#3942

MEASURED SAVINGS

Fifty Million Retrofits Later

by Sam Cohen

Energy savings and cost data from single-family retrofit projects throughout the country have been compiled in one data base. Shell measures and heating system retrofits can be compared for their relative effectiveness at saving energy.

Each year, residents of the 66 million single-family homes in the United States will pay approximately $80 billion for electricity and other fuels. Nobody knows how much is invested each year in retrofits to reduce this bill, but it is certainly over $½ billion. Did the retrofits save energy? Were these good investments? In spite of the billions of dollars involved, the amount of money being spent on evaluating whether the retrofits are cost-effective is small in comparison. Measured savings are scandalously rare, even though many energy professionals believe that certain retrofits are nearly always reliable and cost-effective.

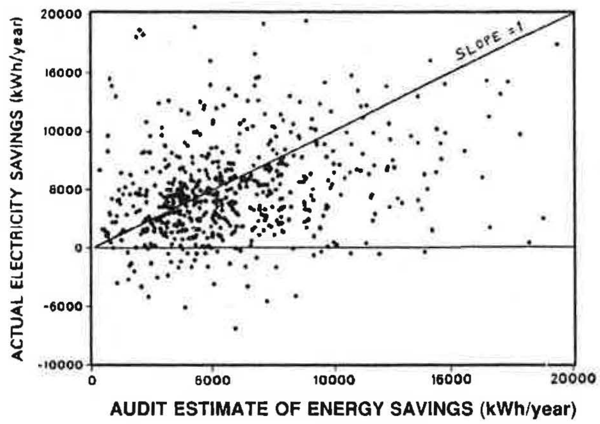

Figure 1. Predicted versus measured savings from the $157 million Bonneville Power Administration (BPA) weatherization program conducted in 1982 and 1983. (When predicted savings match actual savings, the point falls on the line with a slope of one.)

Lost in the Data Mines since '84, BECA Bobbie returns with a cartload of booty.

Practically the only source of information about the comparative successes (and failures) of retrofits is the Lawrence Berkeley Laboratory (LBL). There, researchers have compiled and analyzed the little measured data that are available. This project, the Buildings Energy-Use Compilation and Analysis (BECA) project, gives rare insight into the performance of various conservation measures. Except for BECA, most projects are evaluated individually so there is no opportunity to increase the sample size (and hence confidence in the results) by comparing similar programs across different utilities or by comparing the economic indicators for different retrofit options. The latest report from Lawrence Berkeley Laboratory researchers focuses on retrofits of single-family homes.[1]

Why is it necessary to measure and document the performance of retrofits? Aren't engineering estimates sufficiently accurate and reliable ways of computing the savings? LBL's experience suggests that engineering estimates of energy savings are notoriously unreliable, often overestimating savings. As evidence of the need for monitored data, consider one comparison between predicted and measured savings. (See Figure 1.)

*Sam Cohen is a research associate at Lawrence Berkeley Laboratory. Fifty million is **Home Energy**'s estimate of the number of energy conservation improvements made to homes 1978–1988.*

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The BPA program was one of the most expensive utility weatherization programs ever conducted. Based on the presumed accuracy of predicted savings, millions of dollars were paid to homeowners who installed retrofits. Clearly, when spending such sums of money, measured data are needed to adjust or confirm estimated savings.

Where Do the Data Come From?

There is no simple way to identify and collect measured data for BECA, but LBL used a literature search, conference participation, and contact with other professionals in the field to collect as much data as possible. (See box.) The new data represent 17,000 retrofitted houses, added to the single-family retrofit data base since the last report in 1984. Since then, there have been two major changes in weatherization programs: addition of heating, ventilating, and air conditioning (HVAC) measures to traditional shell measures, and increased collection of high-quality submetered data.[2] Since 1984, LBL has made substantial progress in determining the energy savings and economics associated with individual retrofit measures. The data base now contains measured savings on packages of retrofits and individual retrofits, including furnace retrofits and furnace replacements; central air conditioning replacement; wall, furnace, and ceiling insulation; warm room zoning; and water heating measures. Table 1 shows the types and sponsors of programs in the updated data base.

Some projects have measured savings but are not included in the analysis. In general, LBL chose subsets of the available data, screened to present savings related to the actual retrofit, rather than unaccounted-for external factors (like, weather). Typical screening criteria included no supplemental heat (e.g., wood), no occupancy changes during the study period, and continuous billing histories. The drawback to this approach is that statistically significant savings are difficult to obtain because of small sample sizes. However, screening gives a higher degree of confidence that the results actually measure changes in energy consumption due to the retrofit.

LBL Seeks Measured Data on Energy-Efficient New Homes

The Buildings Energy-Use Compilation and Analysis (BECA) project at Lawrence Berkeley Laboratory is seeking measured performance data on new homes that exceed the energy-efficiency requirements of state or local codes. Data are needed on single-family, multifamily, and mobile/manufactured homes, including energy use (preferably submetered, but at least utility bill data), energy-saving features, and added costs associated with those features. The information will be used to update the BECA-A data base. Results will be published in reports, articles, and an electronic data base available from LBL. All data contributors are acknowledged in the reports, unless confidentiality is requested. If you know of suitable data sources, or are planning a project that may produce such data, please contact BECA staff at the address below. Please use the same address if you would like more information on the BECA project, or a list of publications.

Buildings Energy Data Group
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Table 1. Average Savings and Economics of Individual Retrofits

Measure	Sponsor	Prog Type[1]	# of Buildings	State (HDD)
Shell Measures				
Wall insulation	MEO	R	8	MN (8,000)
"	ORNL	R	6	WI (7,500)
"	1984 WI WAP	L	7	WI (7,500)
Ceiling insulation (R-0 to R-19)	PG&E	U	33	CA (2,200)
" (R-0 to R-19)	PG&E	U	16	CA (2,700)
" (R-11 to R-30)	Publ. Serv. Co.	J	33,000	CO (6,000)
" (to R-30)	Consol. Gas	U	71	MI (6,300)
Interior foundation insul. (R-0 to R-11)	MEO	R	8	MN (8,000)
" (R-0 to R-14)	Robinson Tech.	R	9	MN (8,000)
Exterior foundation insul. (R-0 to R-10)	MEO	R	5	MN (8,000)
" (R-0 to R-10)	Robinson Tech.	R	6	MN (8,000)
Warm room zoning	LBL	R	5	MO (5,300)
"	NCAT	R	25	PA(5,600)
Heating and Cooling System Measures				
Cond. Furn. Repl. Unit	MEO	R	3	MN (8,000)
"	ORNL	R	7	WI (7,500)
Forced Draft Furn. Repl. Unit	MEO	R	13	MN (8,000)
Forced Draft Boil. Repl. Unit	MEO	R	4	MN (8,000)
Furn. Repl. (Eff. Unknown)	1984 WI WAP	L	33	WI (7,500)
Condensing heat extractors	ASE/ORNL	R	43	KY (4,500)
"	ASE/ORNL	R	35	MN (8,000)
Elec. vent damp. and elec. ign.	ASE/ORNL	R	42	MN (8,000)
Power gas burners	ASE/ORNL	R	16	KY (4,500)
"	ASE/ORNL	R	14	MN (8,000)
Flame retention burners	State of OR	R	92	OR (4,700)
"	Brookhaven	R	19	NY (5,500)
"	State of MI	R	76	MI (7,000)
Central air conditioner replacement	Fleming Group	R	12	TX (2,900 CDD)
Hot Water System Measures				
Water Heater Wrap	Hood River	U	74	OR(5,600)

[1] U = Utility. R = Research. L = Low income.

Selected Findings

Shell measures typically result in savings of 10–20%. Most HVAC measures that do not involve expensive equipment replacements (like furnace replacements), result in savings of approximately 5–10%. Condensing heat extractors and flame retention burners are the exceptions. (See discussion below.) The energy savings and economics of individual retrofit measures are given in Table 2 (on page 16).

Ceiling insulation retrofits are the most cost-effective shell measure documented in the BECA data base. The four studies in our data base show cost of conserved energy (see box, "Interpretation of Economic Indicators") values of $1.80 to $4.40/million Btu, even in relatively mild climates. This measure is straightforward and well-documented. Consequently, we have analyzed no new studies within the last five years.

Wall insulation, on the other hand, is still being studied because of its complexity of installation, higher costs, and uncertainty about savings predictions. This retrofit is labor-intensive because either siding is removed or holes are drilled (and then filled and refinished) in order to pack each section of the wall with a fill material (usually cellulose). Savings predictions are difficult because wall insulation produces savings by both reducing the conductivity of the wall and by blocking infiltration and convective loops within the wall. Also, changes in wall surface temperature after insulation may lead to lower air-temperature settings to maintain the same level of comfort. The three studies in our data base were done in climates of 7,500 to 8,000 heating degree-days (HDD, base 65°) and show costs of conserved energy of $3.60 to $7.30/million Btu. Foundation insulation had the worst payback time of any retrofit in the BECA data base. LBL found only two relevant studies, both of which treated houses in Minneapolis. These houses already had high levels of wall and attic insulation and consequently had low pre-retrofit energy use. The cost of installing sheetrock was included for interior foundation insulation. The second study, done by Robinson Technical Services, found payback periods of 61 and 127 years for the interior and exterior foundation insulation, respectively. The Minneapolis Energy Office (MEO) study on foundation insulation showed a 17-year payback for the interior foundation insulation retrofits and a 19-year payback for the exterior. In any case, the energy paybacks are poor. However, the extra living space is a significant non-energy benefit that may make the interior foundation insulation retrofit attractive despite the long payback period. Also note that for energy-saving purposes, ceilings and walls are generally insulated before foundations. However, a retrofit done in a poorly insulated house (to create living space in the basement) would have a shorter energy payback period than was found for the well-insulated homes in our database.

Creating "warm rooms," that is zoning and weatherizing only a portion of a house, can produce large savings (approximately 25%) at costs similar to those of conventional weatherization programs, which achieve 10–15% savings. The two warm-room studies in the BECA data base use different methods to create warm zones.

In the Missouri study, insulation crews insulated and air sealed selected areas of the house. They then closed the appropriate registers in the heating system to further the zoning effect. In some cases, closing off registers may lead to inefficient operation of a forced-air system, without adjustments or modifications to the burner and fan (or in extreme cases, furnace replacement).

Effects of Weather

Analysis of energy savings requires that the consumption be normalized to a typical weather year. Otherwise, the weather during the monitoring period will affect the perceived savings. Weather normalization is usually done by one of four methods: (listed in order of accuracy)

- regression of end-use submetered data,
- regression of whole building (utility bill) data using a variable reference temperature,
- regressions using a fixed reference temperature, or
- scaling the space-heat data by heating degree-days (HDDs).

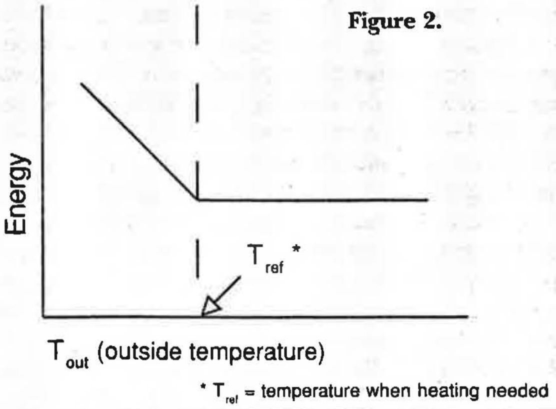
The reference temperature is the outdoor temperature below which space heating is needed to maintain the house at the desired indoor temperature. Typical U.S. homes have reference temperatures approximately 7° F below the indoor temperature setting during the heating season, representing 7°F of "free heat" from internal gains. However, superinsulated homes may have as much as 20°F of free heat. Submetering allows one to determine how much energy goes to a particular energy-consuming device and is thus the most accurate method for determining the savings from individual measures. Regressions of whole-house daily fuel use versus outdoor temperature assume that below the reference temperature, space heating energy use is linearly proportional to outdoor temperature. Baseload energy use is assumed to be independent of outdoor temperature. Thus, energy use (E) equals the baseload energy (B) plus a term proportional to outdoor temperature. If the outdoor temperature is greater than the reference temperature, no heating is needed and the second term is zero.

$$E = B + k(T_{ref} - T_{out})_+$$

The constant of proportionality (k) depends on how efficiently the house uses space heating energy. (See Figure 2.)

Most recent studies that do not involve submetered data use the Princeton Scorekeeping Method (PRISM), a software package which uses a variable reference temperature regression. PRISM finds the reference temperature which gives the best linear relationship of fuel use to outdoor temperature.

Figure 2.



Interpretation of Economic Indicators

The simple payback period (SPT) is a function of climate, house characteristics, and energy price.

$$SPT = \frac{\$\ \text{Investment}}{(\text{Annual Energy Savings})(\text{Energy Price})} = \frac{I}{(\Delta E)(P)}$$

Extreme climates, high energy prices, or high pre-retrofit energy consumption will yield short paybacks. (A well-insulated house will save less energy from a furnace replacement or other retrofit, though it may save the same percentage that a poorly insulated house would).

The cost of conserved energy (CCE) is another economic indicator. The advantage of the CCE is that it does not depend on energy price. It tells you how much it will cost to save a unit of energy. If the CCE is less than the local energy cost (typically $0.60/therm), then the retrofit is a good investment.

$$CCE = \frac{(A)}{(\Delta E)} = \frac{(\text{Annualized Cost Investment})}{(\text{Annual Energy Savings})}$$

Variables that are uncertain are the real discount rate and the lifetime used to calculate the annualized investment cost (A) for the retrofit. (The real discount rate plus inflation is the actual percentage that a bank theoretically charges on a loan.) For our calculations, we used a real discount rate of 7% corresponding to a loan at roughly 10% interest.

Adjusting Savings Estimates For Climate

The colder the climate, the faster a heat-saving retrofit will pay for itself. Both simple payback periods and CCEs are inversely proportional to energy savings. Assume that absolute energy savings (million Btu, not percent) are proportional to heating degree days (HDDs), then adjust the given economic indicators to a different climate by multiplying them by the appropriate ratio of HDDs.

$$CCE(2) = CCE(1)\ HDD\ (2)/HDD\ (1)$$

$$SPT(2) = SPT(1)\ HDD\ (2)/HDD\ (1)$$

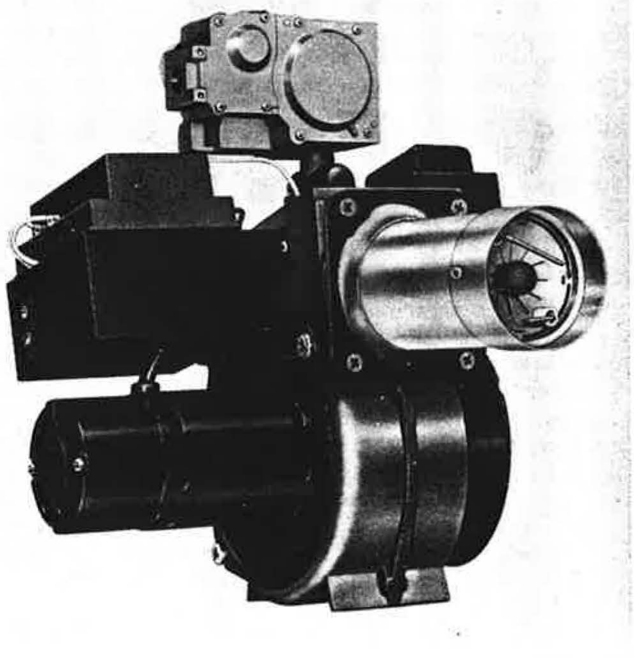
where (1) and (2) correspond to climates 1 and 2, respectively. The initial energy consumption of the building and energy price are also important factors. Since SPT is proportional to energy prices, high local energy prices yield faster paybacks. If energy bills are already low or the house is already efficient, the economics are less favorable. You've already saved the energy that others are still wasting.

In the Pennsylvania study, retrofitters insulated attics and installed a small, high-efficiency gas heater near the center of the house. Rooms near the heater were the warm zones. The disadvantage of this method is that the occupant has less control over temperatures throughout the house. Pipes may freeze in some cold areas, or other rooms may have to be kept too hot in order to heat rooms further from the heater. However, the old heating system can be turned on during extreme cold weather. Since only part of the house is heated, zoning necessitates a change in lifestyle to achieve large savings. For a single person living in a large house, zoning may work well.

Retrofitting oil furnaces with flame-retention burners is the most cost-effective HVAC measure of those that yield large savings. The costs of conserved energy (CCEs) for the three studies in the data base ranged from $1.90 to $2.90/million Btu. The Alliance to Save Energy also looked at the persistence of savings from flame-retention burners. They found that steady-state efficiency dropped only from 81% to 77% in a five-year post-retrofit period, even though many furnaces received no maintenance, such as changing air filters. Assuming a linear decay in efficiency, the payback period increases from 3.6 to 4.1 years. (Note: The Alliance used national energy prices and mixed results from two different climates, Maine and Wisconsin, so it is difficult to compare these payback periods to what would actually be expected in those or other states.)

The potential savings from retrofits involving condensing heat extractors are large, but the only data available to BECA are from a study where the hardware was poorly designed. The energy-saving principle behind a condensing heat extractor is to remove the heat of vaporization from the water vapor going up the chimney. The condensed vapor is then vented through a drain in the exhaust system. The Alliance to Save Energy's gas furnace retrofit pilot program installed condensing heat extractors at a cost of $720 each. The gas savings varied widely, averaging 14% in Kentucky but only 4% in Minnesota. Additionally, the electricity use of oversized 0.25 horsepower fans appeared to offset much of the gas savings.

When considering the economics and energy savings of furnace replacements, there are two ways to measure the effectiveness of the solution. The first is to attribute the entire cost and energy savings of the new furnace to higher efficiency. The second option is to assume that the furnace needed replacing anyway and attribute only the incremental cost between a high-efficiency model and a



R.W. Beckett

Flame-retention burners mix oil and air more completely than conventional burners to burn the fuel more thoroughly.

new baseline model to higher efficiency. The investment is then $300 to $600, rather than $2,000 to $3,000. In this second case, only the energy savings between the new baseline model (presumably more efficient than the old furnace) and the high efficiency model should be attributed to higher efficiency. Assuming a more efficient furnace is installed, the resultant energy savings are smaller than those listed in Table 2. However, the cost is reduced by a factor of five or more while the energy savings are reduced by approximately half. Thus, the second method will indicate that furnace replacements are much more cost-effective. For the analysis below and in Table 2, we have attributed the entire replacement cost to higher efficiency to give a "worst case" scenario.[3]

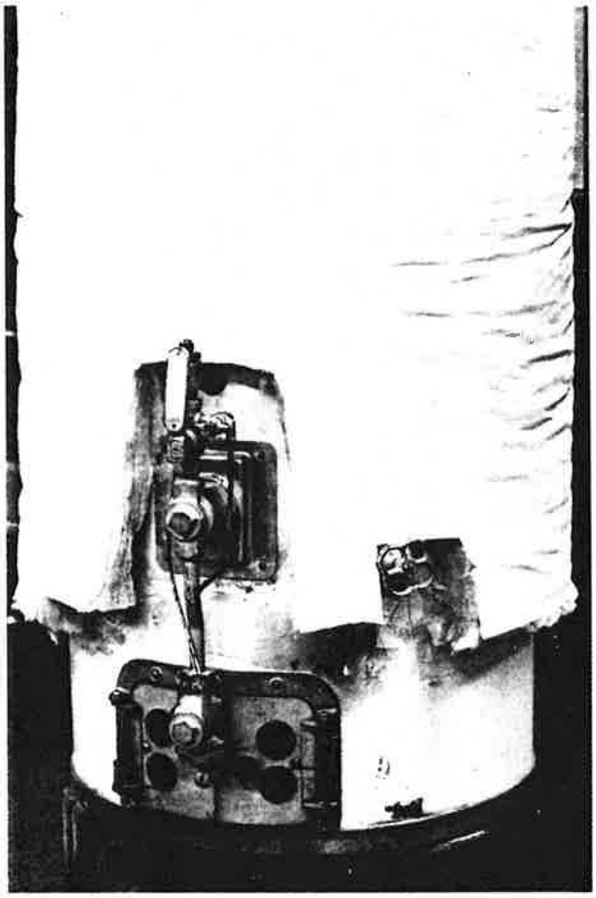
The 1984 Wisconsin low-income weatherization program achieved a CCE of $6.10/million Btu for furnace replacements, but no data were collected on the efficiency or capacity of the replacement furnaces. The Wisconsin Audit Field Test conducted by Oak Ridge National Laboratory (ORNL) found a $6.70/million Btu CCE for condensing furnaces with an average installed cost of $2,310. The Minneapolis Energy Office study on condensing furnace replacements showed a $15.00/million Btu CCE with an average cost of $4,750 for the new furnaces. The price for the Minneapolis study is excessive because condensing furnaces were new on the market at the time. Also, condensing furnaces may cost $100 to $200 more in warm climates where they are sold in lower volume.

Power burners are simple and reliable retrofits, with marginal economics. A fan pushes or pulls air through a heat exchanger. With the forced draft, a larger heat exchanger can be used and consequently more heat is removed from exhaust gases. The Alliance to Save Energy installed power burners on gas furnaces in Kentucky and Minnesota as part of a pilot program. The power burners cost $560 and had CCEs of $6.40 and $5.40/million Btu respectively.

Electronic ignition and vent damper combinations achieve savings by reducing off-cycle losses. Electronic ignition reduces energy use because it avoids an unnecessary, constantly burning pilot light. Vent dampers shut when the furnace is off and reduce convective losses up the chimney when the furnace has cycled off. The Alliance to Save Energy tested this combination retrofit in Minnesota, an extremely cold climate, and found a 4% savings. This retrofit might show larger savings in a milder climate where the furnace is constantly cycling on and off. For the one study in our data base (Minnesota), electronic ignition and vent damper combination retrofits cost $440 and showed a CCE of $10.00/million Btu.

A central air conditioning replacement study in Austin, Texas, showed a CCE of 14¢/kWh for new high-efficiency air conditioners with an average installed cost of $2,760. The average pre- and post-retrofit energy efficiency rating (EER) values were 6.8 and 11.4 respectively. The payback would be shorter if the air conditioner needed replacing anyway. Then, as with furnace replacements, the cost attributed to conservation would be only the incremental cost between a low- and high-efficiency replacement.

Another program studied in the BECA database, Hood River Conservation Project, was a five-year test of an extensive residential energy conservation retrofit program,



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Water heater tank wrap, which proved to save much energy in the Hood River Conservation Project.

offered free of charge to participants. This project showed the importance of water heating measures, which provided one-fourth of the electricity savings in these all-electric homes. The water heating measures included tank wraps, low-flow showerheads, and pipe insulation near the hot water tank. These measures cost, on average, only $30 per house out of a total average cost of $4,800, and resulted in paybacks of less than one year.

Recommendations

Don't be afraid to do low- or no-cost measures if they are simple tasks. The savings listed above document measured savings, mostly observed through whole house utility bill data. Small savings are often lost in the "noise" or are too small to be measured accurately. However, inexpensive measures with small energy savings can be just as cost effective, or more so, than expensive measures that save large amounts of energy. An example of this would be sealing the duct joints where the heating and/or cooling distribution system goes through an unconditioned space. Duct tape is cheap and little time is required to do the job. Intuitively, you know that you are saving energy, but you probably will not be able to see the difference due to other larger fluctuations in your energy bill. With more submetered data being collected, we hope to obtain information on measures that provide small savings. In conclusion, any house that does not have ceiling insulation or a

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highly insulated water heater should receive these retrofits. Any oil furnace that is less than 75% efficient and is expected to last more than five years should be retrofitted with a flame-retention burner. In cold climates, wall insulation is the next measure to install. Though it is expensive, the savings are large. Beyond this list, the order of retrofit measures depends on your climate and house. Remember, inexpensive and no-cost measures, such as sealing obvious air leaks and turning down thermostats at night, are virtually always worthwhile. ■

Endnotes

1. LBL Report 28147, October 1989. Available through The Building Energy Data Group: (415)486-7288.
2. Submetering involves direct measurement of the energy consumption of a particular device, rather than inferring it from whole house measurements (usually from utility bills).
3. See LBL Report 28147 for a comparison of the results of the two methodologies.

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Table 2. Average Savings and Economics of Individual Retrofits

Measure	Savings MBtu	%[1]	Cost[2] ($1989)	SPT (yrs)	CCE[3]
Shell Measures					
Wall insulation	19	12	1,600	12	$.73/therm
"	21	20	1,600	10	$.66/therm
"	19	17	810	6	$.36/therm
Ceiling insulation (R-0 to R-19)	15	13	690	6	$.44/therm
" (R-0 to R-19)	20	21	680	4	$.33/therm
" (R-11 to R-30)	20	13	500	6	$.24/therm
" (to R-30)	33	13	630	4	$.18/therm
Interior foundation insul. (R-0 to R-11)	20	15	2,090	17	$1.00/therm
" (R-0 to R-14)	6	6	2,180	61	$3.20/therm
Exterior foundation insul. (R-0 to R-10)	11	10	1,340	19	$1.20/therm
" (R-0 to R-10)	2	3	1,710	127	$6.70/therm
Warm room zoning	48	28	1,580	11	$.47/therm
"	31	23	2,400	12	$.85/therm
Heating and Cooling System Measures					
Condensing furnace replacement	28	16	4,750	24	$1.50/therm
"	30	24	2,310	11	$.67/therm
Forced draft furnace replacement	19	13	3,040	22	$1.40/therm
Forced draft boiler replacement	30	13	3,590	17	$1.00/therm
Furnace replacement (efficiency unknown)	26	20	1,860	10	$.61/therm
Condensing heat extractors	19	14	720	7	$.54/therm
"	7	4	720	23	$1.60/therm
Elec. vent damper and elec. ignition	6	4	440	14	$1.00/therm
Power gas burners	10	6	560	11	$.64/therm
"	11	6	560	10	$.54/therm
Flame-retention burners	20	23	560	5	.39¢/gal
"	22	14	460	2	.40¢/gal
"	32	25	570	2	.27¢/gal
Central air conditioner replacement	5	12	2,760	13	14.2¢/kWh
Hot Water System Measures					
Water heater wrap	3.4	8.4	30	0.6	6¢/kWh

1. Percent savings refers to the main space heating fuel only.
2. For central heating and cooling system replacements, the entire cost of the appliance, not the incremental cost, is considered.
3. Cost of conserved energy. (See box "Interpretation of Economic Indicators")