Advanced Retrofit: A Pilot Study in Maximum Residential Energy Efficiency

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In an effort to optimize the energy performance of existing single-family housing, the Advanced Retrofit pilot program was sponsored by Massachusetts Electric and administered by Conservation Services Group. The intent of the program was to advance the direction of energy conservation by achieving the highest energy savings possible, by combining field experience with innovative technologies in electrically heated homes. Cost-effectiveness was not a constraint in this pilot program. A random sample of electrically heated homes which had previously been treated through MECO's Residential Space Heat program received treatment. The treatment included advanced analysis and modeling of air flows and energy consumption, maximum air sealing of the building shell, and installation of a wide range of energy efficient measures, such as replacement windows and doors, insulation, efficient lamps and light fixtures, electronic thermostats, and ventilating heat pump water heaters. Billing analysis comparing pre-and post-treatment energy consumption was used to evaluate the savings. Preliminary results indicate that reductions in energy consumption of 25% can be achieved. The lessons learned from this pilot may point the way to greater potential cost-effective savings in conventional residential energy efficiency programs.

INTRODUCTION

The purpose of this paper is to describe an innovative pilot program called Advanced Retrofit sponsored by the Massachusetts Electric Company (MECO) and administered by Conservation Services Group (CSG) in 1995. The program was designed to maximize energy savings in electrically heated homes by installing energy conservation measures including new technologies and employing innovative weatherization strategies. Since the primary goal of the program was to acquire experience with new approaches, the project was carried out without constraints of cost-effectiveness.

Billing analysis comparing pre-and post-treatment energy consumption was used in a preliminary evaluation of the energy savings associated with the program. A follow-up evaluation is planned for the future when more post-treatment data are available. In addition to billing analysis, anecdotal information on process issues was collected from program participants and the vendor. This information was used to develop lessons learned and recommendations for potential future applications of the technologies or modifications to the existing residential energy efficiency program.

BACKGROUND

The 1990's have seen remarkable growth in both the scope and quality of energy conservation. While the Massachusetts Electric Company has offered an energy efficiency program to residential electric heat customers for over five years, recently interest has grown in achieving wider-scale application of efficient technologies. The idea of a pilot program to achieve increased energy savings grew out of the collaborative efforts of New England Electric System and the Conservation Law Foundation. Conservation Services Group which has many years of experience delivering MECO's Residential Space Heat program as well as other utilities' residential energy efficiency programs also provided significant technical assistance.

THE ADVANCED RETROFIT PILOT PROGRAM

Selection of participants in the pilot program formally began in February 1994. An initial group of 42 single family detached homes in four towns within the service territory was randomly selected for audit and evaluation. All of the homes had been treated through the Residential Space Heat program one to three years previously. Twenty-six homes were selected for treatment in the pilot program, based on the results of the audits. All of the homes in the final sample had electric heat as the primary heat source and had no coal or wood secondary heating; all had been tested for radon and had concentrations that posed no threat; and all had the homeowners' agreement. A variety of home styles, including ranch, Cape, and Colonial, were represented. Households ranged in size from 2 to 6 occupants; the occupants spanned a wide range in age. All were middle to high income households.

Based on the audits and evaluations, conservation plans were developed for each house in the program. The charge was to undertake all recommended customer-approved energy-efficiency actions which would produce significant energy savings. The target was to achieve a level of savings of 25% or more of base consumption. Currently, the Residential Space Heat program achieves savings which are 6% to 10% of base level consumption. This program recommends, arranges for, and pays for the installation of conservation measures in electrically-heated homes. The program is currently available to customers who have electric heat and live in one-to four-unit dwellings. Trained technicians conduct a home audit. Energy efficient measures are then installed by contractors hired by the Company. Measures may include additional attic insulation, night setback thermostats, air sealing and weather stripping, storm windows, electric water heating conservation measures such as tank wraps, showerheads and faucet aerators, compact fluorescent lamps, fluorescent fixtures, and educational materials. Some measures are installed at the time of the initial visit, while others require a second visit to the home by a contractor.

The Advanced Retrofit Program audits took place from May through July 1994. The audits and evaluations made use of advanced analysis methodology, including the use of infrared scans to determine locations of air leakage. Computer simulation of energy consumption with the REM building energy simulation model was used to assist in designing the energy efficiency strategies and predicting achievable levels of energy savings. Blower door tests and pressure diagnostics were performed at every site. (Pressure diagnostics using a digital manometer identify where the most important leaks occur).

The proposed energy efficiency strategies included a wide range of products and services which were modeled from a ‘‘whole system’’ perspective. A key strategy was maximum air sealing of the building shell. Conventionally air-sealing is done up to the minimum ventilation guideline, the level that still allows for fresh air in the house. However, in this pilot advanced methods were used when the Total Available Reduction (TAR) was unattainable. TAR is measured as the difference between the leakiness of the house initially and the minimum ventilation guideline. When TAR was exceeded, indoor mechanical ventilation at levels of 15 cubic feet per minute (cfm) per person were installed, allowing for maximum tightening of the shell.

As shown in Table 1, the energy efficient measures installed in the 26 homes included thermal, lighting, and water heating technologies. They ranged from existing technologies such as dense-pack air-sealing, low-e replacement windows with U-value .299, fireplace chimney-top dampers, and compact fluorescent light fixtures, to new technologies such as light-activated thermostats, E-tech domestic heat pump water heaters, and ventilating heat pump water heaters.

Brief descriptions of the measures installed are provided below:

Windows. Vinyl-framed double-paned low-e argon filled windows with heat mirror suspended film and U-value of .299 were used to replace either aluminum framed single paned windows without storm windows or to replace windows in evident disrepair.

Insulation. Cellulose up to R-60 was added in attics. Fiberglass batts up to R-30 were installed in basements. Cellulose insulation was added in houses where IR scan results indicated that the preexisting fiberglass batts were not effective. Follow-up inspection indicated that there was limited success in insulating walls.

Thermostats. Wall-mounted thermostats controlling electric baseboard heat were replaced with electronic light-sensitive setback thermostats. A 4 degree setback was used.

Air-Sealing. Three types of air-sealing were used in this program: (1) Recessed lighting in attics was replaced by air-tight recessed lights; (2) In addition, as mentioned in the paragraphs above, air-sealing employed traditional air-sealing techniques plus dense-packing between floors to a level exceeding the Total Available Reduction (TAR). Dense-packing involves blowing cellulose under high pressure into the joist cavity between floors in a house. Indoor mechanical ventilation was added when TAR was exceeded due to air-sealing. In most cases, 17 watt panasonic bath fans with programmable electronic timers were used to increase ventilation. (3) Spring-loaded chimney top dampers were installed to stop outdoor air at a distance further from the living space than conventional chimney dampers. Follow-up blower door tests indicated that these were not very effective.

Domestic Hot Water Measures. Three types of water heaters were used to replace conventional electric water heaters: (1) The E-tech heat pump water heater, which is an appendage to an existing water heater, and which draws energy from air nearby; (2) Ventilating heat pump water heater, which is an integrated unit and includes duct work, drawing energy from air from remote parts of the house; and (3) High efficiency electric water heater with an energy factor of 94.

Lighting. Interior incandescents were replaced with compact fluorescents and exterior incandescents were replaced with high-pressure sodium lamps or fluorescents lamps.

Installation of the measures began in August 1994 and was completed in early 1996. At the time of the preliminary impact evaluation, approximately 90% of the measures were installed. A summary of the number of measures installed and distribution of measure costs is presented in Table 1.

Table 1. *Measures Installed in the Advanced Retrofit Pilot Program*

Measure	Quantity/Description	% of Total Measure Cost	Average Measure $/House
Windows	19 houses, 290 windows	49%	$6,793
Insulation	26 houses	17%	$1,722
Thermostats	23 houses, 205 thermostats	7%	$ 833
Air Sealing	26 houses	6%	$ 661
DHW	8 E-techs	5%	$2,007
	2 Ventilating Heat Pump water heaters	3%	
	1 high efficiency water heater	0.4%	
Fixtures	20 houses	5%	$ 648
Ventilation	including:	2%	
	19 high quality bath fans		
	1 heat recovery ventilator (recaptures heat from exhaust air)		
Bulbs	300+ Compact Fluorescents	2%	$ 186
Chimalator	17 chimney covers	1%	$ 183
Airetraks	10 electronic speed cycle controllers for bath fans	0.2%	

Site management, carpentry, and other administrative costs are not included in the average measure costs per house shown below.

EVALUATION

Both process issues and energy impacts associated with this program were evaluated. Process evaluation issues included vendor and homeowner satisfaction with the installation process, the performance of the measures, and with how well the measures fit with the occupants' lifestyle. To date, only anecdotal information about process issues has been collected from Conservation Services Group and from customers. Some examples of field experiences are described in the following paragraphs. These anecdotes and other information collected by Conservation Services Group staff have produced a list of ''lessons learned'' and recommendations summarized below in Table 2.

In one house, the water heater was located in a finished basement where the grandchildren play. The occupants were concerned because the E-tech Heat Pump Water Heater was initially installed facing the basement area where the children play. The unit has fans which would be at the face level of a small child. The E-tech was subsequently moved to behind the water heater, more removed from the play area. In addition to improving the safety of the area, the sound of the unit was more muffled in the more remote location. The noise associated with the E-tech unit is comparable to that of a room air conditioner.

In another house, an E-tech unit was installed in an unfinished basement room. The dehumidifying effects of the E-tech unit contributed to the customer's decision to refinished the basement, effectively increasing the living space in the house.

In several houses, E-techs were deemed unsuitable because the existing water heater could not accommodate the unit. In some cases, the existing water heater could not be wired to the unit. E-tech units require sophisticated wiring, because back-up heat, fans, and the heat-pump itself must all be supported. In other cases, the water heater was too small to accommodate the family's needs with an E-tech unit. In a family for which a 30-gallon tank just meets its needs, a larger volume tank would be required with an E-tech unit, because the recovery rate of the E-tech unit is slower.

Table 2. *Lessons Learned and Recommendations from the Advanced Retrofit Pilot Program*

E-tech Domestic Hot Water Heat Pumps

- Evaluate the total environment in which the unit will operate, not just its mechanical environment. Determine whether it will be aesthetically acceptable, will block movement through a room, and whether it will susceptible to damage or will be exposed to children who may injure themselves.
- Determine the types of water tanks that are acceptable for this technology, with respect to volume, age, and thermostatic control wiring.
- Educate the occupants concerning the advantages and potential disadvantages of the units before they agree to accept one.

Lightstat Thermostats

- Evaluate the total environment in which the unit will operate.
- Educate the occupants concerning the advantages and potential disadvantages of the measure. These measures are very successful, but only when they do not conflict with occupants' life-style. For example, people who watch TV at low light levels were cold and dissatisfied due to the thermostat's heat setback.

Coordination of on-site work

- Have insulators and air-sealing crews work on the site together to increase efficiency and reduce burden to homeowner.
- Perform any attic access recessed light change-outs before or at the same time as insulation jobs.
- Allow extra lead time when obtaining new technologies to avoid disappointing homeowners with delays or changes in installation schedules.
- Recognize and prepare for the challenges of coordinating installations which require multiple trades (plumbers, electricians, etc.).

Several customers complained about light-sensitive thermostats in certain locations in their homes. For example, a customer who liked to watch television in low light was uncomfortable because the thermostat set the temperature back. Other customers did not like the thermostats in the bathrooms, because they did not like cold bathrooms. In one home, a light-sensitive thermostat was located on a wall in a second floor hallway where a stairwell light was needed to illuminate the stairs. Every time someone went upstairs, the thermostat clicked audibly as the light was blocked temporarily by the person passing the thermostat. The customer found the sound annoying. Finally, customers who are rarely home during the day were disappointed not to be able to have a daytime setback without readjusting the set temperature.

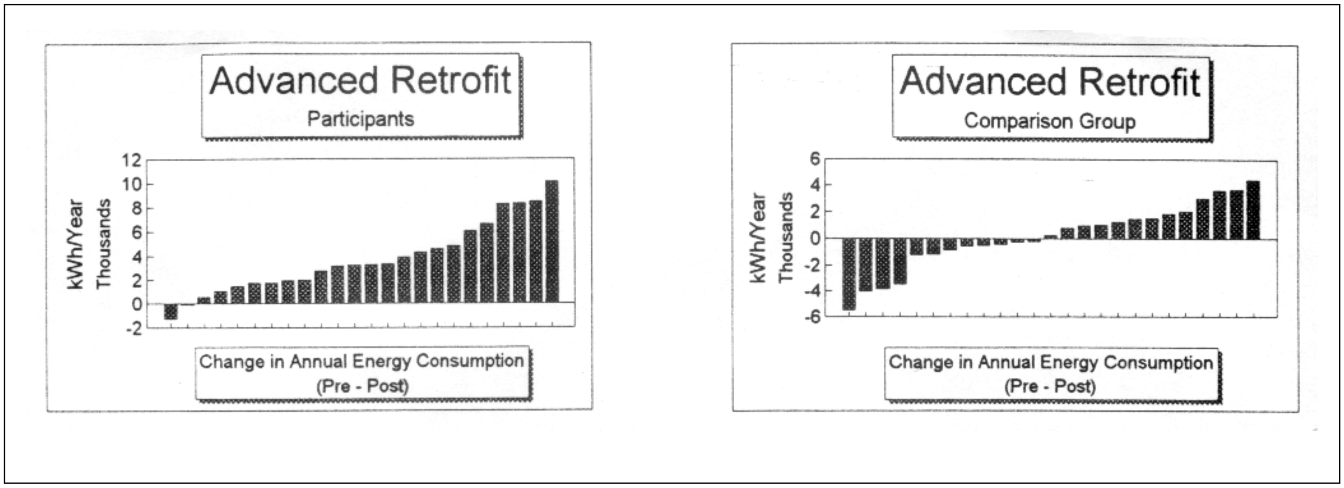
The impact evaluation assessed the energy savings produced as a result of the pilot program. It used a billing analysis to compare the change in weather-normalized annual energy usage before and after the pilot program. Results are based on energy usage estimates obtained from 24 of the 26 participants in the pilot program and a comparison group of 27 nonparticipants. Two of the houses in the pilot were eliminated from the analysis. One house was eliminated from the analysis because the base level energy consumption was an outlier when compared to the base usage of the other participants. The other was screened out based on diagnostic statistics generated in estimating annual energy usage. The comparison group was developed from customers in the four regions who were eligible to participate in the pilot but were not selected by the random sample, or whose homes had unacceptably high concentrations of radon but were otherwise eligible to participate.

Previous experience with engineering models indicated that they tend to overestimate energy savings. While they are able to disaggregate savings by specific end-use, their results are not currently confirmable. Therefore no attempt was made to disaggregate savings by specific end-use.

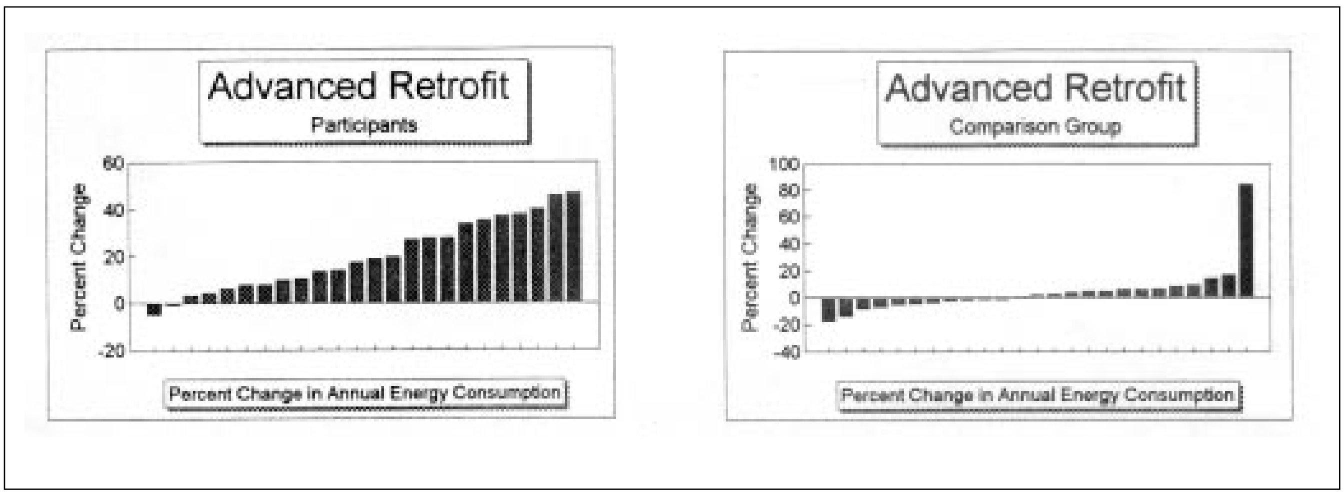
Average weather-normalized energy usage per household were estimated using the Princeton Scorekeeping Method (PRISM) software. Data required by the PRISM software includes historical temperature data, billing histories and accompanying meter read dates for each household. Data from the Worcester and Boston weather stations were used. PRISM is usually run using one full year of data from the pre-installation period and a full year from the post-period. In this analysis, the pre-installation period was from August 1992 through August 1993. The post-period was from December 1994 through July 1995. Energy savings are calculated as the difference in energy consumption in participants' homes before and after participation, adjusted by the change in the comparison group's energy use, to account for the effect of nonprogram-related factors.

Figure 1 illustrates the changes in annual energy use observed for each household included in the impact evaluation. Two of the 24 households in the pilot program increased energy consumption during the post-participation period. One household showed a relatively small increase in usage;

__Figure 1.__ Advanced Retrofit Program Preliminary Impact Evaluation



Change in annual energy consumption for each household participating in the Advanced Retrofit pilot program and each household in the comparison group.



Percent change in annual energy consumption for each household participating in the Advanced Retrofit pilot program and each household in the comparison group.

this may be due to the customer's increased use of a porch in which the windows were replaced. The other household with increased consumption in the post-period had an E-tech heat pump water heater installed in the basement office. The office is heated by an electric space heater. It is likely that the E-tech unit is drawing heat from the office space to heat the water, and that the customer has increased use of the space heater as a result. All other members of the pilot program decreased consumption. The decreases in consumption ranged from 500 to 10,100 kWh per year. By contrast, nearly half (13) of the 27 households in the comparison group increased consumption during the post-participation period. Half of the households in the control group decreased consumption. The decreases, ranging from 200 to 5,500 kWh per year, tended to be smaller than the decreases observed in the pilot households.

IMPACT EVALUATION RESULTS

Table 3 reports the change in average energy use per participant as determined by the billing analysis. The pilot and comparison groups are shown separately. On average, the households in the pilot program reduced energy usage by 3,743 kWh/year (90 percent confidence interval: ± 16% or 599 kWh). On average, households in the comparison group show a very slight increase in energy usage during the before and after period. However, this estimate is very imprecise,

Table 3. *Summary Results of Advanced Retrofit Program Billing Analysis Weather-Normalized kWh/year Usage Pre- and Post-Participation*

	Pilot Participants			Comparison Group		
	Pre	Post	Pre-Post	Pre	Post	Pre-Post
Average	24,074	20,331	3,743	28,065	28,100	−35
Std Dev.	6,750	6,289	2,881	9,651	12,303	5,320
n	24			27		

as indicated by the large standard deviation associated with the average Pre-Post value, shown in Table 3.

Adjusted savings are 3,602 kWh per year per household. These are estimated from the results shown in Table 3, using the following equation:

$$\text{Adjusted Energy Savings} = (A * B/C) - D$$

where: A = Pilot pre-installation consumption
B = Comparison post-installation consumptions
C = Comparison pre-installation consumption
D = Pilot post-installation consumption.

This estimate of average energy savings is 15% of base energy consumption in the pilot group. The savings are approximately 5% to 10% higher than the savings achieved in MECO's Residential Space Heat Program in 1994. This is especially noteworthy given that the savings from the pilot program are over and above savings achieved after recent participation in the conventional conservation program. The Advanced Retrofit program's energy savings estimates are preliminary and will be updated in the future. They were developed before all of the measures were installed and before a full year of post-participation billing history was available.

CONCLUSIONS

The Advanced Retrofit pilot program has generated significant energy savings as well as information which may be helpful in expanding existing residential energy efficiency programs. Among the information obtained from the program, key findings include:

(1) Innovative technologies, such as light-controlled thermostats and heat pump domestic water heaters, are not appropriate for all eligible customers. The technologies must be compatible with the occupants' lifestyles.

(2) Replacement windows accounted for nearly half of the measure costs in the program. Future evaluations should examine the relative contribution of replacement windows to the whole-system energy savings. If significant savings can be achieved without window replacements, the program would be more likely to be cost-effective.

(3) Additional insulation and the strategic air-sealing combined with mechanical ventilation where necessary are relatively low-cost measures that were recommended for every house in the pilot program. Increased energy savings could be achieved by treating a house more strategically through the traditional Residential Space Heat Program.

(4) While the savings achieved from the pilot are not cost-effective, the strategic approach to air-sealing and many measures including innovative technologies are relatively affordable and should be further evaluated for inclusion in conventional residential conservation programs.

Preliminary impact evaluation results from the Advanced Retrofit pilot program indicate that there is significant potential for energy savings beyond the savings achieved by the conventional energy efficiency program. Estimated savings of 15% of base usage were achieved. Taken together, savings of 5% to 10% of base usage from the initial (conventional) treatment of the houses and savings from the pilot program of 15% more suggest that savings on the order of 25% overall are achievable.

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