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Blower-Door-Directed Infiltration Reduction Procedure Description and Field Test

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ABSTRACT

A blower-door-directed infiltration reduction procedure was field-tested on 18 homes in south central Wisconsin. The procedure, developed by the Wisconsin Energy Conservation Corporation, includes recommended retrofit techniques as well as criteria for estimating the amount of cost-effective work to be performed on a given house.

The procedure produced an average 16% reduction in air leakage rate. For houses recommended for retrofit by the procedure, 89% of the targeted leakage reductions were accomplished with 76% of the recommended expenditures. The retrofit costs represent a significant savings over costs of previous yet similar programs.

No statistically significant average energy savings were measured, as determined from pre- and post-retrofit furnace consumptions normalized to a common weather base. Measured savings for individual houses varied widely indicating that factors not considered either masked or reduced the expected savings. Possible causes are discussed. Whether results of controlled experiments could reveal causes for the lack of demonstrated savings in this and similar field tests is a point raised, but left unanswered.

INTRODUCTION

Infiltration reduction has long played a major role in the weatherization of residential buildings. In many weatherization programs, standard procedures include the automatic caulking and weatherstripping of doors and windows, possibly leaving other major leakage sites, such as attic bypasses and electrical outlets, unattended. Frequently, no quantitative measure of the success of the infiltration retrofit is available. Several studies have indicated that implementation of infiltration retrofits is often less effective than expected. One study indicated that 35% of a state's low-income energy assistance program funds went to infiltration retrofits. Yet, many of the homes still had major infiltration problems (Hewitt et al. 1984). A second study showed that 50 low-income homes showed no significant leakage rate reductions after retrofits that included air infiltration control (Kanarek et al. 1985).

Blower doors were developed in the mid-1970s as a means to quantify the leakiness of a house and assist in locating principal air leakage sites[2] (Kronvall 1978; Harrje et al. 1979). However, few systematic procedures have been developed for implementation of the blower doors into major weatherization programs, particularly those federal or local weatherization assistance programs for low-income families.

The Wisconsin Energy Conservation Corporation (WECC) subsequently developed an infiltration reduction procedure utilizing a blower door specifically designed for implementation in the state's Low-Income Weatherization Assistance Program. Major house leaks are repaired with the blower door in place, permitting tracking of the home's leakage rate during retrofit. The procedure also includes guidelines regarding how much infiltration work should be performed, based on the initial leakiness of the house and available funds.

The need to field test this procedure prompted a joint effort to provide evidence of its effectiveness. This paper briefly describes the infiltration reduction procedure, the field test of the procedure, and the measured results.

THE INFILTRATION REDUCTION PROCEDURE

The blower-door-directed infiltration reduction procedure was developed by the WECC based on its experience with blower doors and that of several private contractors and local utilities (Schlegel et al. 1986). A retrofit crew first walks through a house in preparation for installing the blower door and checking for any indications of moisture problems. With the blower door installed, readings are taken to determine the air leakage rate at 50 pascal depressurization in air changes per hour, designated ACH50.

This initial leakage rate is used in two guidelines generated by the WECC that estimate the level of effort for infiltration work to be performed on the house. A recommended expenditure level for labor and materials is determined by the equation*

$$Expense\ (\$) = (ACH50)^2 \times [\text{House Area}(\text{ft}^2)\ ] / 1400.$$

This was translated into an approximate number of man-hours through division by an assumed rate of $20/h,

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*More recent application of the infiltration reduction procedure in Wisconsin uses a variation of this equation:

$$Expense\ (\$) = (ACH50)^2 \times [House\ Volume\ (ft^3)\ ] / 20{,}000 + Setup$$

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Retrofits of Low-Income, Single-Family Buildings in Wisconsin: Blower-Door-Directed Infiltration Reduction Procedure, Field Test Implementation and Results" (Gettings et al. 1988).

RESULTS AND DISCUSSION

Air Leakage Reductions and Retrofit Costs

Table 2 lists the 18 houses of the test group that remained eligible for infiltration retrofits. For each house the table shows the initial leakage rate measured by the retrofit crews, leakage rate reductions targeted by the procedure and actually attained, and the recommended and actual cost of the retrofits. The house designations within the table, for instance, R21, have little significance other than indicating in which Wisconsin county the house was located — Dane, Green, or Rock.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) lists typical leakage rates as falling between 6 and 10 ACH50, with the tighter Swedish homes averaging as low as 3 ACH50 (ASHRAE 1985). In comparison, the average pre-retrofit leakage rate for the homes within this study was 8.3 ACH50. Twenty-two percent of the homes had pre-retrofit leakage rates above the ASHRAE typical values and 44% below. Thus, the homes studied provided a wide range of typical initial leakage rates, though somewhat skewed to the lower rates. This bias toward the lower rates, unexpected for lower-income housing, resulted in the guidelines recommending retrofits in only seven of the houses. The possibility exists that in some areas, particularly colder climates, existing housing may be tighter than expected, freeing weatherization assistance program funds for other energy retrofit work.

TABLE 1
ACH50 Reduction Targets, Guideline 2

Pre-Retrofit ACH50	ACH50 Reduction Target
8 or less	Seal leaks that affect comfort
8 to 10	Reduce ACH50 by 1
10 to 12	Reduce ACH50 by 2
13 to 15	Reduce ACH50 by 3
16 to 18	Reduce ACH50 by 4
18 or greater	Reduce ACH50 by 5

The 1.3 ACH50 average reduction in air leakage rate achieved by the retrofits in all 18 houses represents a 16% decrease. The average recommended cost per house was $77, compared with the actual average expenditure of $106 per house. Some of this over-expenditure may be attributed to the cost of performing the blower door tests, necessary whether or not retrofits were implemented. The

TABLE 2
Targeted and Attained Air Leakage Rate Reductions and Retrofit Costs

House	Initial Leakage Rate (ACH50)	Targeted Leakage Rate Reductions	Attained Leakage Rate Reductions	Recommended Cost ($)	Actual Cost ($)
R21	19.5	5.0	6.0	256	216
R22	16.8	4.0	1.4	291	126
R35	16.2	4.0	1.9	129	98
D26	14.7	3.0	4.7	218	211
R03	9.2	1.0	0.8	94	96
R52	9.0	1.0	1.3	88	75
R43	8.6	1.0	0.7	49	39
D04	7.9	0.0	3.7	44	301
R07	7.7	0.0	0.2	55	50
R01	7.2	0.0	1.0	42	60
D41	5.9	0.0	0.4	31	186
G27	5.3	0.0	0.2	24	88
R06	5.2	0.0	0.8	21	92
R39	3.9	0.0	0.1	13	92
R31	3.4	0.0	0.0	9	63
R04	3.2	0.0	0.0	8	13
R27	3.1	0.0	0.0	7	25
G01	2.6	0.0	0.0	5	68
Averages					
All Houses	8.3	1.1	1.3	77	106
Retrofitted Houses	9.8	1.4	1.7	97	124
Recommended For Retrofit	13.4	2.7	2.4	161	123

The entries in the table above have been grouped according to whether retrofits were actually performed and whether those performed were recommended by the procedure's guidelines, based on initial leakage rate. Retrofits were recommended and performed for the first seven listed. Retrofits were also performed on the second group of seven, even though the guidelines did not specifically recommend them. The last group of four houses had no retrofits implemented and were not recommended for retrofit.

The three sets of averages correspond to (1) all 18 houses, (2) the 14 houses in the first two groups in the table, those in which retrofits were implemented whether or not they were recommended for retrofit by the procedure guidelines, and (3) the seven houses in the first group in the table, those in which retrofits were both recommended and performed.

furnace run times and normalized to average weather. Negative values indicate a computed increased energy use during the post-retrofit period compared with the pre-retrofit period. The last column lists the 90% confidence intervals for the metered savings, based on the degree of fit of the linear regressions between furnace run times and outdoor air temperatures.

Major features apparent from the table are (1) divergent values of metered savings, (2) metered and predicted savings having little or no correlation, and (3) confidence intervals for the metered savings, which are large in comparison with the magnitude of the values themselves. All of these situations could indicate neglect of important factors affecting the heating loads of the houses, as characterized by furnace run times.

The metered savings vary widely in both positive and negative directions. A substantial number of the savings are negative, producing a −27 therm average for all 11 houses, or an average −2 therms for only those houses retrofitted. These values are not statistically significant, based on their 90% confidence intervals. Thus, the reductions in air leakage accomplished did not induce consistently measurable reductions in energy consumption.

The 28 control houses showed an average 5 therm increase in consumption from pre- to post-retrofit periods, with a 44-therm 90% confidence interval on either side of this value. Thus, the control group correctly indicated no net statistically significant consumption change, which otherwise may have biased the test group.

Because the experiment was performed during a single winter, seasonal variations in many factors could contribute to the negative average annual metered savings obtained. Changing wind speed and direction, solar or internal loads, and ground temperature are but a few. For example, ground temperatures vary much more slowly than the ambient air temperature. Thus, a house experiences less ground heat loss earlier in the winter, during the pre-retrofit period, than later on, during the post-retrofit period.

The effect of occupant "take back," where occupants maintain greater indoor air temperatures following the retrofits than before, was investigated as a probable cause of the lack of average savings. Monitored indoor air temperatures on three of the test homes provided some evidence for this phenomenon. However, estimates for the test group as a whole, based on this sample, predict an increased average metered savings (decreased average consumption rise) of only 18 therms, from −27 therms to −9 therms.

Additional factors likely play a part in producing the lack of correlation between metered and predicted results. Differences in the weather base used in computing the predicted and metered savings affect the comparison of these two quantities. The predicted savings assume 7700 HDD at base 65°F, while the 36-year average Madison weather used for normalization of the metered data yields 7400 HDD at the same base temperature. This represents only a 4% difference, not significantly altering the results.

The predicted results assume a constant conversion factor of 1 air change per hour at 50 pascal pressure equal to .05 air change per hour infiltration under actual conditions (Sherman 1987). This conversion is approximate and itself subject to many factors, particularly the prevailing wind conditions as well as location of leakage sites, shielding of the structure, indoor-outdoor temperature differences, etc. More detailed correlations exist (Kronvall 1978; Grimsrud et al. 1979; Shaw 1981), but all require information not available from the test.

Seasonal variations peculiar to the individual houses would have to be responsible for the inconsistency in differences between predicted and metered annual results from one house to another. Differences in solar or internal loads, massiveness, or duct leakage could have this effect. It is unlikely, however, that the disparities seen, as high as 200 therms, could be produced by a single factor. (Two hundred therms is equivalent to the heat loss through the R-11 walls of a 1200 ft^2 house of aspect ratio 2 over 4000 hours at an outdoor temperature of 30°F).

Note that in only five of the 11 cases is the predicted value outside the 90% confidence limits of the metered results. This reflects more the magnitude of the confidence limits than any correlation between the results, and suggests a need to increase the precision of the estimates. The confidence intervals indicate to what degree the linear regressions fit the relationships between measured fuel use and ambient temperature. Thus, a lack of fit can be caused not only by inaccurate or imprecise data, but also by any actual condition that lessens the linearity of the relationship. Weekly variations in climatic as well as internal parameters, such as solar loads, wind speed or direction, occupancy, and internal loads, would all contribute to the scatter.

Whether more controlled experiments considering more factors could reveal the cause for the lack of demonstrated energy savings due to the retrofits is almost a moot point. Time and expense to monitor the information required would be prohibitive in any project whose primary goal was to increase the energy efficiency of a number of homes. Whether results of a carefully controlled experiment could be applied to work in the field without substantial added expense is doubtful.

Elements other than energy efficiency may also play a role. In programs where the key emphasis is not solely on reducing the homeowner's energy bill, occupant comfort may be as important. Addressing the questions of where do the occupants spend most of their time in the home, or where are they the most uncomfortable, may produce results more satisfying to the homeowner than the typical energy conservation approach.

CONCLUSIONS

The primary objective of this study was to evaluate the effectiveness of implementing a blower-door-directed infiltration reduction procedure. Application of the procedure in the field test described in this study indicates the following:

1. Significant air leakage rate reductions can be achieved through the use of a blower-door-directed infiltration reduction procedure.

2. Average retrofit costs may be reduced by using a blower-door-directed procedure in conjunction with guidelines for estimating the amount of cost-effective retrofit work to be performed.