
% Energy Saved

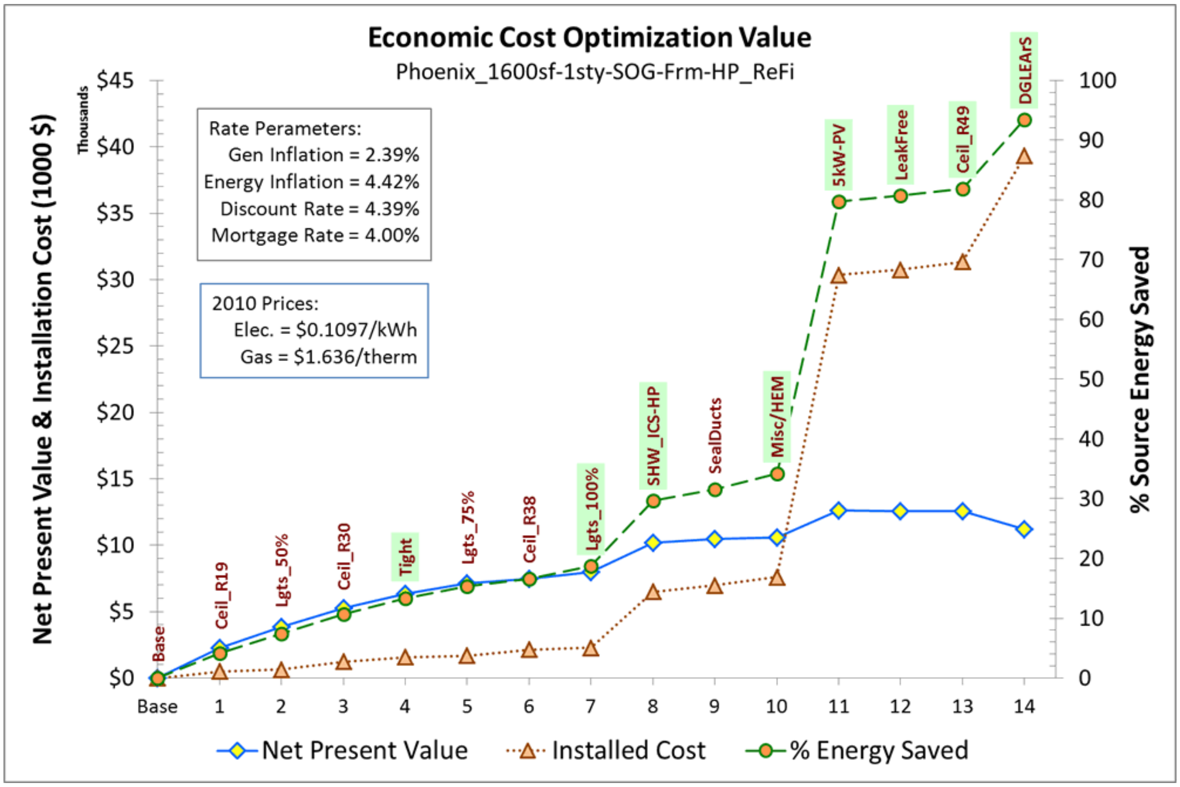

Economic Cost Optimization Value
Los Angeles_1600sf-1sty-Crwl-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
140
120
100
80
60
40
20
0
Base
1
2
3
4
5
6
7
8
9
10
11
Base
Lgts_50%
Lgts_75%
PipeIns
Lgts_100%
5kW-PV
HWwrap
Misc/HEM
LowFloSh
Ceil_R30
Ceil_R19
ES_Washer
Net Present Value
Installed Cost
% Energy Saved

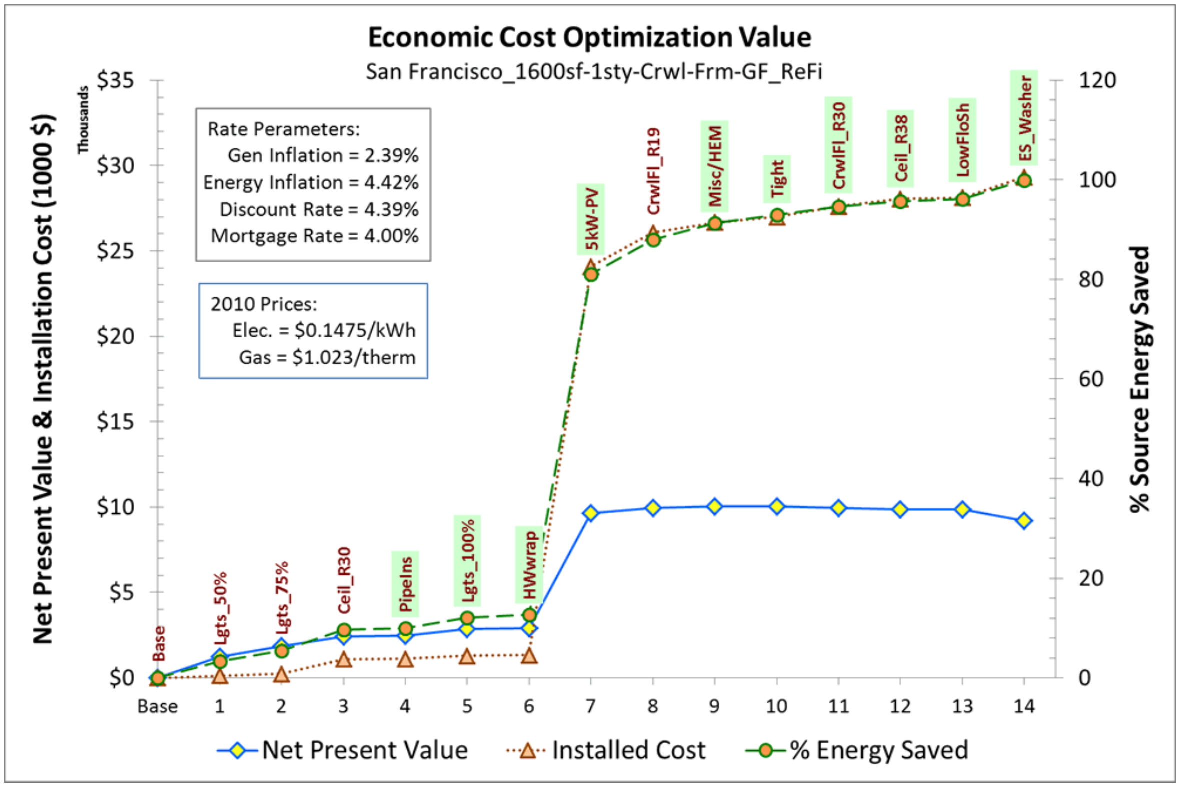

Economic Cost Optimization Value
Miami_1600sf-1sty-SOG-CMU-HP_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1144/kWh
Gas = $1.844/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Base
Lgts_50%
Ceil_R19
Tight
Lgts_75%
Lgts_100%
SealDucts
Ceil_R30
LowFloSh
SHW_ICS40
SHW_ICS-HP
LeakFree
Misc/HEM
SEER21AC
5kW-PV
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved

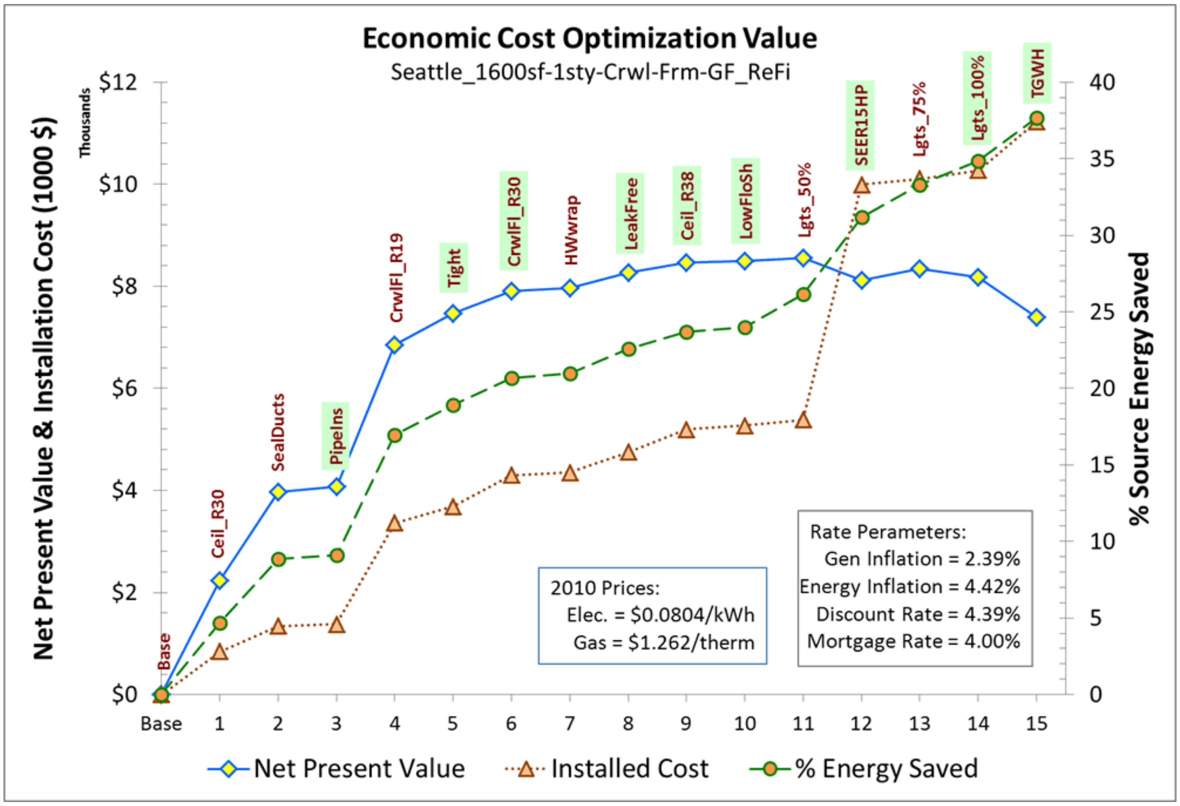

Economic Cost Optimization Value
Minneapolis_1600sf-1sty-Bsmt-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1059/kWh
Gas = $0.903/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$10
$9
$8
$7
$6
$5
$4
$3
$2
$1
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
Ceil_R30
Lgts_50%
BsmtW_R19
Ceil_R38
PipeIns
HWwrap
Lgts_75%
AFUE-96
Lgts_100%
LowFloSh
Ceil_R49
Misc/HEM
Base
1
2
3
4
5
6
7
8
9
10
11
12
Net Present Value
Installed Cost
% Energy Saved

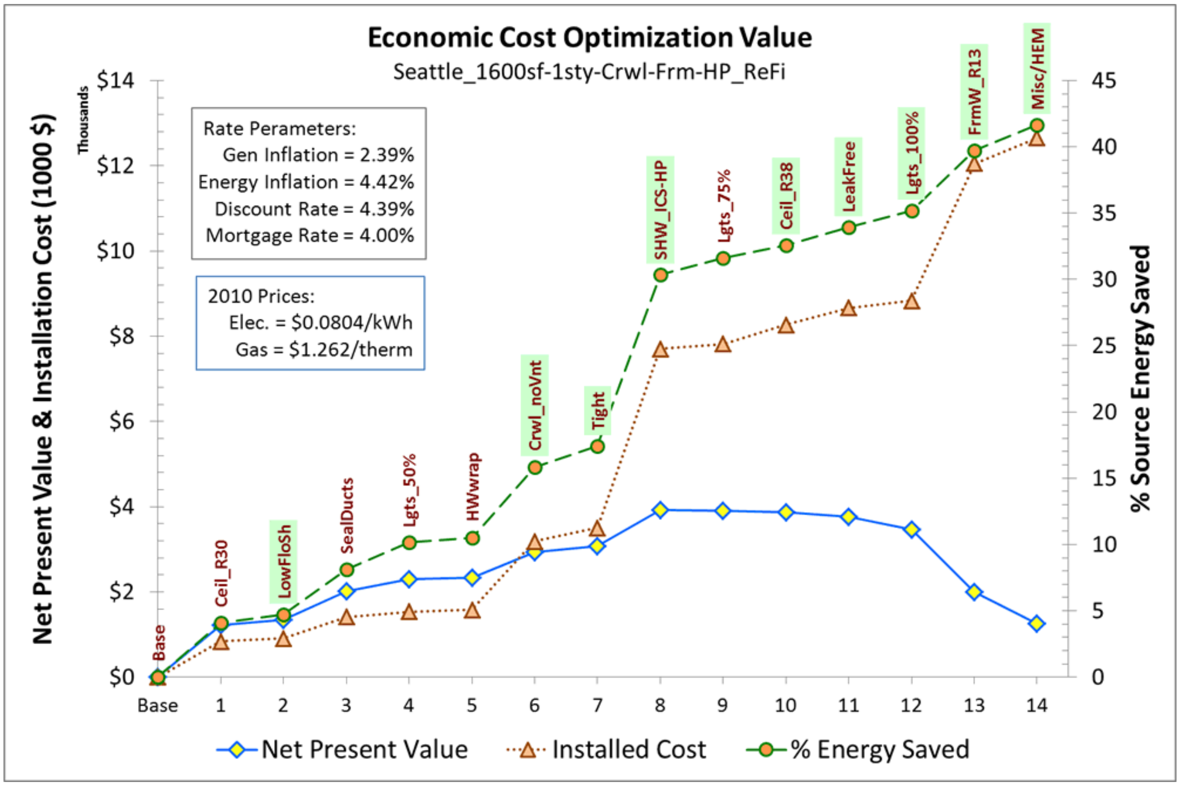

Economic Cost Optimization Value
New York_1600sf-1sty-Crwl-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1874/kWh
Gas = $1.448/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$50
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Base
Ceil_R30
Lgts_50%
Tight
Crwl_noVnt
PipeIns
SealDucts
Lgts_75%
Ceil_R38
Lgts_100%
HWwrap
LeakFree
Misc/HEM
5kW-PV
AFUE-96
LowFloSh
FrmW_R13
Tighter
Ceil_R49
ES_Washer
TGWH
StrmWin
CrwlFl_R30
VTight
Ceil_R60
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Net Present Value
Installed Cost
% Energy Saved

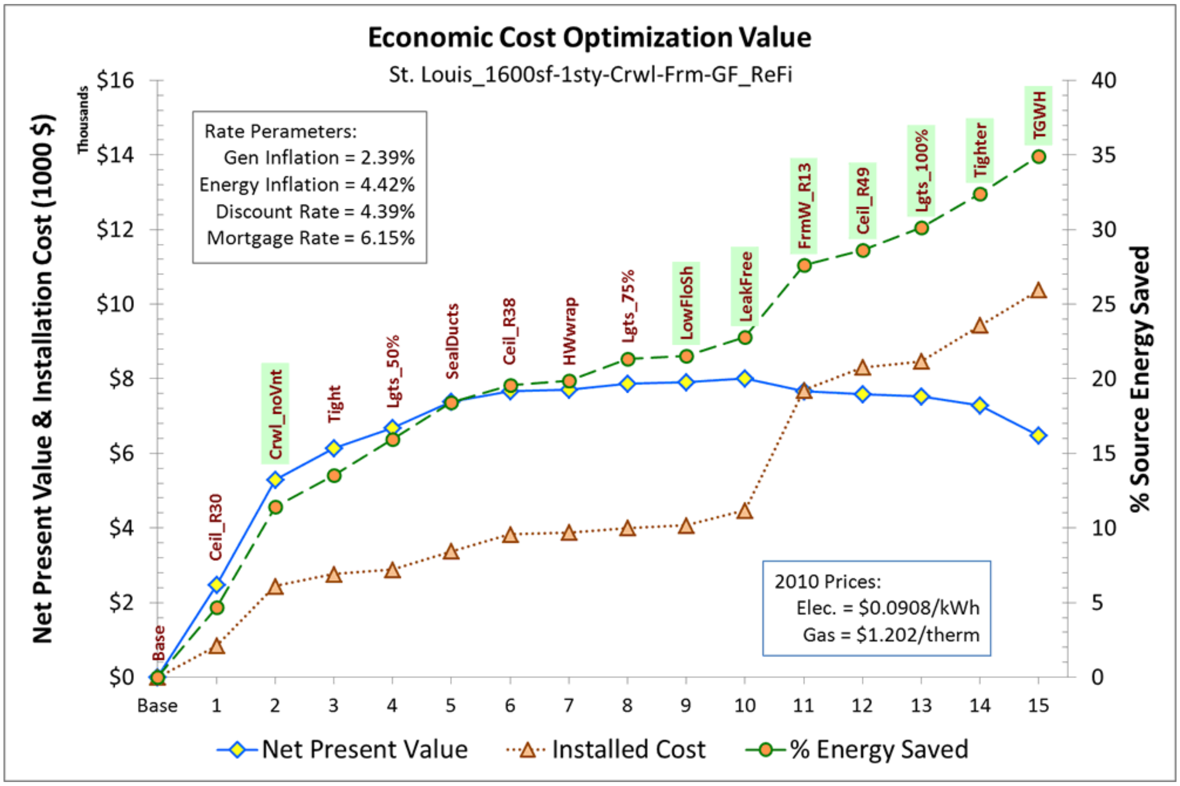

Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-GF_ReFi
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Net Present Value & Installation Cost (1000 $)
Thousands
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Base
Ceil_R19
Lgts_50%
Ceil_R30
Tight
Lgts_75%
PipeIns
Ceil_R38
Lgts_100%
SealDucts
HWwrap
Misc/HEM
Ceil_R49
5kW-PV
LowFloSh
SEER15GF96
SHW_ICS40
SHW_40/80PV
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
16
17
18
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Phoenix_1600sf-1sty-SOG-Frm-HP_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$45
$40
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
100
90
80
70
60
50
40
30
20
10
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1097/kWh
Gas = $1.636/therm
Base
Ceil_R19
Lgts_50%
Ceil_R30
Tight
Lgts_75%
Ceil_R38
Lgts_100%
SHW_ICS-HP
SealDucts
Misc/HEM
5kW-PV
LeakFree
Ceil_R49
DGLEArs
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
San Francisco_1600sf-1sty-Crwl-Frm-GF_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$35
$30
$25
$20
$15
$10
$5
$0
% Source Energy Saved
120
100
80
60
40
20
0
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.1475/kWh
Gas = $1.023/therm
Base
Lgts_50%
Lgts_75%
Ceil_R30
PipeIns
Lgts_100%
HWwrap
5kW-PV
CrwlFl_R19
Misc/HEM
Tight
CrwlFl_R30
Ceil_R38
LowFloSh
ES_Washer
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-GF_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Base
Ceil_R30
SealDucts
PipeIns
CrwlFl_R19
Tight
CrwlFl_R30
HWwrap
LeakFree
Ceil_R38
LowFloSh
Lgts_50%
SEER15HP
Lgts_75%
Lgts_100%
TGWH
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
Seattle_1600sf-1sty-Crwl-Frm-HP_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
45
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Base
Ceil_R30
LowFloSh
SealDucts
Lgts_50%
HWwrap
Crwl_noVnt
Tight
SHW_ICS-HP
Lgts_75%
Ceil_R38
LeakFree
Lgts_100%
FrmW_R13
Misc/HEM
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 4.00%
2010 Prices:
Elec. = $0.0804/kWh
Gas = $1.262/therm
Net Present Value
Installed Cost
% Energy Saved


Economic Cost Optimization Value
St. Louis_1600sf-1sty-Crwl-Frm-GF_ReFi
Net Present Value & Installation Cost (1000 $)
Thousands
$16
$14
$12
$10
$8
$6
$4
$2
$0
% Source Energy Saved
40
35
30
25
20
15
10
5
0
Base
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Rate Perameters:
Gen Inflation = 2.39%
Energy Inflation = 4.42%
Discount Rate = 4.39%
Mortgage Rate = 6.15%
2010 Prices:
Elec. = $0.0908/kWh
Gas = $1.202/therm
Base
Ceil_R30
Crwl_noVnt
Tight
Lgts_50%
SealDucts
Ceil_R38
HWwrap
Lgts_75%
LowFloSh
LeakFree
FrmW_R13
Ceil_R49
Lgts_100%
Tighter
TGWH
Net Present Value
Installed Cost
% Energy Saved

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