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THE M200 ENHANCED LOW INCOME WEATHERIZATION DEMONSTRATION PROJECT

ACEEE 1990 Summer Study on
Energy Efficiency in Buildings

Final Report

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The objective of the M200 Enhanced Low-Income Weatherization Demonstration Project was to refine and transfer enhanced weatherization procedures from pilot projects into an approach that could be implemented on a production basis. The protocol was based on a decentralized decision-making process, which gave the work staff the tools and responsibility for diagnosing the needs of each house, prescribing the necessary interventions, and ensuring job quality. The protocol was developed to show that large, cost-effective energy savings are attainable within the framework of current DOE and state weatherization guidelines.

During the summer of 1988, nine local non-profit agencies weatherized 128 low-income houses using the enhanced protocols. The results of the air-sealing work found an average 36% reduction in air leakiness per house. The average pre-weatherization normalized annual consumption was 1375 therms per house while the post-weatherization NAC was 1132 therms per house, for an average savings of 17.7%. The average cost per house for labor and materials of the weatherization work (including auditor, crew, furnace contractor, and inspection) was $1,306 and total program costs (including overhead and administration as well) of $1,570 per house. Simple payback of the weatherization cost was 10 to 11 years and the total program payback period was 12-13 years.

INTRODUCTION

The M200 Enhanced Low-Income Weatherization Demonstration Project was developed to show that cost-effective energy savings could be obtained within the framework of current DOE and state weatherization guidelines. The purpose of the project was twofold: 1) to refine and transfer the procedures for enhanced weatherization that have been identified by various pilot projects performed in Minnesota and elsewhere around the country, and 2) to incorporate these procedures into a production-based protocol that could be implemented by local weatherization agencies. The most important lesson learned from previous weatherization pilot projects is that the auditors and work crews must be well trained to perform the work effectively and must be provided with the resources and flexibility to do a good job.

The underlying philosophy of the approach recognizes that residential energy use is governed by a complex interaction of the building's thermal envelope, mechanical systems, and occupant lifestyle. The protocol was developed to deal effectively with each of these aspects. The approach taken for the demonstration project represents a paradigm shift in how weatherization work is implemented in Minnesota. Under current practice, the decision-making process for weatherization rests with the auditor who determines the work to be done from a priority list. The crew then receives the job order and performs the designated work. An objective of this project was to bring the work crews into the decision-making process, providing them with the responsibility for diagnosing most of the house shell, prescribing the necessary interventions, and ensuring that the job is done well. This approach reduces the task duplication and miscommunication often found with separate auditor and crew and fosters an attitude of worker participation and control in the weatherization process.

METHODOLOGY

Description of the M200 Weatherization Protocol

The M200 Weatherization Demonstration Project took place over a year and a half time period, begun in the spring of 1988. Nine agencies participated in the project: the three Twin Cities metro agencies and six agencies located throughout the remainder of the state. Ten work crews were chosen from these agencies. A one-week classroom training of the intake workers, auditors, work crews, inspectors, and state monitors took place during the middle of May 1988. In-field training was performed with each of the agencies, once during the early summer and later after the agencies completed several houses. Over the summer of 1988, 200 low-income homes were weatherized using the protocol, approximately 20 houses per crew. Fuel bill data for the 1987-1988 heating season were collected for each house. Comparison with the fuel use of the 1988-1989 heating season provided a measure of the energy savings and cost-effectiveness of the project.

The intent of the protocol was to combine the best-known proven techniques for insulation and air sealing with appropriate heating system measures (including furnace performance, proper distribution, and cost-effective retrofits). Existing procedures were modified to assure a safe and healthy environment for the occupants as well as durability for the house structure. A limit was set to air sealing consistent with ASHRAE standards for minimum ventilation. Special attention was given to correcting conditions leading to moisture problems and ice dams, and to eliminating sources of possible indoor air pollution emanating from the ground and/or combustion sources.

Other enhancements to the standard procedures included effective education of the residents to stimulate practices that save energy and reduce the risk of moisture and indoor air quality problems. Decision trees and checklists were developed for the auditors and work crews in order to provide the most cost-effective retrofits for each individual house. The work crew checklist is shown in Table 1. The blower door was used for pre-weatherization tests, during air sealing, and in post-weatherization inspections. In particular, a protocol was developed to stop air sealing when no longer cost-effective and to ensure ventilation needs (see Table 1). Sidewall insulation procedures were modified in order to (a) reduce conductive heat losses and (b) seal important air leakage sites that are difficult and time consuming to fix by conventional air-sealing methods (Fitzgerald et al. 1990). Infrared viewers for audits, air-sealing work, and post-weatherization inspections were made available to all the agencies and were used on about half of the houses.

Project Evaluation

Evaluation of the energy savings of the houses was performed using the Princeton Scorekeeping Method (PRISM) (Fels 1986). The program calculates a weather-normalized annual energy consumption, known as the Normalized Annual Consumption (NAC), which is a measure of the fuel consumption of a house under average weather conditions. Comparing the NAC values of the post-retrofit data with the pre-retrofit year provides a measure of the energy savings of the weatherization protocol, adjusted for differences in weather conditions of the two years being compared. In general, PRISM has been shown to provide a reliable index of consumption and has been extensively used to measure energy savings in retrofit programs (Fels 1986).

House Selection

Several restrictions on house selection were instituted to ensure that the relevant energy data were easily accessible, to simplify the analysis with monthly and bimonthly data, to eliminate the effect

Table 1. The M200 Project Work Crew Check List

1. Tube in wall insulation if:
    a. the existing insulation is 1" or less,
    b. the existing insulation does not fill the cavity and an air gap exists on the warm side of the wall, or
    c. regardless of the amount of wall insulation, there are critical areas in the wall that are major air leakage paths (found from blower door or IR camera diagnostics or common sense). Pack the cellulose at high density for air sealing at those sites.
2. Seal major air leaks and bypasses.
3. Blow in attic insulation if less than R-20.
4. Repair or replace storm windows.
5. Seal cold air returns.
6. Seal large leaks in the supply ducts.
7. Install water heater jacket and insulate 6' of hot water supply (if not done by auditor).
8. Install low-flow shower head (if not done by auditor).
9. Perform secondary air-sealing work until a 100 cfm_{50} reduction costs more than $40 or the minimum cfm standard is reached (1200 cfm_{50} for five or less occupants or the number of occupants * 225 cfm_{50} for six or more).
10. Pressure balancing tests. If negative pressure in the basement exists, check for and seal any missed leaks in the returns.
11. Insulate supply ducts if easily done and basement air temperatures can drop below 55°F.
12. Add rim joist and foundation insulation if economical. In particular, add foundation insulation for walkout basements and basement walls with greater than 40% exposure.

of a change in residents on energy use, and to provide reliable estimates of energy savings. For some agencies located in rural areas, the housing selected for the M200 project were not very representative. For these agencies, as much as 40% of their clientele reside in farm houses where the fuel sources used do not fit the selection criteria. Because many of the agencies did not have a large pool of houses that met all the selection criteria, the houses that were included in the study were not chosen entirely randomly. To fill the quota for each agency, houses were added to the project as they became available from fuel assistance records and fit the selection criteria.

For the evaluation, two additional criteria affected the eligibility of the houses in the study. To ensure the validity of the PRISM results, two PRISM statistical parameters were used to judge the fitness of the house's fuel bill data to the model: the R^2 of the PRISM best-fit regression line and the standard error of estimate of the NAC. A house remained in the study if the PRISM analysis of the pre- and post-weatherization data resulted in an R^2 greater than or equal to 0.95 and a standard error of 5% or less.

RESULTS

House Sample

From the analysis of the pre- and post-weatherization heating season data, 72 of the original 200 houses were dropped from the study because they failed to meet the analysis criteria. Of this final sample of 128 houses, 39% of the houses were weatherized by the three Twin Cities metro agencies while the remainder were distributed throughout the rest of the state. The sample distribution ranged from a minimum of seven houses for one agency to a maximum of 29 houses for another. Since many agencies in the state use a bidding process to select private contractors to perform their weatherization work on a per house basis, eight of the 128 houses were weatherized by a contractor-bidding agency. This small experiment examined how the M200 protocol could be modified to permit pre-specified job orders for the bidding process.

Of the houses surveyed from the 128 house sample, 97% were occupied by homeowners and the remaining 3% were rented. The average number of occupants was 2.8 people, with 34% of the houses containing one occupant, 16% with two occupants, 17% with three people, and the remaining 33% with four or more residents. The average age for the head of the household was 52 years, with 37% of the houses having a head of household greater than 60 years old. Eleven per cent of the houses had a handicapped person in residence.

Ninety-seven percent of the homes were heated with natural gas while the remainder (four houses) were heated electrically. Of the natural gas homes, 16% had hydronic systems, 5% used a gravity hot air system, and 79% had forced air furnaces. Thirty-nine percent of the homes had air conditioning, with 10% of the sample having central air. The average living space floor area was 1,346 square feet and the average exposed surface area (above-grade wall and roof) was 2,182 square feet. Thirty-five percent of the homes sampled were one story, 25% were story-and-a-half homes, 6% were split level, 29% were two story homes, and 5% were two story with a walkout basement.

Work Done and Costs

For the overall sample, 51% of the homes received some wall insulation work. Seventy percent of the homes received attic bypass sealing work and some additional attic insulation. Forty seven percent of the houses received rim joist insulation while only 16% received some foundation insulation, divided evenly between exterior and interior applications. In terms of window work, 35% required broken glass repair (at an average cost of $21 for labor and materials) and 32% received some caulking, weatherstripping, and/or repair of windows and sashes (at an average cost of $104). Only two homes had storm doors repaired or replaced and 11 homes had work done on the primary doors. The average cost for the storm door work was $179 and an average of $293 was spent on the primary door repair or replacement. Twenty percent of the sample received clock thermostats at an average cost of $67 while 66% had work done on the heating system at an average cost of $145. Seventy percent of the homes received a water heater wrap, costing an average of $14. Two households did *not* require a weatherization crew visit at all.

The average cost for weatherization work done on the 128 house sample (including auditor, work crew, furnace contractor, and inspection) was $1,306. The reported average labor costs were $822. This results in a 63/37 split in labor to materials costs for the M200 protocol. DOE guidelines specify a maximum 60/40 split. When the programmatic costs reflecting overhead and administration are included, the total cost for the M200 work was $1,571. This is within the DOE guideline of $1,600 per house for the average programmatic cost for low-income weatherization. Since eight homes received work according to the experimental contractor-bid protocol, removing these houses from the total sample may provide a clearer reflection of the performance of the M200 protocol. For the 120 house sample, the average weatherization work cost was $1,294 per house and total programmatic costs were $1,558 per house.

Energy Use

For the total 128 house sample, the average pre-weatherization normalized annual consumption (NAC) was 1375 therms per house. This represents an annual fuel bill of $687.50 (assuming a natural gas cost of $0.50 per therm). Since only four homes were electrically heated, all energy use data was converted to therms and energy costs were calculated according to natural gas costs for simplicity. Pre-weatherization energy use ranged from a maximum of 2712 therms to a minimum of 583 therms. For the post-weatherization year, the average NAC was 1132 therms per house, with a maximum of 2217 therms and a minimum of 486 therms. The average reduction in energy use, therefore, was 243 therms per house and a savings of 17.7%. The average post-weatherization annual fuel bill was reduced to $566, for a cost savings of $121.50 per year. With a weatherization cost of $1,306.46 per house, the average simple payback for the 128 house sample is 10.8 years. The average simple payback for total programmatic costs is 12.9 years. For the 120 unit sample (excluding the 8 contractor-bid houses), the average energy savings was 18.2%, with a weatherization work payback of 10.2 years and a programmatic payback of 12.3 years.

Air Leakage Reduction

The blower door measurements before and after weatherization give a measure of the air leakage reduction resulting from the retrofits. For the total 128 house sample, the weatherization work produced an average 35.8% reduction in air leakiness per house, going from an average pre-weatherization blower door reading of 2433 cfm_{50} down to 1563 cfm_{50} post-weatherization.

DISCUSSION

The discussion of findings will focus on the results obtained by the 120-unit sample of houses weatherized by the eight agencies using in-house work crews. The poor energy savings of the contractor-bidding agency (over 30 year paybacks) show that adoption of the M200 protocol under the constraints of a bidding process is problematic. The level of detail of the job order needed for the bidding process served to countermand the decision-making process which brought cost-effective savings to the other eight agencies. Since the M200 protocol was designed for agencies using in-house crews, the analysis of the 120 house sample should provide a fairer measure of the efficacy of the protocol.

Comparison of Savings with the State-Wide Utility Bill Study

The 18.2% savings and the 10.2 year simple payback of the 120 house sample represents a substantial improvement over the savings provided by the standard Minnesota weatherization protocols. In 1986, a state-wide evaluation of the low-income weatherization program in Minnesota was performed (Carmody 1986). A random sample of 221 units weatherized over the summer of 1984 was collected from the files of the 29 Community Action Program, county, and other non-profit weatherization agencies that had participated in the program. PRISM analysis of the pre- and post-weatherization years showed an average 7.8% fuel savings. Adjusting for changes in fuel use for a control group produced a net overall program savings of 9.5%. The total program cost (materials, labor, overhead, and administration) in 1984 was $1450 per house. Of the 221 unit sample, 155 houses were single family detached housing (the remainder being multifamily units and mobile homes). For the single-family houses, the average fuel savings was 9.3%. Adjusting for the control group makes the net savings 10.9%. With a pre-weatherization consumption of 1259 therms and a post-weatherization consumption of 1142 therms, the simple payback of the total programmatic costs is 24.8 years for single family, detached homes.

No statewide control group was available to gauge the changes in energy conservation behavior between the pre- and post-weatherization years of the M200 houses. As an alternative, however, aggregate utility bill data can be used as a control group. Results from an aggregate energy use study by the Center for Energy and the Urban Environment for residential natural gas customers within the City of Minneapolis show that the aggregate mean natural gas consumption went down by 0.3% during the same time period as the M200 project (Dunsworth, personal communication, 1989). The net overall program savings of the M200 protocol would be adjusted to 17.9%. Using this energy use change as a control, the M200 project increased the net adjusted per cent savings by 160% over the results from the 1986 statewide utility bill study (to be referred to henceforth as the "Utility Bill Study"). Programmatic payback periods were nearly halved by the demonstration project.

When comparing the results of different weatherization program evaluations, it is important to recognize that discrepancies in energy savings may be attributed to differences in housing sample rather than weatherization methodologies. Because higher pre-weatherization consumption generally results in higher energy savings, differences in the average pre-weatherization NAC of a sample may contribute to the improved savings of the M200 Project. As described above, the average pre-weatherization NAC for the 1986 Utility Bill Study was 1259 therms while the average pre-weatherization NAC for the M200 Demo was 1375 therms, about 9% greater than the Utility Bill Study. Figure 1 shows the breakdown in number of houses in the M200 and Utility Bill Study samples over various ranges of pre-weatherization fuel consumption. The figure shows that for both samples, the houses are normally distributed through the range of NAC values with the majority of the Utility Bill Study houses having an NAC of 800 to 1600 therms. The M200 houses have the largest sample in the range of 1200-1600 therms and nearly three times the number of houses in the highest consumer range (over 1600 therms). While these differences in pre-weatherization NAC do indicate a greater potential for energy savings for the M200 project, these differences cannot be considered the sole reason for the improvements in cost-effectiveness.

Figure 2 shows a comparison of energy savings provided by the two studies for the various ranges of pre-weatherization fuel consumption. For the single family homes of the Utility Bill Study, the greatest percent energy savings (almost 15%) were obtained for the high consumers, using over 2000 therms. Savings for the lowest consumers were 11.5% while the majority of Utility Bill houses enjoyed savings in the 8-10% range. The M200 houses obtained the smallest level of savings for the lowest consumers (7%), with steadily increasing savings for the higher consumers, up to 2000 therms. With the exception of the low consumers, the M200 houses obtained at least 50% greater savings than the corresponding Utility Bill houses and, in the case of houses using 1200 to 2000 therms of energy, over twice the savings. Thus, even though the M200 sample had a higher average pre-weatherization fuel use than the Utility Bill Study homes, comparison of house samples with similar pre-weatherization fuel use shows that the M200 homes obtained substantially higher energy savings for pre-weatherization fuel use greater than 800 therms.

The pattern in Figure 2 indicates how well the M200 protocol identified energy savings opportunities. With the lower consumers, savings opportunities are typically fairly limited and the marginal cost of increased energy savings rather high. For these houses, some cost-effective savings are expected but overall savings are not expected to be of the same extent as the higher consumers. The lower savings observed for the low consuming M200 homes are a response to the goal of minimizing ineffective work and providing higher program cost-effectiveness. As the pre-weatherization fuel use increases, the opportunities for savings increase and the marginal costs of capitalizing on these opportunities permit more cost-effective weatherization work to be performed.

Energy Savings of the M200 Project

The overall savings of the 120 house sample of the M200 project was 18.2%. Figure 3 shows a scatter plot of the energy savings per dollar of weatherization work versus pre-weatherization NAC of this sample. Despite the scatter of the data, the results show a general trend of increasing cost-effectiveness with higher pre-weatherization fuel consumption. Because the possibilities for cost-effective savings should be more pronounced with the higher consumers, the results show that the work performed is, for the most part, taking advantage of these savings opportunities. All the negative savers have a pre-weatherization NAC of less than 1300 therms. These low consumers typically will not provide many opportunities for cost-effective weatherization work and the weatherization effort should be proportionately less for these homes.

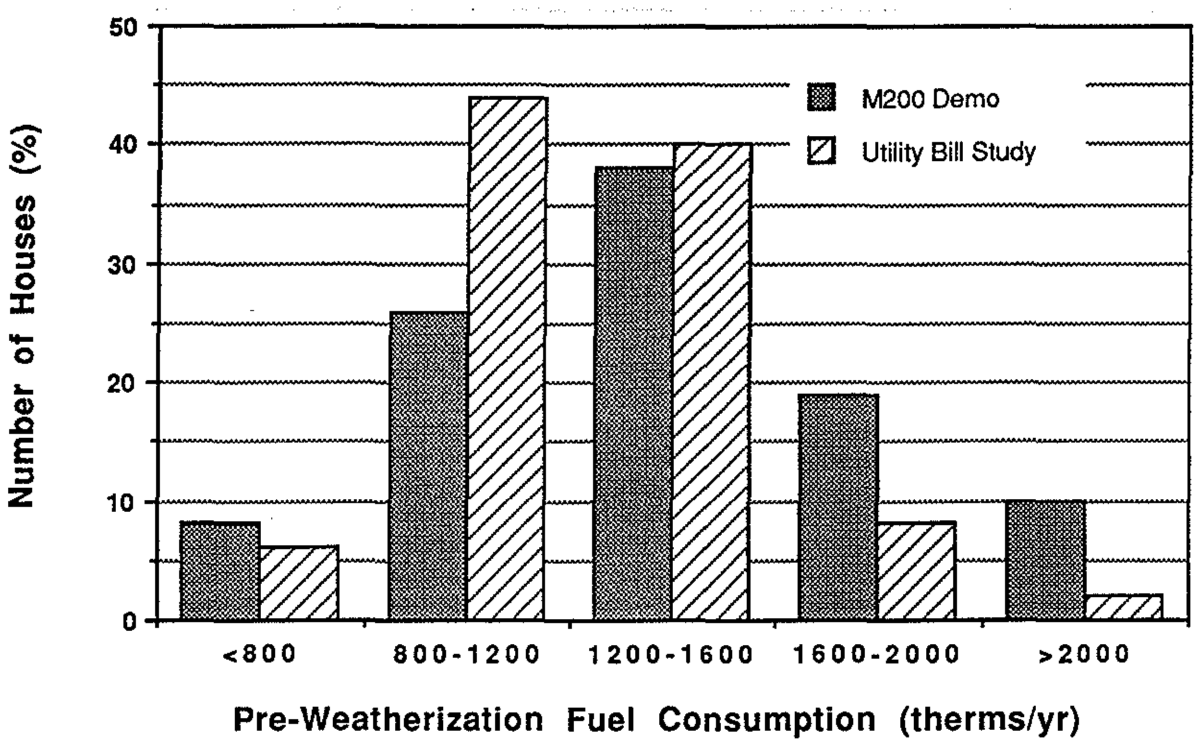

Figure 1. *Comparison of the House Sample Breakdown by Pre-Weatherization Fuel Consumption Between the M200 Project and the 1986 Utility Bill Study*

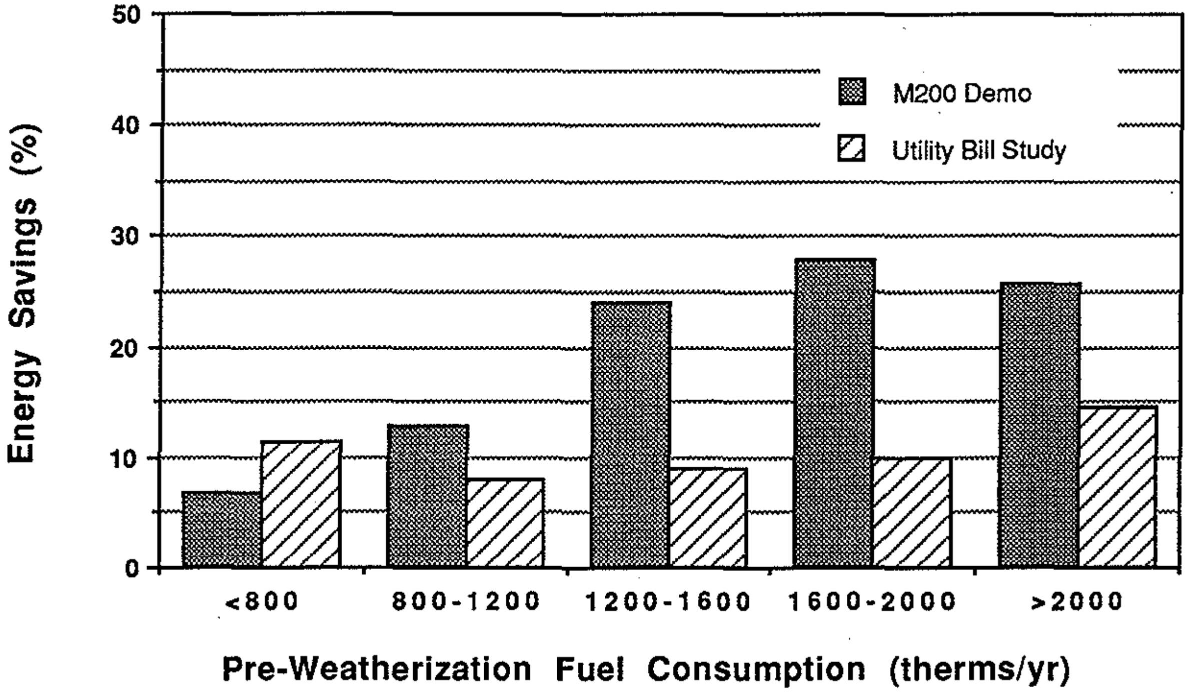

Figure 2. *Comparison of the Energy Savings Breakdown by Pre-Weatherization Fuel Consumption Between the M200 Project and the 1986 Utility Bill Study*

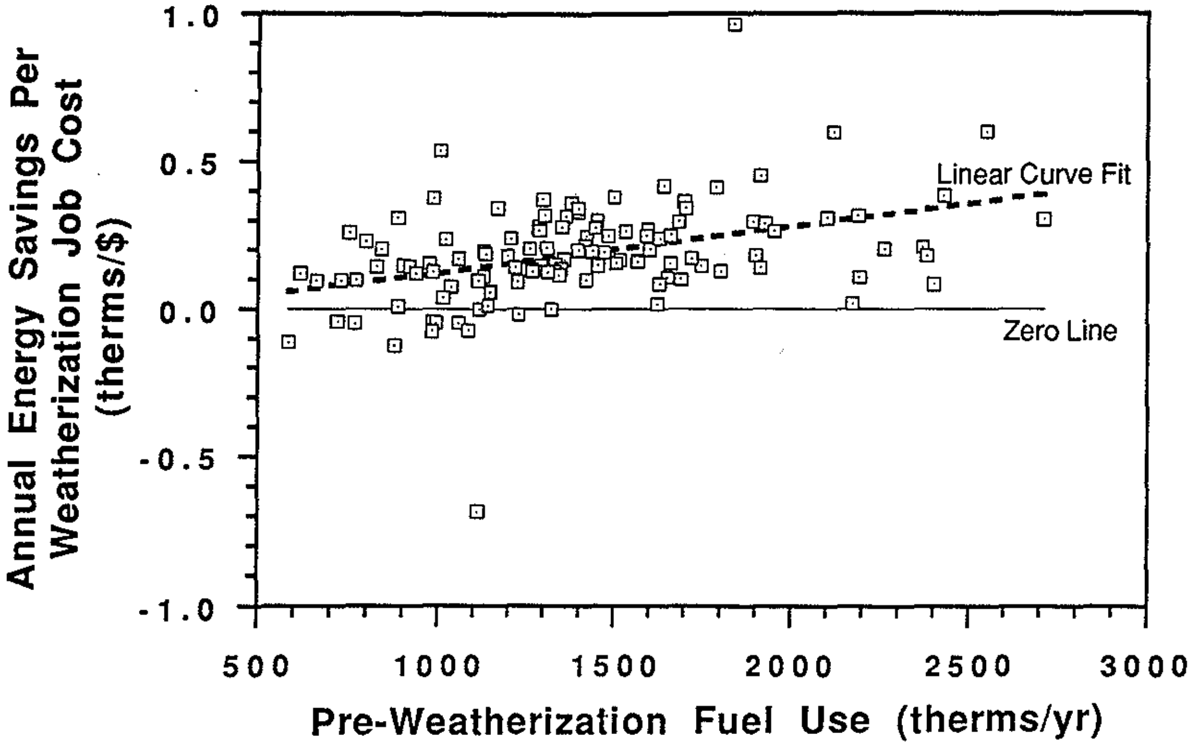

Figure 3. Comparison of the Annual Energy Savings Per Weatherization Job Cost Versus the Pre-Weatherization Fuel Consumption

PRISM results are also provided in terms of the heating-only NAC. This separates out the base load use for each house and provides an indication of the impact of weatherization on the heating energy use. For the 120 house sample, the average pre-weatherization heating-only NAC was 1123 therms per house. Since only two of the 120 houses were electrically heated, these homes were ignored. Pre-weatherization heating-only energy use ranged from a maximum of 2433 therms to a minimum of 450 therms. For the post-weatherization year, the average heating-only NAC was 840 therms per house, with a maximum of 2300 therms and a minimum of 357 therms. The average reduction in energy use, therefore, was 283 therms, for a savings of 25.2%.

Typical base load use in the natural gas heated homes was domestic hot water and cooking. The average pre-weatherization base load was 289 therms per year and, after weatherization, the average base load use increased by 4%, to 302 therms. While this result suggests a deficiency in the project concerning base load gas use, it should be remembered that the individual PRISM parameters "provide physically meaningful *indicators*" but "changes [in their values due to weatherization] may not be statistically significant." (Fels 1986)

Air Sealing

For the 120 house sample, the average pre-weatherization blower door reading was 2483 cubic feet per minute at a house depressurization of 50 Pascals, with all interior and basement doors open (cfm_{50}). Weatherization produced an average reduction of 36.1% down to an average final reading of 1586 cfm_{50}. An integral part of the M200 protocol was the use of blower doors by the weatherization crews. The object of the blower doors was to aid in finding obscure air leakage sites and to provide a measure for establishing the cost-effectiveness of the air-sealing. Figure 4 shows the pre- and post-weatherization blower door results for the 120 house sample. Results are shown in terms of cfm_{50}. In addition to the scatterplot of the data, two

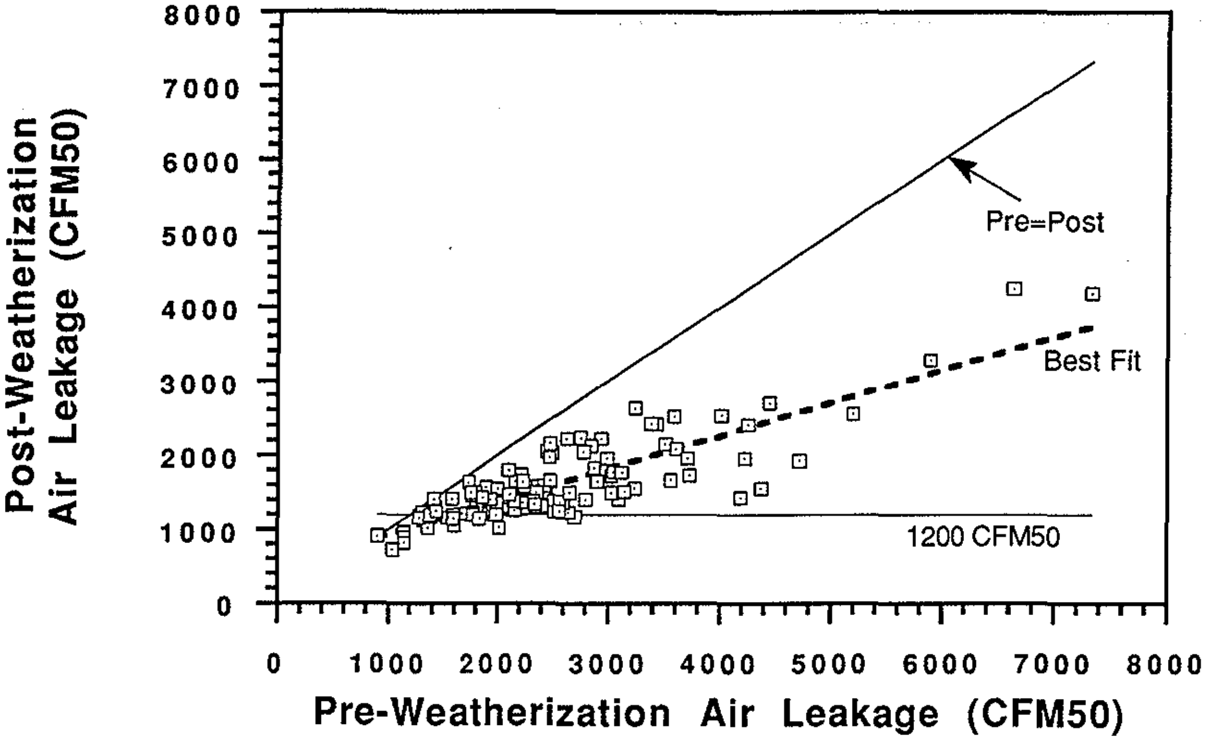

Figure 4. Comparison of the Post-Weatherization Air Leakage Versus the Pre-Weatherization Air Leakage of the M200 Project Houses

solid lines are also drawn on the graph: the post=pre line signifying no change in airtightness and the 1200 cfm_{50} line representing the minimum airtightness limit to air-sealing used in the M200 protocol. Most of the data points lie within the area demarcated by the two solid lines and exhibit a wide scatter below a pre-weatherization blower door measurement of 4500 cfm_{50}. Post-weatherization blower door readings below 1200 cfm_{50} mainly occur for houses starting at 2000 cfm_{50} or less. Houses with pre-blower door readings of 1200 cfm_{50} or below also received some air-sealing work to improve comfort and control moisture. For all homes with a final blower door measurement below 1200 cfm_{50}, makeup air was provided to the furnace.

The dashed line running through the data points is a linear regression of the air-sealing data. While the regression fit bisects the scatter of data points, the temptation to use the regression line as a means of setting air-sealing goals should be tempered by the scatter surrounding the line. Because of the wide variety of conditions that result in air leakage, prediction of air leakage reduction from pre-blower door measurements should be considered haphazard at best. Agency material and labor costs, the expertise of the work crew, and the existing condition of the house make cost-effective air-leakage goals difficult to determine.

Client Comfort

At the end of the post-weatherization heating season, residents were sent questionnaires asking about thermal comfort in their homes. Of the 73 who responded to the questionnaire, 57 reported increased comfort, 6 reported no difference, and 10 weren't sure. The respondents were asked to rank the comfort in the home on a scale of 1 (cold) through 3 (pleasant) to 5 (hot). The average rank before the weatherization work was done was 1.9. The average comfort rank after the weatherization was done was 3.2, for an average increase in comfort of 1.3 units. For those respondents who noticed an increase in comfort, 32 of the 57 also reported lowering their daytime thermostat settings after weatherization, from an average setting of 72°F pre-weatherization to a post-weatherization setting of

68°F. Thirty of these respondents also exhibited a change in their nighttime thermostat setting, from a 69°F average down to an average setting of 65°F. For the 25 respondents who reported increased comfort but did not change their thermostat settings, their average daytime setting was 69°F and their nighttime setting was 65°F. Three of the residents who responded that they had experienced no change in comfort indicated that the comfort level they experienced before weatherization was achieved by turning their thermostats way up. After the weatherization work, they were able to achieve the same comfort level at a lower thermostat setting. Of the 16 respondents who either reported no change or were uncertain of a change in comfort, 13 made no change in their daytime or nighttime settings. Their average setting in the daytime was 74°F and their average nighttime setting was 67°F.

In terms of perceived comfort for these three groups, the respondents who noticed a difference in comfort and also lowered their thermostat setting, the original comfort level was 1.7 on average. This increased to 3.3 after weatherization. For those who noticed increased comfort but kept their thermostat setting unchanged, the average comfort level was 1.8 and 3.4 before and after weatherization. The respondents who did not notice any change in comfort and did not modify their thermostat settings, the average pre-weatherization comfort level was 2.5 and the average post-weatherization comfort level was 2.7.

In summary, nearly half of the respondents (32 out of the 73 respondents) found that the weatherization work not only increased the comfort levels of their homes but provided an additional energy benefit by allowing them to reduce their thermostat settings. The respondents who reported either uncertainty or no change in comfort maintained their thermostat settings at a fairly high level. This suggests that these occupants did not adopt some of the lifestyle changes advocated in consumer education. Although their reported comfort level prior to weatherization was slightly higher than the group that reported a change, the no change group reported an average post-weatherization comfort level lower than the group that reported a comfort change.

Empowerment of the Work Force

An often overlooked but extremely important facet of a successful weatherization program is providing conditions for the workers to perform at their optimum level. An integral aspect of the M200 protocol was to provide the auditors and crews with the flexibility and control to take ownership of the project and to strive for better results. At the conclusion of the project, the nine participating weatherization agency directors were interviewed to gauge their impressions of the M200 project. The high morale of the workers was cited as the most important benefit of the project. One director commented that by abandoning a fixed approach, crews got out of their trance. Because of the problem-solving approach of the protocol, they dropped their zombie-like attitudes and began to search out problems. The protocol brought an increased sense of adventurousness which increased worker initiative and led to higher performance and greater job satisfaction. Giving the crews an analytical approach to their work provided them with tangible results and gave them an immediate response to and reinforcement of their workmanship.

CONCLUDING REMARKS

The M200 protocol was designed to provide cost-effective energy savings, maintain healthy interior environments, improve structural durability, and aid low-income occupants in learning ways to manage their energy use and comfort. The underlying philosophy of the approach recognizes that residential energy use is governed by a complex interaction of the building's thermal envelope, mechanical systems, and occupant lifestyle. The results of the study show that large, cost-effective energy savings (18% savings and 10 year paybacks) are achievable within the framework of current DOE and state weatherization guidelines.

The M200 experience is being used to develop an improved weatherization program for wider application. This program (known as the MWX90) is similar to the M200 protocol with one major difference: one energy advisor replaces the two auditors to reduce program costs. A two volume training manual and videotape case studies of the MWX90 approach are forthcoming.

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