ANALYSIS OF WEATHERIZATION MEASURES IN LOW-INCOME MOBILE HOMES

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Abstract

This study assesses the effectiveness of energy conservation measures (ECMs) installed in mobile homes during the summer of 1986. The ECMs were based on new weatherization techniques developed by the Energy Resources Center (ERC) of the University of Illinois at Chicago (UIC) for the Illinois Department of Commerce and Communities Affairs (DCCA) and presented in the "Mobile Home Retrofit Handbook" (Knight and Rangelov, 1986).

Energy savings of 546 program participants, that had their mobile homes weatherized between May 1986 and September 1986, were assessed. In addition, energy consumption for a control group of 301 mobile home residents that had been approved for weatherization, but had not received weatherization assistance as of August 1987, were also assessed. Overall savings in aggregate "normalized annual consumption" was 6.5% (for all weatherized mobile homes having an R^2 of greater than 0.80). The overall control sample showed no changes in the energy use behavior of the mobile home residents.

A statistical analysis to evaluate average energy savings and a cost-benefits analysis to identify the economic effectiveness of the various retrofit measures was performed. Changes in energy consumption for the different climatic regions of the State of Illinois were also estimated.

Introduction

The Illinois Department of Commerce and Community Affairs (DCCA) administers the Illinois Home Weatherization Assistance Program (IHWAP). In 1984, DCCA funded Arthur D. Little, Inc. to assess the effectiveness of the energy conservation measures (ECMs) installed under the IHWAP. Preliminary results indicated that weatherization did not prove effective, on average, for mobile homes. Based on these results, the DCCA funded ERC to provide technical assistance for the mobile home weatherization program. This assistance included the development of the ***Mobile Home Retrofit Handbook*** (Knight and Rangelov, 1986). In addition, ERC conducted workshops to train Local Administering Agencies (LAAs) and their work crews in the techniques presented in the ***Handbook***. The workshops trained LAAs in new mobile home retrofit methods and identified retrofits that when field installed proved too labor intensive and not very durable. In 1986, the ***Handbook*** was revised to reflect these findings.

In 1987, ERC evaluated the performance of materials and installation techniques recommended in the ***Mobile Home Retrofit Handbook*** and installed during the summer of 1986 (Wolf, 1988), reviewed new material and techniques introduced to the market for use in mobile home weatherization programs (Rozo, 1987), and evaluated the energy savings performance of the weatherized mobile homes (Bournakis, 1988). This part of the study, the energy savings evaluation, examines energy savings of mobile homes weatherized under IHWAP. The purpose of the study is three-fold:

1. To evaluate the overall energy savings of mobile homes weatherized using the techniques and materials recommended in the ***Mobile Home Retrofit Handbook.***
2. To identify ECMs that contribute to higher energy savings.
3. To compare the energy effectiveness of the new mobile home weatherization techniques to the performance of the IHWAP operations in 1984.

Project Design

The study follows the form of a "scorekeeping" study (Fels *et al.*, 1982). To account for the energy use change resulting from an improvement it is required to account for changes in use due to any cause. By comparing similar groups of mobile homes with and without the improvement, an effort was made to compare samples having similar fuel use performance characteristics, excepting the variability introduced by the improvement. The net energy use change is then ascribed to the improvement. The accepted "Normalized Annual (energy) Consumption" (NAC) methodology is used to assess

change in energy use due to retrofit improvements (Stram and Fels 1982). The overall change in a large sample of mobile homes receiving an improvement compared to those without the improvement indicates the value of this improvement were it more widely applied.

Using monthly utility billing transcripts to identify fuel use change, the study compared the relationship between fuel use and weather before and after the improvement. A "best fit" regression is found for fuel use and weather, separating metered periods before and after the weatherization. This is done for each mobile home. Regression analysis separates that portion of total energy use which is related to weather from the "base load" or "fixed" use. Weather-related and non-weather-related energy consumption data per mobile home are used, with weather representing the typical (normal) temperature climate of each locale, to develop an NAC. Differences in this "normalized" energy use are taken in aggregate for test and control groups. The change of energy use of the control group is used to adjust the savings of the test group for the "normal" variation of energy use between periods which would not be due to the weatherization program.

The suitability of any mobile home's energy use change to reflect normal variation or variation resulting from the weatherization program depends on the regression of fuel use to weather. That is, before we ascribe weather-related energy use reduction to an improvement, we must first establish that the energy use is weather-related. For this reason, those mobile homes demonstrating a regression coefficient of determination (R^2) less than 0.80 in either the before or after period are not considered in the aggregate.

Project Start-up

All mobile homes weatherized between May to September of 1986 using the new weatherization techniques were surveyed, and program participants with natural gas as their primary heating fuel were selected for the energy savings evaluation study. Local weatherization agencies were contacted to provide information on retrofit measures installed and "Consent of Disclosure Forms" for release of fuel billing transcripts by the utility companies.

Natural gas fuel billing transcript information was requested from utilities in August 1987. All fuel billing transcripts were delivered by January 15, 1988. Fuel billing transcript information from utilities for the "before" and "after" period was placed in computer files as it arrived. Most billings started in May 1985 and ended in August 1987. Billings were carefully grouped so that each started and ended with an actual utility read amount.

The PRISM (Princeton Scorekeeping Method) computer program was used to determine house-by-house NAC. The PRISM computer program makes a best estimate of annual fuel use from weather-related and non-weather-related use rates. PRISM derives, by iterative regression, the base temperature for which degree-days best fit the trend of consumption per degree-day. This base for figuring degree-days is the estimated "balance point" of the mobile home. This is done separately for each "before" and "after" weatherization period. Analysis was performed for a one-year pre-weatherization period and for one succeeding year. Six climatic zones were created to account for temperature differences across the State, and each mobile home was assigned to one of these regions.

Energy Savings Results

Energy savings of 546 program participants that had their mobile homes weatherized between May 1986 and September 1986 were assessed. In addition, energy consumption was assessed for a group of 301 mobile home residents that had been approved for weatherization, but had not received assistance as of August 1987. The control group was used to identify changes in energy consumption which are not related to physical modifications but to behavior pattern changes of the residents regarding domestic energy use, such as better management.

Out of 546 test and 301 control mobile home samples, statistical analysis was performed on 227 test and 73 control mobile homes. The elimination of more than 60% of the sample was caused by changes in occupancy, insufficient number of actual billing data for the "before" or "after" periods (all mobile homes with less than five actual billings were eliminated from the sample), or an R^2 less than 0.80. The overall quality of the savings estimates is indicated by the R^2 distribution of the PRISM regressions (Figure 1).

The plot shows that the bulk of values have an R^2 greater than 0.975 (67% of the sample), with increasingly fewer values at lower levels. Approximately 91% of the sample shows an R^2 greater than 0.80, with 85% of the mobile homes having an R^2 greater than 0.90. This indicates that the results are statistically significant. A small fraction of mobile homes with an R^2 less than 0.50 is likely to produce unreasonable NAC estimates, with correspondingly unreliable savings estimates. Mobile homes that exhibit poor fit between energy use and weather can greatly distort the mean savings estimates of any group of interest, including aggregate savings of the total sample. Thus, these mobile homes were ex-

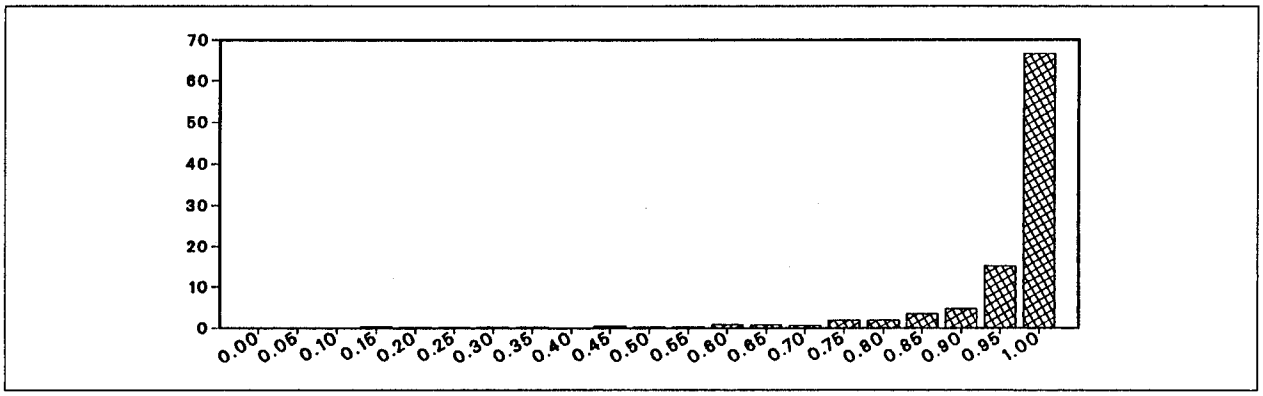

Figure 1. Range of R-Square Distribution

cluded from the sample selected for energy savings analysis.

Overall energy savings in aggregate NAC is 6.5% (Table 1) for all weatherized mobile homes having an R^2 greater than 0.80. This is equivalent to savings of 56 therms per year. However, at an average weatherization cost of $1,072 per mobile home, the simple payback period is 35 years.

Figures 2 and 3 show the range and distribution of energy use and energy savings for the statistically significant sample of weatherized mobile homes. The energy use graph indicates a reduction in the post-weatherization period compared to the pre-weatherization period. Energy savings range from 41% savings to 21% of energy use increase. Approximately 70%, or 160 mobile homes, reduced energy use during the post-weatherization period. The rest 30%, or 67 mobile homes, increased energy use.

The control group (Table 2) showed no changes in the energy use behavior of the mobile home residents. Energy consumption showed no significant changes in the post-weatherization period compared to the pre-weatherization period. Energy savings range from 25% savings to 21% of energy use increase. Approximately 50%, or 37 mobile homes, reduced energy use during the post-weatherization period. The other 50%, or 36 mobile homes, increased energy use. The control sample of each region is not large enough to get statistically significant results to adjust the savings of the test group.

A more "stringent filter" was applied to mobile homes to see whether the aggregate results would be influenced. This more stringent criterion was a minimum R^2 of 0.95 (for both the "before" and "after" normalized annual consumption). However, there was no significant change in overall energy use savings compared to the sample with an R^2 greater than 0.80.

Selected ECM Impacts

There is a considerable interest in identifying the effectiveness of the different retrofit measures implemented. Average energy savings for individual retrofit measures (Table 3) were identified by subtracting the energy savings of mobile homes without a specific retrofit from the energy savings of mobile homes with that specific

Table 1. Energy Savings by Climatic Region (Test Group)

	Total	Chicago	Rockford	Peoria	Springfield	St. Louis	Cairo
Energy use (therms, before)	861.21	792.18	964.60	965.51	875.06	773.08	613.45
Energy use (therms, after)	805.58	811.13	891.39	906.57	819.68	700.66	594.69
Number of mobile homes	227	2	20	74	64	38	29
Weatherization cost ($)	1072	1227	1146	1119	1053	1088	915
Savings (therms)	55.63	-18.95	73.21	58.94	55.38	72.48	18.76
Percent savings (%)	6.46	-2.39	7.59	6.10	6.33	9.37	3.06
Payback period (years)[a]	35.05	—	28.45	34.51	34.55	27.28	88.73

[a]Based at a cost of $0.55 per therm.

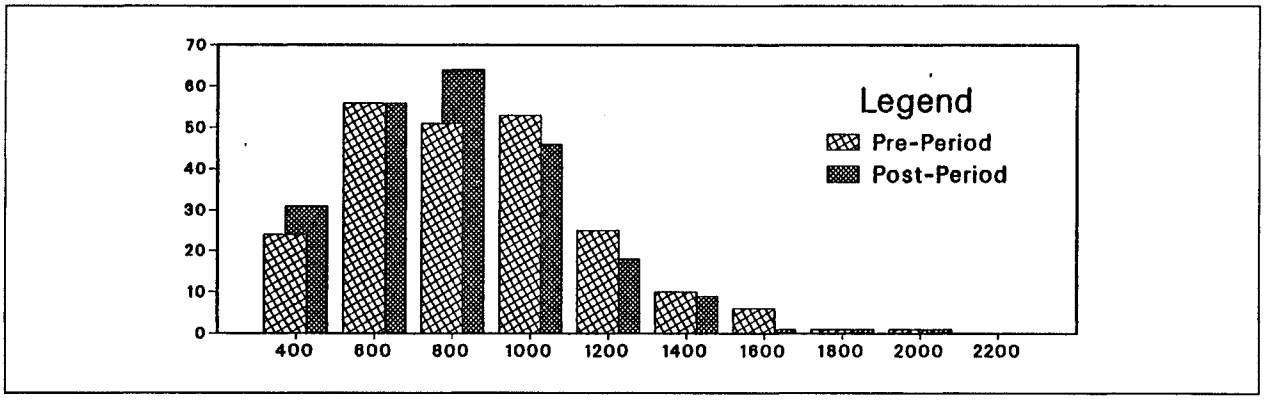

Figure 2. Range of Energy Consumption

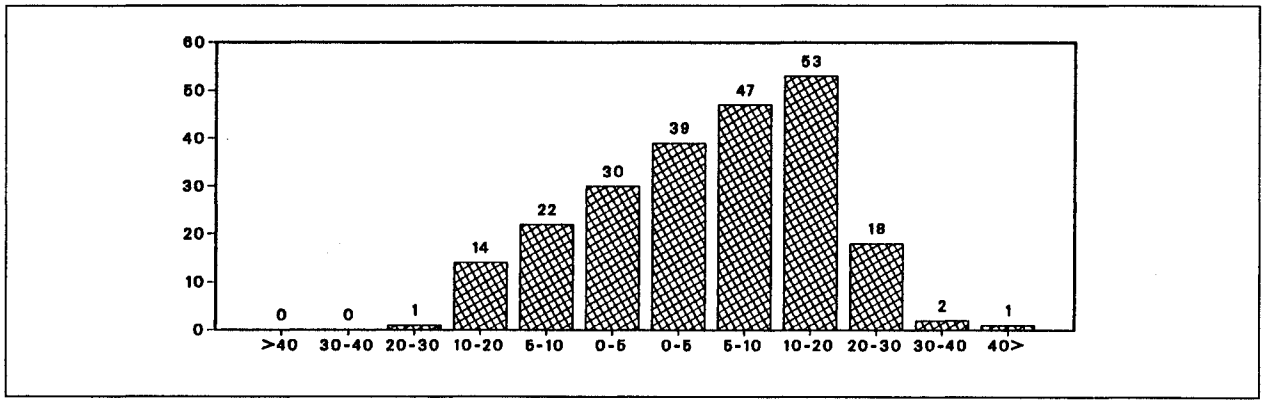

Figure 3. Range of Energy Savings

Table 2. Energy Savings by Payback Period (Years)

	Total	Chicago	Rockford	Peoria	Springfield	St. Louis	Cairo
Energy use (therms, before)	878.00	907.45	2165.72	911.63	871.54	808.97	679.73
Energy use (therms, after)	872.28	894.83	2132.10	910.40	870.91	802.97	631.11
Number of mobile homes	73	4	1	20	28	16	4
Savings (therms)	5.72	12.62	33.62	1.23	-0.63	-6.00	48.62
Percent savings (%)	0.65	1.39	1.55	0.13	-0.72	-0.74	7.15

retrofit. However, this procedure, based on historical energy data used in this study, cannot accurately estimate the energy savings attributable to individual weatherization measures. Engineering calculations, or controlled experiments carefully designed are needed for this purpose.

By comparing the energy performance of mobile homes with and without a specific retrofit, the following were identified:

- All weatherized mobile homes received infiltration improvement measures. Infiltration improvement measures usually include caulking, other air infiltration sealing, and window and door replacements. Energy savings in mobile homes that received only minor infiltration improvements (caulking and other air infiltration sealing at a cost of $100 or less) are higher compared to savings when window or doors were replaced. Minor infiltration work saved an estimated 7.8%. However, the sample of mobile homes with minor infiltration improvements is too small to provide statistically significant results. Window and door replacement saved approximately 4.5%.
- Mobile homes with floor insulation saved approximately 4.6% more energy than mobile homes with no floor insulation installed. The number of mobile homes with floor insulation which saved energy (82%) is 14% higher compared to mobile homes with no floor insulation installed (68%) which reduced energy use.
- The installation of setback thermostats did not significantly improved the energy performance of mobile homes (energy savings less than 1%). The number of mobile homes with setback thermostats that saved energy (72%) improved by 3% compared to mobile homes with no setback thermostats installed (69%).
- Insulated skirting improved the energy performance of mobile homes by only 0.3%. However, the number of mobile homes with insulated skirting that improved their energy performance (68%) decreased by 3% compared to mobile homes that received no skirting (71%).
- Insulation of existing skirting improved the energy performance by 2.0% compared to mobile homes that did not received insulation of existing skirting. The number of mobile homes which saved energy improved by 5% (to 75%) when existing skirting was insulated.
- Storm windows increased energy savings by 4.6%. However, the sample was too small for statistically significant results. Storm windows improve the share of mobile homes that saved energy by only 1% (to 71%).
- Wall insulation and storm doors were installed in three and two mobile homes respectively. There are no sufficient data to evaluate changes in energy usage as a result of these retrofit measures.

A cost-benefit analysis was performed to identify the economic effectiveness of the various retrofit measures to the weatherization program. Energy savings and weatherization cost for each of the retrofit measures were estimated (Table 3). Simple payback method was used to rank the cost-effectiveness of each retrofit measure. Floor insulation and minor infiltration work are the most effective retrofit combination, i.e., having the lowest payback period. Storm windows, with 6.2 years, also have a relatively low payback period. However, there are not enough mobile homes for a statistically significant sample. Setback thermostats and insulation of

Table 3. Energy Savings by Weatherization Measure

Measure	Net Percent Savings	Number of Homes	Therms Saved per Home	Dollars Saved per Home	ECM Cost per Home	Payback Period
All mobile homes	6.5	227	56	31	1072	34.6
Minor infiltration	7.8	8	65	36	50	1.4
Window and door replacement[a]	4.5	219	39	21	598	28.5
Floor insulation installed	4.6	38	37	20	86	4.3
Setback thermostat installed	0.9	119	7	4	39	9.8
Insulated skirting installed	0.3	47	2	1	217	217.0
Insulation of existing skirting	2.0	28	17	9	111	12.3
Storm windows installed	4.6	17	42	23	142	6.2
Wall insulation installed	9.8	3	92	51	72	1.4
Storm doors installed	-1.1	2	-10	6	69	—

[a]Estimated by subtracting the weighted average savings attributed to other retrofit measures. Window and Door Replacement is part of the Infiltration work. Cost exceeds $100.

existing skirting, with a payback period of approximately 10 years, are only marginally effective weatherization measures. Insulated skirting is not an economicly effective measure. It would appear that window and door replacement is not cost effective. However, window and door replacement remain high priority retrofit measures because, according to occupants interviewed during the site visits, it increases comfort levels. No sufficient information exists to evaluate the economic effectiveness of wall insulation and storm doors.

Regional Impacts

Changes in energy consumption for different regions were estimated. Following the specifications developed by the Illinois Department of Energy and Natural Resources (DENR), six climatic zones were created to account for temperature differences across the State, and each mobile home was assigned to one of these regions. The energy savings of mobile homes in the different regions were 7.6% in Rockford, 6.1% in Peoria, 6.3% in Springfield, 9.4% in St. Louis, and 3.1% in the Cairo region (Table 1). The St. Louis region has the best energy savings performance, with Cairo saving the least. The Chicago region does not have a sufficiently large sample size for statistically significant results. There are very few mobile homes located in the Chicago metropolitan area.

The frequency of individual ECM installations by region (Table 4) was also examined. Infiltration measures, which include window and door replacement were installed in all mobile homes. The second most frequently used retrofit measure is the setback thermostat, installed in 52% of the total sample. Setback thermostats have been shown to add less than 1% to the energy savings. Over 50% of the Springfield and Peoria region mobile homes had setback thermostats installed.

Insulated skirting was installed in 21% of all mobile homes and saved 0.3% over mobile homes with no insulated skirting. Thirty-one percent of Springfield and 26% of Peoria mobile homes had insulated skirting installed.

Floor insulation has been documented to save an additional 4.6% compared to mobile homes with no floor insulation. This retrofit measure was installed to only 17% of the sample. In the St. Louis region, which showed the highest energy savings, floor insulation was installed in 29% of the weatherized mobile homes, almost twice as many mobile homes than any other region. Only 10% of the mobile homes received floor insulation in the Cairo region. Energy savings for this region were only 3.1%.

Impact of New Weatherization Techniques

An analysis of the energy variation in mobile homes weatherized under the IHWAP in 1984 (A.D. Little, 1987) showed energy use increased an average of 0.3% after weatherization. Thus, the new weatherization techniques implemented in 1986 raised energy savings by approximately 6.8% over the previously applied weatherization methods.

Agency records on the mobile home retrofit measures implemented show sporadic installation of floor insulation, identified as a priority for mobile homes in the ***Retrofit Handbook.*** Only 17% of weatherized mobile homes received floor insulation, compared to 2.2% in 1984. Insulation of existing skirting (perimeter insulation) saves considerably less (2.0%) than previous estimates (10.7%). Storm windows, installed to 7% of the sample, save 4.6%, consistent to the A.D. Little results (5.8%). The ***Retrofit Handbook*** and the A.D. Little

Table 4. Frequency (Percentages) of ECMs Installed in Mobile Homes by Region

Measure	Total (%)	Chicago	Rockford	Peoria	Springfield	St. Louis	Cairo
Total Weatherized Sample	N = 227	N = 2	N = 20	N = 74	N = 64	N = 38	N = 29
Minor infiltration work	4	50	0	7	2	0	3
Window/door replacement	96	50	100	93	98	100	97
Floor insulation	17	50	15	15	14	29	10
Setback thermostat	52	100	35	53	64	45	45
Insulated skirting installed	21	50	0	26	31	13	7
Insulation, existing skirting	12	0	5	19	13	13	0
Storm windows	7	50	0	4	14	8	3
Wall insulation	1	0	0	0	3	3	0
Storm doors	1	0	0	1	2	0	0

study recommended the installation of ceiling insulation and wall insulation. However, no ceiling insulation was installed and only three mobile homes received wall insulation. There is not sufficient information to make any conclusions on these retrofit measures.

Conclusions and Recommendations

The energy savings are consistent with the findings from the mobile home site visits. The findings of the field visits were reported in "Mobile Home Weatherization Materials and Installation Practices" (Wolf, 1988). A summary of findings from that report is quoted below:

> *Results from the study have concluded that more emphasis should be placed on floor insulation and less on setback thermostats and insulated skirting. The setback thermostats should be emphasized less because of people not using them. Also, skirt insulation has been proven in the past to save little or no energy.*

Minor infiltration work showed the most energy savings (minor infiltration work includes caulking and other air infiltration sealing — window and door replacement is not included). However, only eight mobile homes in the sample received minor infiltration work. Windows and doors were replaced on 219 of the mobile homes in the sample. Although the energy savings are comparable to those of floor insulation, the payback for window and door replacement is considerably higher. Economically speaking, it would appear that window and door replacement is not cost effective. However, window and door replacement remains a high priority retrofit. Savings for this measure could not be accurately isolated from the remaining retrofits, since window and door replacement is an integral part of the infiltration work. In addition, occupants interviewed during the site visits reported increased comfort levels as a result of window and door replacement.

Floor insulation was installed in only 17% (38) of the mobile homes. The St. Louis climatic region, which showed the highest energy savings of the six climatic regions at 9.4%, had almost twice as many mobile homes where floor insulation was installed than any other climatic region. It appears that the higher energy savings in this region is directly related to the number of mobile homes that received floor insulation. It is concluded that statewide energy savings would increase if more emphasis is placed on the installation of floor insulation.

Setback thermostats showed disappointing energy savings at less than 1%. This is consistent with the A.D. Little findings for setback thermostats installed in mobile homes (2.0%). Setback thermostat installation was reviewed during the mobile home site visits. Clients were not using the setback feature in more than half of the mobile homes where setback thermostats were installed. Four recommendations related to improved use of setback thermostats were made:

- better instructions for thermostat use,
- use thermostats with instructions printed on cover,
- use thermostats that have standard batteries, and
- use thermostats that are easy for setting time and temperature.

Setback thermostats have the potential for significant energy savings if they are used properly. It is recommended that setback thermostat installation be continued with increased emphasis on the above recommendations.

Energy savings for skirting insulation and insulation of existing skirting showed no surprises. Energy savings attributed to insulated skirting are consistent with insulated skirting savings shown by other studies. On paper, energy calculations show that savings can be obtained from insulated skirting, although the payback and savings-to-investment ratio are marginal. However, given the field conditions, it is very difficult to install an insulated skirting system that is effective in reducing heat loss. Poor foundation conditions cause mobile home shifting which destroys the integrity of the insulated skirting system. Occupants frequently remove sections of the skirting to store items beneath the mobile home and fail to replace the removed sections. Skirting must be ventilated during the summer. Often, the skirting is ventilated during the winter as well. Ambient conditions beneath the mobile home are comparable to the outdoors. Emphasis should be placed on insulating the floor. If the floor cannot be insulated, insulated skirting should not be installed.

To summarize, the mobile home weatherization program improved energy savings by 6.8% over the past two years. However, this figure is low compared to energy savings achieved by conventional site-built housing (11.9%, A.D. Little). Implementation of certain retrofits are key to achieving higher energy savings. In addition, to ensure consistent energy savings results among different regions, it is necessary to adjust retrofit priorities (eliminate insulated skirting) and place greater emphasis on floor insulation. Although floor insulation is considered a priority after stopping air infiltration, only 17% of all mobile homes weatherized received this measure.

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