ECONOMIC INCENTIVE MODEL FOR SUSTAINABLE ENERGY USE IN U.S. CONSTRUCTION

K.R. GROSSKOPF, Ph.D.[1]

Charles J. KIBERT, Ph.D., P.E.[2]

[1] M.E. Rinker Sr., School of Building Construction, University of Florida, 336 Rinker Hall, P.O. Box 115703, Gainesville, Florida, USA 32611-5703, kgro@ufl.edu

[2] M.E. Rinker Sr., School of Building Construction, University of Florida, 342 Rinker Hall, P.O. Box 115703, Gainesville, Florida, USA 32611-5703, ckibert@ufl.edu

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Abstract

This research explores the potential of market forces to improve adoption of sustainable energy measures from the perspectives of three stakeholders; 1) the energy consumer, 2) the energy supplier and 3) society. First, survey data from 400 new U.S. homebuyers examines the consumer's willingness to pay for energy conservation measures (ECMs). Second, a case study explores the impact of energy conservation on a medium-sized energy supplier in terms of lost sales revenue and avoided supply costs with the anticipation that net benefits, if any, could be used to further incentivize ECM investment. Finally, the cost of emissions abatement is introduced as a means of capturing some of the externalized cost of energy use that is largely borne by society in varying degrees of health risks, climate destabilization and economic loss. From each of these stakeholder perspectives, market "enablers and barriers" for sustainable energy use in residential construction have been identified. Results indicate that actual returns from sustainable energy investments exceed most consumer expectations. Conversely, avoided supply costs attributed to ECMs were found to rarely justify investment incentives to consumers, unless the supplier chooses (or is required) to internalize the cost of energy-related emissions.

Introduction

Many environmental impacts are known as "externalities" since the costs of these detrimental acts often accrue to persons other than those responsible for them. Eco-economic theory contends that if the cost of externalities were internalized into market pricing, then market forces could be used to stimulate more efficient and sustainable use of resources. However, existing supply and demand structures that reward or discourage sustainable energy use in residential construction must first be identified. Toward this end, the performance and subsequent cost savings for several high-efficiency, energy conservation measures (ECMs) were computer modeled in three major climatic regions of north, central and south Florida, a sub-tropical region of the southeast United States. A market survey was then administered to consumers in each of these regions to determine their willingness to pay for ECMs that were typically more expensive to purchase than minimally code compliant alternatives, yet provided a substantial operational cost savings. Results found consumer willingness to pay for ECMs to be largely dependent on initial costs and life-cycle return on investment as defined by such metrics as internal rate of return (IRR), capital cost recovery (CCR) and savings to investment ratio (SIR). Several ECMs were found to be marketable under existing market conditions and several others could be marketable if added investment incentives were provided.

In addition to the consumer, other apparent benefactors of sustainable energy use in the U.S. housing market are energy suppliers or "utilities." Although suppliers lose sales revenue when energy use reduction occurs, these losses may be more than compensated by subsequent reductions in generation, transmission and distribution infrastructure. In theory, part of these avoided costs could be returned to consumers in the form of purchase rebates and discounts to stimulate additional conservation and avoided utility supply costs. Analysis of a sample case study however, finds that relatively few ECMs result in sufficient capacity reductions necessary to offset loss of electric sales. As a result, internalizing the cost of energy-related externalities such as the cost of emissions abatement is introduced as a yet another way to stimulate added ECM investment as well as account for the "true cost" of energy use within the built environment.

Consumer Payback and Willingness-to-Pay

The U.S. Model Energy Code (MEC), first published in 1983 and most recently amended in 2001, provides minimum national energy standards for new residential and commercial buildings in the U.S. For the purposes of this study, ECMs were defined as those energy-related building materials and systems that exceeded minimum MEC performance standards. To computer model the performance and subsequent cost savings of several commercially available ECMs, two "virtual" housing units were selected. These housing units were approximately 140m^2 (1,500ft^2) each in conditioned floor area, the average size of 3.8 million units and 532 million m^2 (5.8 billion ft^2) of single-family dwelling stock in the state of Florida. Simulations were conducted using climatic data for the cities of Jacksonville, Orlando and Miami. These metropolitan areas represented three distinct climatic zones in Florida and nearly half of the state's 18 million residents (U.S. Census, 2000).

An energy performance baseline was first established for each housing unit using MEC compliant building materials and equipment. ECMs were then "installed" individually into both case study housing units. The reductions in energy consumption observed for each housing unit, modeled in each of the three climatic regions, were compared to the performance baseline. To normalize differences in energy consumption attributed to differences in housing unit geometry and climate, the annual energy savings in kilowatt hours per year (kWh/yr) for each ECM was divided by unit quantities (e.g. m^2 of insulation), and average heating and cooling degree days for each region. Results showed that the differences between the minimum and maximum observed energy savings for each ECM varied less than 10% when normalized in this way (Figure 1).

Since most ECMs have a declining utility function whereby the benefits of each additional ECM decline as the number of ECMs increases, the baseline performance and cost savings of ECMs modeled individually cannot simply be added together. For example, a home in Orlando, Florida having 25m^2 of insulating, low emissivity (solar heat gain) windows may reduce the energy consumption of a 2.9 coefficient of performance (COP) heating, ventilating and air conditioning (HVAC) system 2,285kWh per year when compared to a minimally MEC compliant window. However, if the HVAC system is upgraded from a 2.9 COP to a 3.5 COP system, the savings attributable to the insulating, low emissivity windows is reduced to 1,904kWh per year (Grosskopf, 1998). Of course, the overall energy savings continues to improve as each ECM is added, but at a rate less than simply adding their individually modeled performance savings together. However, since the cost to implement each alternative *is* additive, the rate of return for multiple ECMs declines rapidly as each new alternative is added. Using the average energy reduction for each ECM listed in Table 1, the corresponding annual cost savings was calculated using an energy cost of $US 0.08 per kWh cost for electricity (Table 2).

A 1998 survey conducted by the University of Florida of 400 homeowners living in Jacksonville, Orlando and Miami, Florida showed that consumers were on average, most willing-to-pay for the high cost, high return ECM (42%) when given a choice of moderate (25%) and low cost, low return (22%) alternatives in several ECM product groups (Figure 2). Eleven percent of respondents were undecided. Further analysis of survey data revealed that consumer willingness to pay was strongly correlated to capital cost recovery (CCR) and savings-to-investment ratio (SIR) as determined by the Pearson product moment correlation coefficient (r). CCR is the length of time necessary for the ECM to pay for itself and is determined by dividing the added capital investment of the ECM by the annual energy savings. SIR represents the ratio of lifecycle savings to added initial costs and is determined by dividing the total energy savings over the life of the ECM by the added capital investment. The lower the CCR and the higher the SIR, the greater the return on investment for the ECM.

As expected, survey results indicated that consumer willingness-to-pay declined as time necessary for capital cost recovery or “payback” increased and savings-to-investment ratio decreased (Table 3). Pearson r values reflecting the extent of correlation between both CCR and SIR in relation to consumer willingness-to-pay exceeded 0.90 on a scale of –1 to 1, whereby 1.0 is a perfect positive correlation. Furthermore, results from all conservation measures surveyed showed for each two-year increase in CCR, an average 25% decline in consumer willingness to pay could be expected.

Supplier Revenue and Avoided Costs

In addition to a reduction in energy consumption, energy conservation can reduce needed generation, transmission and distribution capacity. Associated with such reductions are both costs and benefits for the supplier. The most immediate and obvious cost to the supplier is a reduction of energy sales revenue. The most immediate benefit is a reduction in peak load and an improvement in load factor. Load factor represents the average load or energy demand in relation to the peak demand. A commercial facility having an average load of 200kW and a peak load of 500kW for example, has a load factor of 40%. As a result, the utility must designate 500kW of “wires” and generation capacity to meet the facility’s peak load, even though on average, only 40% of this infrastructure would be utilized at any one time. Building into this equation safety reserves and line losses, perhaps 75% or more of the generation, transmission and distribution (T&D) infrastructure dedicated to this facility sits idle. For this reason, commercial energy users are often required to pay demand charges ($US/kW) and load factor penalties. By contrast, most residential users pay for only energy consumption ($US/kWh). As a result, the cost for underutilized capacity within the residential market is borne entirely by the supplier. For most utilities, conservation measures are a viable means to improve load factor within the residential market. The benefits of energy conservation are realized most during peak load conditions when the cost of electric generation is greatest (Table 4). Consequently, the loss of energy sales from conservation can in some cases be compensated by avoided peak load generation.

In general, reductions in sales produce corresponding reductions in variable costs. However, fixed costs by definition hold constant within a relevant range of sales volume. As a result, a reduction in sales caused by a reduction in energy use may not necessarily result in a reduction of fixed costs. When energy reductions are sufficient to reduce fixed costs, the benefit usually occurs at some point in the future because the infrastructure necessary to serve the current demand is already in place. Fixed cost reductions accrue largely in the form of avoided future expansion of infrastructure, operations, and personnel. Subsequently, the potential benefits of avoided future capacity are highly dependent on both the timing and magnitude of the conservation effort. Depending on the extent to which avoided peak load costs exceed lost sales revenue, utilities may provide market-based incentives (or disincentives) to stimulate sustainable energy use and corresponding peak load reductions.

Table 5 provides both fixed and variable costs associated with “blended” baseload, intermediate load and peak load electric generation, transmission and distribution for a 450MW public utility serving approximately 240,000 residents in Gainesville, Florida. Since 1963, this utility has on average, increased its generation capacity in increments 50MW every five years to meet the energy demands of 1.22% annual population growth. For this utility, a successful conservation program must achieve a summer peak load reduction of at least 50MW to have a meaningful avoided cost impact. Given the lead time necessary to implement the conservation program as well as the time necessary to design, permit and construct a power plant, load reductions must be realized five years in advance of system expansion.

Using the aggregate performance of the sample ECMs shown in Table 1, a total of 7,720kWh energy reduction is estimated for the average single-family dwelling unit. With an average load factor of approximately 40% and 6% line loss, this average single family dwelling unit could reduce summer peak loads by 2.34kW. Given that 50MW is the minimum amount of capacity reduction necessary to avoid (delay) adding generation capacity, at least 21,368 dwelling units must be willing to implement these (or comparable) ECMs within the next five years (2005-2010). At approximately $US 0.08/kWh, the utility can expect to lose $US 617.40/yr in electric sales from each of the required 21,368 dwelling units implementing the conservation measures listed in Tables 1 and 2 for a total reduction in revenue of $US 13.2M/yr for the 15-year lifecycle of the conservation measures (2005 USD).

Using the fixed and variable cost information provided in Table 5, the utility can expect to avoid $US 77.9M in generation and T&D facilities expansion five years from the start of the conservation program and an additional $US 4.5M/yr in operations and maintence (O&M) costs over 15 years (2005 USD). It is assumed however, that costs and benefits will accrue incrementally during a five-year (2005-2010) ECM implementation period. Life-cycle cost analysis indicates that the net present value of the conservation program from the utility’s perspective is -

$US 16.1M, meaning in this case, the loss in electric sales revenue exceeded the benefit of avoided system capacity.

From this perspective, it becomes apparent that the utility is more inclined to provide incentives to those conservation alternatives that maximize peak load reductions (kW) and minimize the loss of baseload energy consumption (kWh) within the residential market. To illustrate this point, the utility considers promoting two conservation measures. The first is an HVAC load control device that will reduce demand 1.0/kW and energy consumption 100kWh/yr per dwelling unit. The second is a program that will incentivize the use of R-30 (229mm) ceiling insulation instead of R-19 (152mm), resulting in a 0.3kW demand and 750kWh/yr energy reduction per dwelling unit. The utility determines that it will lose $US 0.067/kWh of residential electric sales but gain $US 61.88 for every kW of avoided demand during its summer peak load. From the utility's perspective, each load control device installed within the residential market will provide approximately $US 58.00 per year in net system benefits. From the consumer's perspective however, a load control device costing $US 300.00 will only save $US 8.00/yr for 15 years. For the consumer to achieve a marginal SIR of 2.0 and IRR of 10%, the utility would have to provide a credit or rebate incentive of $US 32 per year to the user. To remain capital cost neutral at 8.75%, program costs and other utility overheads could not exceed $US 22.00 per device per year. By comparison, the loss of 750kWh worth of sales revenue in exchange for 0.3kW demand reduction for the insulation measure costs the utility -$US 33.00 per year in net system benefits. Because the insulation measure reduces energy consumption more evenly throughout the day and throughout the year, the measure contributes significantly more toward baseload reduction than peak load reduction. Although the later option is cost effective for the consumer, it is not cost effective for the supplier.

Societal Externalities

As illustrated, the consumer is motivated to minimize initial costs and maximize energy reduction (kWh) in order to optimize payback. Conversely, the utility seeks to minimize energy reduction (kWh) and maximize demand load reduction (kW) in order to maintain sale volume while reducing fixed costs. Left to traditional supply and demand economics, this paradox would significantly limit the number of ECMs cost effective for both consumer and supplier. However, the inclusion of energy-related externalities that reflect the “true cost” of energy consumption, may provide the added incentive necessary for sustainable energy use in residential construction. The environmental impacts caused by energy use such as air emissions, strip mining, habitat destruction and watershed pollution are known as “externalities” since the cost of these acts are rarely internalized by either the supplier or consumer. The uncontrolled release of $NO_{x,}$ SO_2 and CO_2 emissions alone contribute significantly to the global greenhouse effect. Aggregating emissions proportionately across Florida’s coal, petroleum, gas and nuclear generation output, it is estimated that 0.0036kg (0.008lb) of SO_2, 0.0023 kg (0.005lb) of NO_x and 0.59kg (1.3lb) of CO_2 are released for every kilowatt-hour of energy used by the consumer (U.S. DOE, 1995). To avoid the daunting task of costing the effects of these emissions on the environment, several U.S. states have instead calculated the cost to remove greenhouse stack gasses as a proxy for emissions externalities (Table 6).

By factoring the average “societal” cost for NO_x, CO_2 and SO_2 abatement into the equation, the consumer could be credited $US 0.028 per kWh conserved in addition to the reduction of $US 0.08 per kWh of energy costs paid to the utility. This ~35% improvement in “payback” results in a corresponding improvement in SIR, CCR and IRR, reducing the need for supplier incentives, and increasing the number of conservation measures the consumer would be willing to pay for. Using the Gainesville case study, the average dwelling unit conserving 7,718kWh/yr could expect to save an additional $US 216.10 per year on utility costs, if the cost of emissions abatement were credited back to the consumer. As a result, consumer SIR increases from 2.55 to 3.44, IRR increases from 14.8% to 19.9%, and CCR decreases from 5.9 years to 4.5 years for the sample package of ECMs listed in Tables 1 and 2. The 1.5 year decrease in CCR could be expected to improve overall consumer willingness to pay an additional 20%. Without consideration of externalities, the *benefit* of eliminating 412 tons of NO_x, 660 tons of SO_2 and 107,197 tons of CO_2 from the conservation of 1.65×10^8 kWh of energy (50MW peak capacity at

40% load factor) would go unaccounted for each year, much in the same way the cost of emissions goes unaccounted for today.

Conclusions

The following case study showed that an average single family home in Florida can reduce energy consumption more than 7,000kWh and summer peak loads by 2.0 kW or more by adopting viable ECMs. As a result, it was postulated that ECMs could be market driven as a result of the “payback” opportunities available to consumers, and, further incentivized by energy suppliers seeking to avoid future generation, transmission and distribution expansion costs.

Since 50 MW was in this scenario the minimum incremental load reduction necessary to avoid future generation expansion, greater than 20,000 dwelling units would have to implement these energy conservation measures assuming an average residential load factor of 40% or less. In doing so, it was estimated the utility would lose $US 617.40 per year in electric sales revenue for each home adopting these measures, or, approximately $US 13.2 million per year. In return, the utility could expect to avoid (save) $US 77 million in generation and distribution costs five years from the start of an energy conservation program and $US 4.5 million per year in operation and maintenance costs. Under these case study specific conditions, the net present value of the energy conservation measures from the energy supplier’s perspective is -$16.1 million, meaning the utility would not be inclined to provide conservation incentives. However, when the average cost of emissions abatement are considered from energy unused, the average homeowner could be credited $US 0.028/kWh, or, an additional $216.10 per year.

This case study was intended to represent the market perspectives of the consumer, the supplier and society by internalizing the benefit-cost motivations of each to create meaningful ECM incentives for sustainable energy use in residential construction.

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Table 1. Sample energy reduction of ECMs modeled in Orlando, FL using 4,570 cooling degree-days (CDD, 10°C Base) and 380 heating degree-days (HDD, 18°C Base). (Grosskopf, 1998)

Energy Conservation Measures (ECMs)	**Unit**	**Energy Reduction (kWh/unit/yr)**	
		Individual ECM	**Cumulative ECMs**
Low-flow shower fixtures	2 ea	410	410
Low-flow, high-efficiency dishwasher	1 ea	850	1,260
3.5 COP air-source heat pump	1 ea	1,520	2,780
Low-flow clothes washer	1 ea	205	2,985
Indoor compact fluorescent lighting	15 ea	350	3,335
Solar water heater	1 ea	2,025	5,365
Insulated, low emissivity windows	23 m^2 (250 sf)	1,905	7,270
R-13 (105mm) batt wall insulation	185 m^2 (2,000 sf)	215	7,485
R-38 (305mm) batt ceiling insulation	185 m^2 (2,000 sf)	235	**7,720**

Table 2. Sample energy cost savings of ECMs modeled in Orlando, FL using a 15-year analysis period. (Grosskopf, 1998)

Energy Conservation Measures (ECMs)	**Unit**	**Capital Cost ($US)**	**SIR**	**Return on Investment ($US)**		**Rate of Return**
				Individual ECM	**Cumulative ECMs**	
Low-flow shower fixtures*	2ea	64.22	11.7	751.99	751.99	78.1%
Low-flow, high efficiency dishwasher*	1ea	140.00	7.8	1,094.37	1,846.36	60.2%
3.5 COP air-source heat pump	1ea	300.00	6.4	1,931.40	3,777.76	49.8%
Low-flow clothes washer	1ea	111.00	3.9	427.75	4,205.51	45.4%
Indoor compact fluorescent lighting**	15ea	162.00	3.4	446.57	4,652.08	39.6%
Solar water heater	1ea	1,326.00	3.0	2,575.20	7,227.28	21.7%
Insulated, low emissivity windows	23 m^2	1,350.00	2.2	2,418.90	9,646.18	16.8%
R-13 (105mm) batt wall insulation	185 m^2	249.00	1.5	271.66	9,917.84	15.9%
R-38 (305mm) batt ceiling insulation	185 m^2	311.02	1.3	297.71	10,215.55	14.8%
		4,013.24			**10,215.55**	

* Includes water savings at $US 3.00 per 3,785L (1,000 gallons)

** Assumes 10,000 hour service life, includes replacement cost at 7.5 years.

Table 3. Consumer willingness-to-pay for sample ECMs. (Grosskopf, 1998)

BMP	CCR (Years)	Change	SIR	Change	Willingness to Pay	Change
Window, insulated	1.4		10.9		48.4%	
Window, insulated LoE	2.7	48%	6.6	-40%	34.1%	-30%
Low-flow appliances	4.5	40%	5.6	-15%	29.3%	-14%
14 SEER heat pump	6.8	34%	4.3	-23%	21.1%	-27%

Table 4. Average baseload, intermediate load and peak load generation costs. (Regan, 2004)

Type	Technology	Utility Cost ($US)
Base load (24 hour per day)	Nuclear	25/MWh
	Coal	27/MWh
Intermediate load (8-12 hour per day)	Natural Gas Combined Cycle	40/MWh
	Natural Gas Steam	46/MWh
Peak load (4-6 hour per day)	Natural Gas Turbine	75-200/MWh

Table 5. “Blended” electric generation, transmission and distribution fixed and variable costs. (GRU, 2004)

Cost	Cost Component	Value of Reduction ($US)
Avoided T&D Facilities	Fixed	104.94/kW
Avoided T&D Personnel	Fixed	6.15/kW/Yr
Avoided Generation Unit	Fixed	1,452.00/kW
Avoided Generation Personnel	Fixed	5.52/kW/Yr
Avoided Generation O&M	Variable	0.0049/kWh
Avoided Generation Fuel	Variable	0.01864/kWh
Fuel Cost Escalation		3.9%/Yr
Inflation		4.0%/Yr
Line Loss Percentage		6.0%
Cost of Capital		8.75%

Table 6. Societal costs for energy-related NO_x, CO_2 and SO_2 emissions ($US/kg). (NREL, 2001)

State	**NO_x**	**SO_2**	**CO_2**
Massachusetts	1.63	0.39	0.01
Minnesota	0.37	0.07	0.01
Nevada	1.54	0.35	0.01
New York	0.42	0.19	0.00
Oregon	1.13	0.00	0.01
Average	1.02	0.20	0.01

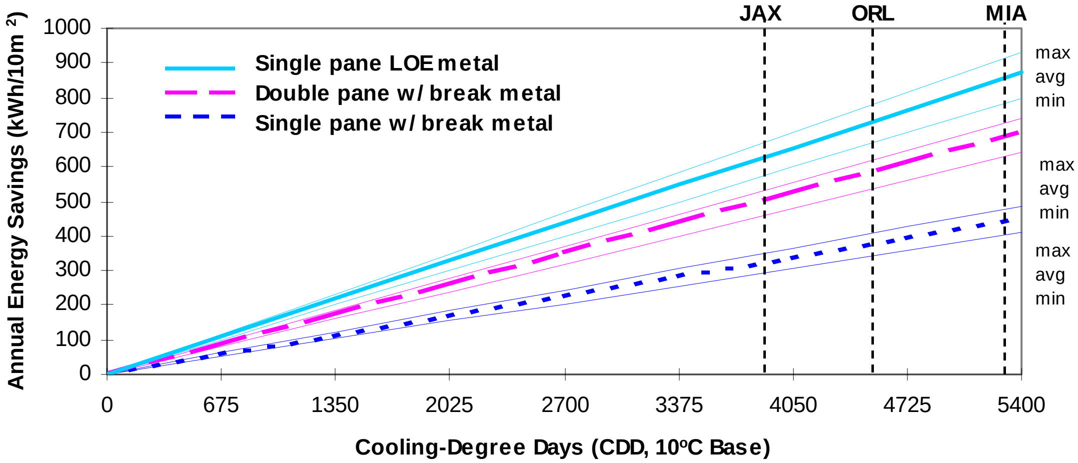

Figure 1. Sample energy efficient window alternatives. Range and average energy reduction when modeled in place of MEC minimally compliant single pane, aluminum frame baseline. JAX = Jacksonville, ORL = Orlando, MIA = Miami. (Grosskopf, 1998)

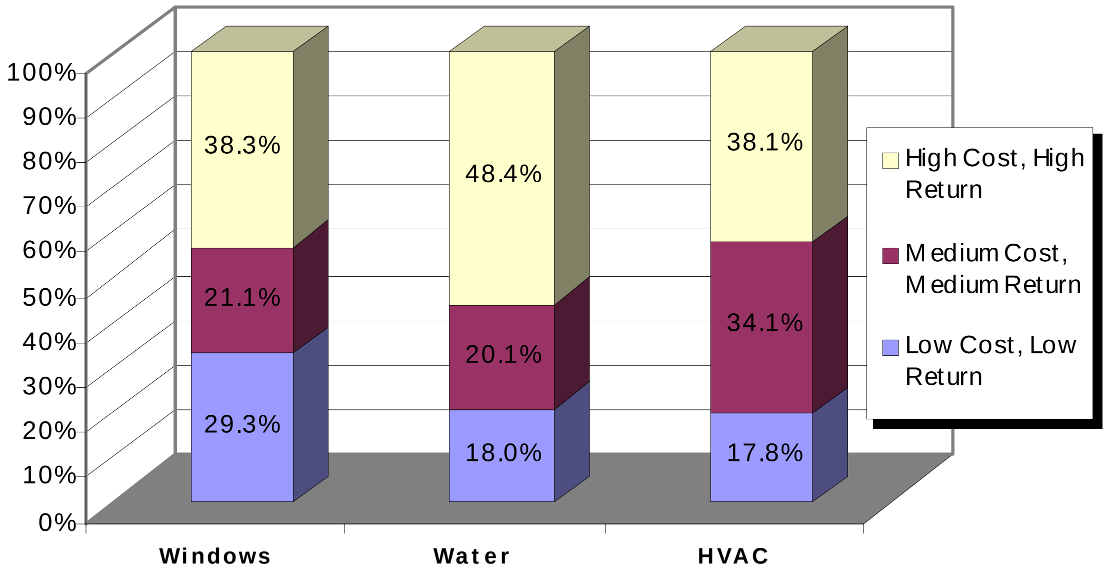

Figure 2. Consumer willingness-to-pay for low, moderate and high cost, high return sustainable window, water and HVAC alternatives.