FUEL SAVINGS ANALYSIS: "HOUSE DOCTORING" AND STORM WINDOWS

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ABSTRACT

For the past three years the Massachusetts Audubon Society (MAS) and the Massachusetts Executive Office of Communities and Development (MEOCD) have conducted fuel savings evaluations on the low-income weatherization programs operated by MEOCD with funding from the U.S. Department of Energy and other sources. This year's study, which took place during the 1985-86 heating season, evaluated the fuel savings attributable to exterior storm windows and "house doctoring" (defined for this study as the use of a blower door and other instruments to locate hidden heat leaks in a building, and the sealing of these leaks).

Results indicate that house doctoring cut fuel consumption 8.9% ± 7.6% (95% confidence interval) while storm windows cut fuel consumption 9.6% ± 9.6%. Savings in a control group of untreated houses was 2.0% ± 8.7%. The simple payback period for the house doctoring work (at an energy cost of $7.10 per million Btu) was 8.1 years while that for storm windows was 6.1 years. Comparison with the results of last year's MAS/MEOCD study show that house doctoring is less cost-effective than the full Weatherization Assistance Program (WAP) operated by MEOCD and approximately the same cost-effectiveness as standard caulking and weatherstripping work. Storm windows are effective at saving energy, but given their fairly high cost, the fact that they are not always used properly, and the fact that they are exposed to the elements and deteriorate over time; they are probably not as cost-effective as the full WAP program.

Based on these findings, we recommend that storm windows remain, and house doctoring become, low-priority weatherization measures for MEOCD energy conservation programs. Generally, only after higher priority weatherization measures have been undertaken should house doctoring and storm windows be considered. However, some aspects of house doctoring may be suitable for inclusion in MEOCD programs.

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INTRODUCTION

During the winter of 1985-1986, the Massachusetts Audubon Society (MAS) conducted a fuel savings evaluation for the Massachusetts Exective Office of Communities and Development (MEOCD) that sought to evaluate the effectiveness of "house doctoring" and storm window installations in MEOCD's low-income weatherization programs.

This study follows two previous analyses undertaken by MAS for MEOCD during the winters of 1983-1984 and 1984-1985 (Nadel 1984a; Nadel, Meyer, and Granda, 1986). The first study showed that a fuel use monitoring method developed by MAS could be used to conduct single-season analyses of residential energy conservation measures (Nadel, 1984b). The second study analyzed a number of MEOCD's energy conservation programs and helped MEOCD restructure these programs for the 1985-1986 heating season.

Among the results of the second study was the finding that standard caulking and weatherstripping work did not save as much energy as had been expected. Studies in other states (e.g., Rodberg, 1986; Council on Economic Opportunity, 1985) indicated that "house doctoring," a new approach to weatherization, might be a better technique to employ.

"House doctoring" is an approach to energy analysis and retrofit originally developed at Princeton University. The basic concepts of "house doctoring" have been extensively described by others (see for example Harrje, et al., 1980; Diamond, et al., 1982). "House doctoring," in its pure form, involves:

1. Diagnosis of a house using special equipment such as a "blower door," infrared camera and a heating system combustion analyzer to locate air infiltration sites, thermal bypasses (places where heat moves around, rather than through, insulation), and convective loops (cyclical air movement patterns that bring cold air into a house and pull warm air away) and heating system inefficiencies;

2. Remedying of simple problems through the application of sealants, weatherstripping and small amounts of insulation, and through basic adjustments to heating and hot water systems; and

3. Prescription of additional major weatherization measures (such as a burner replacement or attic insulation) to take place after the "house doctor" has left.

For this study, since MEOCD already incorporated basic heating and hot water system improvements and major weatherization measures into its programs, MAS and MEOCD decided to examine only the air infiltration, thermal bypass and convective loop aspects of house doctoring. Specifically, this study sought to examine the heating energy savings and cost-effectiveness of these aspects of house doctoring and to determine how these aspects might best be incorporated into the MEOCD energy conservation programs. Therefore, throughout this paper, we will refer to "house doctors" and "house doctoring" (hereafter without quotation marks) as the contractors and the technology that seeks to reduce heat waste in buildings through reducing air infiltration rates, thermal bypasses, and convective loops using blower doors and other diagnostic and sealing equipment.

Concurrent with an examination of house doctoring, MAS carried out an evaluation of the heating savings attributable to storm window installation. While theoretical analyses, such as those based on heat loss calculations, have estimated the savings attributable to storm windows, MAS knew of no fuel savings analysis which measured the fuel savings actually achieved in houses receiving storm windows. MEOCD was interested in the economics of storm windows because, despite the fact they have moved storm windows to the bottom of their priority list of weatherization measures, storm windows are still installed in many houses served by their programs.

METHODOLOGY

Selection of Study Houses

MEOCD selected community action agencies that were willing to participate in the study. Each agency was asked to choose approximately 12 low-income houses that were heated exclusively by oil or gas central heating systems that did not also provide hot water. In addition the houses had to be suitable candidates for house doctoring work, storm window installation, or inclusion in the study's control group. Houses chosen for the house doctor group were one- and two-family houses that had not previously been served by MEOCD's Weatherization Assistance Program (WAP). Houses in the storm window group were one-, two- or three-family structures in which all or nearly all of the windows in the selected unit were single-glazed. Prior participation in WAP was not a selection criterion for this group. Most houses selected for the control group were participants in last year's MAS/MEOCD weatherization study.

Initial plans called for the house doctor and storm window groups to include 40 houses each, and a control group composed of 20 houses. The community action agencies however, were able to identify only 76 houses. Of these, 30 had to be dropped from the study because of: other weatherization work done on the study houses during the monitoring period (6 houses), premature removal of monitoring equipment (5 houses), clients moving/being hospitalized (3 houses), improper installation of monitoring equipment (3 houses), poor data quality (3 houses), excessively late monitoring equipment installation (2 houses), a major change in living habits during the monitoring period (2 houses), use of the kitchen stove for space heating (2 houses), inability of contractors to do weatherization work within the time and financial constraints of this project (2 houses), and other reasons (2 houses). With the attrition in the initial sample, we were left with a final sample of 29 house doctor houses, 11 storm window houses, and 6 control houses. The storm window sample was so small primarily due to difficulties finding houses with few or no storm windows. The control group was small because the attrition rate in the initial control group was over 50% -- all of the cases of late installation or premature removal of monitoring equipment discussed above occurred in the control group.

Monitoring Methodology

The fuel usage analysis technique employed was a slight modification of the system discussed in previous MAS papers (Nadel 1984b; Nadel and Meyer, 1985). During the approximately sixteen week study period (December, 1985 - March, 1986), conditions in each house were monitored using an electronic "temperature difference accumulator" and a run-time meter wired directly into the heating system.

The temperature difference accumulator monitors indoor-outdoor temperature differences. A digital read-out displays cumulative degree-hours difference Fahrenheit between two thermistors, one placed outside the house and the other placed in a typically heated location within the living space. Temperature difference data were converted into degree-hour data by subtracting 8° F for each hour the temperature difference accumulator ran.[1]

The burner timer is a 24-volt device that measures actual fuel burner run-time in hundredths of hours. A transformer was incorporated within the timer circuit so it could be used on 115 volt oil burners, 24 volt gas burners, and millivolt gas burners. In order to facilitate meter readings, thermostat wire was run from the burner or transformer to the living space so that the timer could be easily read. The timer exclusively measures heating energy use. Energy used for hot water and cooking was not included in the study.

The study was divided into two periods of approximately equal duration. The first, or baseline, period ran from December through January, and the

[1]Internal sources of heat, such as people, lights, and appliances, help heat a house. A house's central heating system runs whenever the outside temperature drops below the point where internal sources of heat are adequate to maintain comfortable indoor temperatures. Recent research has shown that this point, called the "balance point," varies from house to house, but averages approximately 60° F (Fels, 1985). Degree-hours is a measure of the difference between the average outdoor temperature for an hour and the balance point. According to heat loss theory, fuel consumption will be directly proportional to degree-hours. Degree-hours differs from indoor-outdoor temperature difference by the difference between average indoor temperature (assumed to be 68° F based on survey results from last year's MAS/MEOCD weatherization study) and the balance point (assumed to be 60° F).

second, or post-weatherization monitoring period, extended from February through the end of March. Monitoring actually ran into April, but, because of a warm spring, little useful data was gathered after the end of March. House doctoring and storm window installation occurred at the end of January and in early February. Because of delays getting monitoring equipment installed and weatherization work done, the precise dates of monitoring varied among houses.

Monitoring equipment was installed by agency personnel and heating system technicians. Meters were generally read weekly by the residents of the study houses and the readings were reported to agency personnel over the telephone on a weekly basis. Generally, meters in each house were read six to eight times during both the baseline and post-weatherization monitoring periods. At the beginning of the study, basic descriptive information was collected on each house and household. At the end of both the baseline and post-weatherization monitoring periods, questionnaires were administered to determine energy use habits and changes in energy use habits between the two monitoring periods.

Data Analysis

Data were analyzed using several statistical techniques. For each week of monitoring, the ratio of heating fuel consumption per degree-hour was computed. Mean savings for each house were calculated by dividing the mean pre-ratio into the difference between the mean pre-ratio and the mean post-ratio. A T-test was run to construct a 95% confidence interval around this mean. Analysis of variance (ANOVA) tests were run to figure the mean savings for groups of houses and 95% confidence intervals around these means.

In some cases temperature difference accumulator data was erratic or unavailable, due to installation, user, and electrical problems. In these cases, fuel consumption data was adjusted using degree day data (base 60) from a nearby weather station. The methodology is described in more detail in Nadel, Meyer, and Granda (1986).

WORK DONE

The house doctor group received caulking, urethane foam sealant, and other air-sealing improvements; the storm window group received standard exterior storm windows; and the control group received no treatment at all. As the work conducted on the storm window and control groups is straightforward, only the work done for the house doctoring group is described below.

For this study, three different house doctor contractors were selected in order that differences in technique might be observed among the contractors. All three contractors were instructed to use a blower door and other equipment to locate air leaks, thermal bypasses, and convective loops in the building shell. Leaks, bypasses, and loops were sealed using caulk, foam sealant, plastic sheeting, aluminum flashing and other materials. In order to prevent indoor air pollution problems, contractors were instructed not to reduce infiltration below 6 air changes per hour as measured by a blower door at 50 pascals of pressure. Within the confines of these instructions, the contractors employed significantly different techniques.

Contractor #1 worked on 19 houses (including 2 two-family homes) distributed throughout the state. They used a blower door and infrared scanner, and with a crew of two, weatherized each house in a day. Their work emphasized caulking and foaming bypasses and openings in the attic and basement, and included considerable re-engineering of attic access hatches and doors. They also did a limited amount of caulking and weatherstripping in living spaces. Their approach was similar to that discussed by Bliss (1984).

In contrast, Contractors #2 and #3 spent two to three days on each of 12 houses (including 1 two-family home,) working with a crew of two to three. Houses worked on by Contractors #2 and #3 averaged 40% larger than houses worked on by Contractor #1, which explains some of the difference between the contractors in time worked on each house. Contractors #2 and #3 used blower doors but did not use infrared scanners. Similar to Contractor #1, Contractors #2 and #3 spent much time caulking and foaming bypasses and openings in the attic and basement. The principal difference in the work done by these three contractors was that Contractors #2 and #3 weatherstripped and caulked virtually every door and window that faced unheated space. Their approach closely follows methods described by Energy, Mines, and Resources Canada (1984).

FUEL SAVINGS

House Doctoring

The largest body of data obtained was from the house doctored units. Heating fuel savings for individual houses ranged from -0.4% to 25.6%, with a mean savings and a 95% confidence interval of 8.9% ± 7.6%. In 18 houses weatherized by Contractor #1, savings averaged 7.5% ± 7.3% (95% confidence interval). In 11 houses weatherized by Contractors #2 and #3, savings averaged 11.2% ± 8.8%. The difference in savings between Contractor #1 and Contractors #2 and #3 are not statistically significant. The distribution of savings achieved in individual houses is illustrated in Figure 1.

Reductions in air infiltration in individual houses, as measured by a blower door at 50 pascals, ranged from 9% to 54% with a mean value of 24%. There was <u>no</u> relationship between the energy savings and infiltration reduction in individual houses (the r^2 of a regression equation explaining energy savings as a function of infiltration reduction was only .06).

We know of only two other studies which look at the energy savings attributable to the infiltration, thermal bypass and convective loop aspects of house doctoring. These studies report savings similar to or less than the savings measured in the MAS study.

Dickinson, et. al. (1982) report an average reduction in heating energy use of 9.2% in a sample of 17 houses which received 22 man-hours of house doctoring. However, they report 0% average heating energy savings in a sample of 20 houses which received only 10 man-hours of house doctoring.

Engels and Peach (1985) report a reduction in total energy use of 10% in 55 houses that received "super-weatherization" and house doctoring. Conventional caulking and weatherstripping was included in the super-weatherization package. In comparison, savings averaged 10% and 14% in two groups of 58 and 59 homes which received only house doctoring. Their study found that the difference in energy savings between house doctoring (as practiced in their study) and conventional caulking and weatherstripping was negligible.

Storm Windows

The storm window sample consisted of 11 houses served by five different community action agencies. Fuel savings in these houses ranged from -0.5% to 20.6%, with savings for the group averaging 9.6% ± 9.6% (95% confidence interval. The distribution of savings in individual houses is illustrated in Figure 2. We know of no other study with which we can compare results.

Control Group

Complete data sets were gathered for control houses from two agencies in eastern Massachusetts. Observed fuel savings in the control group ranged from -9.1% to 9.4% with a mean for the group of 2.0% ± 8.7% (95% confidence interval).

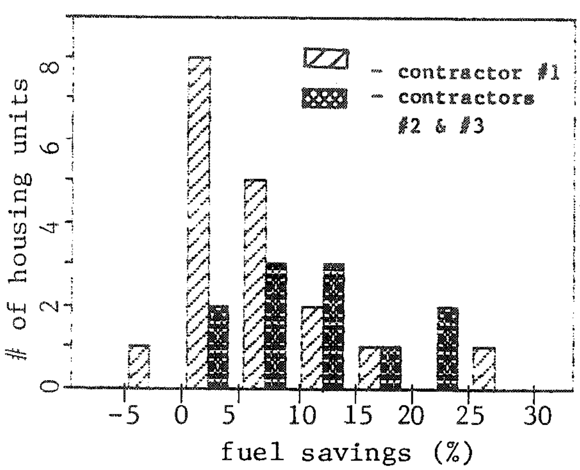

Figure 1. House doctor energy savings distribution.

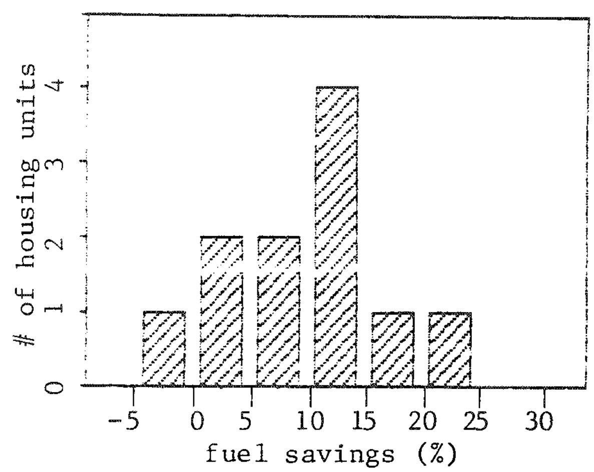

Figure 2. Storm window energy savings distribution.

Given the small sample sizes, the confidence intervals around the savings estimates are fairly large. The savings figures should thus be considered estimates rather than definitive figures. However, we believe these estimates are reliable because savings in the control group are near zero and because the savings estimates in this study are similar to those found in other studies.[2]

IMPACT OF WEATHERIZATION ON OCCUPANT COMFORT

The questionnaires administered at the end of each monitoring period asked residents to rate the comfort of their house during the preceding monitoring period on a one to four scale. Pre- and post-weatherization comfort ratings were compared and the results analyzed with a Wilcoxin Signed Rank Test. The storm window group showed the biggest improvement in comfort. Comfort ratings in the storm window group increased an average of 0.7. This increase is statistically significant at the 99% level. Homes served by Contractor #2 (the one who did the most extensive caulking and weatherstripping in the living space) showed the next biggest perceived comfort increase. Comfort ratings in these homes rose an average of 0.5. Due to the small sample size (8), this improvement is statistically significant at only the 80% level. Homes served by Contractor #1 (who did little caulking and weatherstripping in the living space) increased an average of only 0.1 rating point, while the control group showed no change in average comfort ratings.

ECONOMICS

Annual heating fuel use was estimated for each house by calculating pre-weatherization fuel consumption per degree-day (base 60) and multiplying these figures by 5500 degree days (which is approximately the average for Massachusetts at a base of 60°). Annual heating costs were estimated for each house by multiplying estimated annual fuel use by average Massachusetts fuel costs during the 1985-86 heating season ($1 per gallon of oil and $.70 per therm of natural gas). Post-weatherization heating fuel use and costs were estimated in a similar manner and savings due to weatherization calculated for each house and for the mean of all houses receiving a particular weatherization treatment. These figures, along with figures on average cost,

[2] As a further check on these study results, MAS is using the Princeton Scorekeeping Method (PRISM) to conduct further analyses on the houses in this study. Since PRISM requires shoulder period (spring and/or fall) fuel consumption data in addition to winter fuel consumption data, data analysis could not be completed in time for inclusion in this paper. Results of the PRISM analyses will be included in the final project report, which will be published by the Massachusetts Audubon Society in the summer of 1986.

simple payback period, estimated measure lifetime, and benefit-cost ratio for each weatherization technique examined in this study are reported in Table I. For comparison purposes, data on several of the weatherization measures examined in last year's MAS study (Nadel, Meyer, and Granda, 1986) are also included.

Due to the fact that these numbers are based on only two months of monitoring data and on a series of assumptions, these figures should be considered tentative rather than definitive. Also, some significant differences between groups in house size and initial energy efficiency (as measured in units of energy consumed per square foot of living space per degree day) contribute to making these economic figures approximate rather than definitive.

As can be seen in Table I, house doctoring is cost-effective (benefit-cost ratio greater than one), but its benefit-cost ratio is lower than the benefit-cost ratio for the full package of measures installed through MEOCD's basic or complete Weatherization Assistance Program (WAP). While house doctoring saves more energy and probably lasts longer than standard caulking and weatherstripping, house doctoring also costs considerably more. Overall, the benefit-cost ratio for house doctoring and standard caulking and weatherstripping appear to be similar. It should be noted that the benefit-cost ratio for rope caulk and plastic storm windows (including initial installation costs and assuming 50% of the materials are reused a second year) is higher than the ratio for either house doctoring or standard caulking and weatherstripping, although not as high as the ratio for the overall WAP program.

Storm windows appear to have a benefit-cost ratio higher than house doctoring but probably a little lower than the overall WAP program. However, these economic figures assume that storm windows will always be used and that their performance will not deteriorate over time. Since some improper use and deterioration can be expected, benefit-cost ratios will probably be lower. On the other hand, storm windows can have other benefits besides direct energy savings. For example, local weatherization program operators often install storm windows in situations where the primary window is starting to deteriorate but does not yet warrant replacement. The storm window protects and extends the life of the primary window, saving energy and a major maintenance expense. We did not attempt to quantify the value of this benefit.

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

House Doctoring and Related Measures

House doctoring, as defined in this study, produced statistically significant energy savings. House doctoring proved to be cost-effective (benefit-cost ratio greater than one), but the benefit-cost ratio for house doctoring was lower than the overall ratio for MEOCD's WAP program. Based on

Table I. Savings, cost, payback, and benefit-cost ratio of house doctoring, storm windows, and other weatherization measures.

Measures	Sample Size	Savings (%)	Annual Savings ($)[a]	Avg. Cost	Simple Payback (yrs)	Est. Lifet (yrs)[b]	Benefit Cost Ratio[c]
House Doctoring	29	8.9	$ 72	$ 584[d]	8.1	10-15	1.2-1.8
Storm Windows	11	9.6	119	720	6.1	10-15	1.7-2.5
Control group	6	2.0	2	0	-	-	-
WAP: basic[e]	47	21.2	197	1160	5.9	15	2.5
WAP: complete[e]	21	28.4	264	1413	5.4	15	2.8
Std. caulking, weatherstripping, and minor repairs	18	7.2	67	225	3.5	5	1.5
Rope caulk & plastic	29	11	102	65	.7	1.5	2.2

Notes:

a. Annual savings for house doctoring and storm windows were calculated for each house and for the mean of all houses. For the other measures, annual savings were estimated by multiplying the percent savings times an average fuel bill of $928 (which was the average fuel bill at 5500 degree days for the house doctor and storm window houses). Given large differences in average annual fuel bills between houses in this year's and last year's study, we felt that direct comparison of this year's and last year's fuel bill figures would be misleading.

b. Lifetimes were estimated by MAS in consultation with MEOCD staff.

c. Benefit-cost ratios were calculated by multiplying annual savings by the estimated average lifetime of the weatherization measure(s) and dividing by the cost of the measure(s).

d. Both Contractors #2 and #3 charged $0.45 per square foot of conditioned space. Contractor #1 charged more due to travel and lodging costs for crews to come from out-of-state. For these calculations, their standard in-state price of $0.45 per square foot was used.

e. "WAP: basic" denotes the basic Weatherization Assistance Program (WAP) as practiced in Massachusetts during the 1984-85 heating season. "WAP: complete" denotes a subsample of last year's study in which additional funds were made available so weatherization priorities (including heating system improvements, attic and sidewall insulation, and standard caulking, weatherstripping and minor repairs) could be completed. Recent changes to the Massachusetts WAP guidelines have made the 1985-86 Massachusetts WAP program nearly identical to the scope of work studied under "WAP: complete."

these findings, we recommend that house doctoring be a low priority weatherization measure in MEOCD's energy conservation programs.

While a thorough house doctoring job is only marginally cost-effective, the house doctoring contractors did find many large heat leaks in the houses they worked on. If conventional weatherization contractors spent a limited amount of time locating and sealing these large leaks, it would seem reasonable to expect that the savings would more than justify the cost. Auditors, crews and contractors working on the MEOCD energy conservation programs should be trained in the identification and sealing of these large leaks.

Living space caulking and weatherstripping (as practiced by Contractors #2 and #3 in this year's study and as studied in depth in last year's study) appear to increase occupants' comfort level. While living space caulking and weatherstripping is generally only marginally cost-effective, living space caulking and weatherstripping should probably remain part of the WAP program in houses with especially leaky windows and interiors and in houses where comfort, and not only energy savings, is a primary concern.

Other aspects of house doctoring not studied in this project are worthy of attention. One of the house doctor contractors employed in this project, in addition to plugging heat leaks, routinely does basic heating system adjustments, such as calibrating thermostats, balancing heating systems, installing low-flow showerheads, insulating water heaters, and checking furnace, boiler, and water heater set points. While this work was not included in this project (under instructions from MAS), these are important low-cost energy savers; MEOCD should make sure that this work is included in all houses served by its programs.

Storm Windows

Storm windows are cost-effective energy savers, but given their relatively high cost, the fact that they are not always used properly, and the fact that they are exposed to the elements and deteriorate over time, they are not as cost-effective as many other weatherization measures. MAS recommends that MEOCD continue its current policy of making storm windows a low-priority weatherization measure. Generally, only after higher-priority weatherization measures have been undertaken should storm windows be considered. The one exception to this rule is a situation in which a storm window will provide critical protection to a primary window. In this situation it may be cost-effective to allow a limited number of storm windows as a medium priority weatherization measure.

Evaluation Method

The fuel use analysis method used in this study provided a single-season determination of savings attributable to particular weatherization treatments. The weakness of the method is the attention required from local agency personnel throughout the monitoring period. The high attrition rate in our sample was primarily due to instances in which local agency personnel failed to adhere to our instructions. Future applications of this monitoring method should include greater centralization of work and/or greater care in the selection, training, and supervision of local agency personnel.

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