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Mobile Home Retrofits Revisited: CMFERT Phase II

by Ron Judkoff

Ongoing testing by the trailer-in-a-warehouse people reveals that many of the best performing retrofits save an even higher percentage of energy under simulated wind conditions than they do in still air. Two new sidewall insulation techniques showed promising results, as well.

The Collaborative Manufactured-Building Facility for Energy Research and Training (CMFERT) has expanded its testing of mobile homes to include simulated wind conditions and new sidewall insulation techniques. Results are in for four more mobile homes in addition to the three investigated in *HE*, Jan/Feb '90, p. 23.

In the previous article, we reported on tests conducted on mobile homes rolled into our specially adapted warehouse in the winter of 1988–89. The retrofits tested included: blower-door-directed air sealing and duct repair, furnace tune-ups, interior storm panels, window repairs and replacements, belly blow (underfloor blown-in insulation), belly wrap (fiber-glass blanket strapped under the rodent barrier), skirting, roof blow, roof cap, and wall insulation (siding peel-back technique).

All of these measures were tested in the controlled environment of the CMFERT warehouse under still-air conditions, that is, without wind. In phase II of the project, conducted during the winter of 1989–90, we re-tested some of these measures in the warehouse under both still air and simulated wind conditions. We also tested the thermal benefits of blown-in belly insulation compared to those of insulated skirting. Finally, we developed and tested two techniques for insulating mobile-home walls that do not require removing the wall panels.

The Phase II project more than doubled our previous sample of mobile homes tested in the CMFERT warehouse from 3 to 7. (All seven mobile homes were selected by representatives of the Weatherization Program of the Colorado Division of Housing as typical of those that they actually treat in the field.) The results from Phase II confirmed the large potential for heating-energy savings in cold climates when using weatherization measures appropriate to the unique construction details of mobile homes.

The warehouse testing technique helps us accurately determine the energy savings potential of a variety of retrofits. However, testing inside a warehouse is not the best way to determine the practicality of the retrofits or the costs of materials and labor. This is best done by applying the retrofits under real field conditions. All the recommended retrofits have been tried on actual job sites by the Region VIII Weatherization Assistance Program in Region VIII (Colorado, Idaho, North and South Dakota, Utah, and Wyoming). Many have also been tried in other areas, such as New York State.[1]

Monitoring Techniques

A detailed description of the monitoring methods appeared in *HE*, Jan/Feb '90, p. 25 and elsewhere.[2] Here, we will briefly review the monitoring techniques and describe the "wind emulator" that we added to the testing method.

The key to our monitoring approach is a warehouse that we modified to allow the mobile homes to be tested under tightly controlled and repeatable conditions of temperature, wind, and radiation. In the warehouse we conduct four kinds of tests:

1) coheating tests[3] with electric resistance heaters to determine the overall conductance of the mobile home (UA_o, also referred to as the building heat-loss coefficient, BLC),
2) tracer gas tests with sulfur hexafluoride to separate the infiltration portion (UA_i) of the UA_o from the conduction portion (UA_c) of the UA_o ($UA_i + UA_c = UA_u$),
3) coheating tests using the mobile home's own furnace to determine the combined furnace, thermostat, and duct efficiency $[Q_{electric\ coheat}/(Q_{gas} + Q_{furnace\ blower})]$, and
4) blower door tests to determine infiltration sites and effective leakage areas in the mobile home and ducts.

We also added a wind emulator to our warehouse facility, which allows the coheating and tracer gas experiments to be conducted under both still-air and wind conditions.

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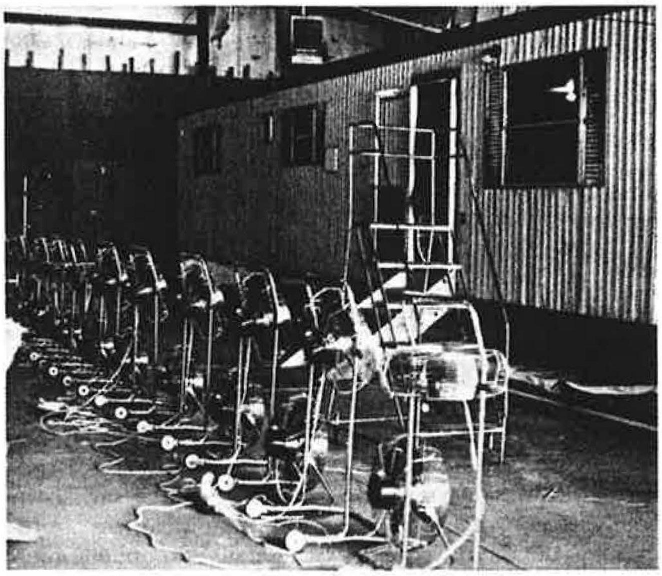
MOBILE HOMES



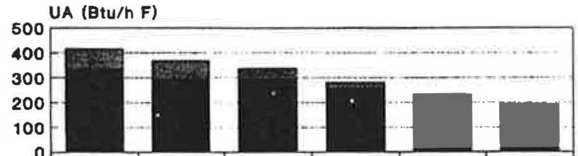
Ron Judkoff

Wind emulator, also known as fans, creates a storm in the test warehouse.

We added the wind tests for several reasons. First, many weatherization professionals questioned the applicability of tests conducted under still-air conditions to the outside world. Many of them especially questioned our past results with respect to skirting, arguing that skirting would be more effective in windy climates (our past results had shown skirting not to be as cost-effective as belly insulation). Second, we hypothesized that savings for some of the retrofits under windy conditions would be even greater than those measured in still-air. For example, in still air, heat leaking out of the ducts into the belly area would be expected to rise back up to heat the floor of the mobile home. However, with wind blowing through the belly, a greater portion of heat leaking out of the ducts could be lost to the outside. Thus duct repair, for example, might actually save more energy than our previous tests, done without wind, had shown.

Figure 1. CMFERT Mobile Home #4 Invader

Measured BLC Overall No Wind
Conduction and Infiltration



	Base	Storms	Heat Waste	Roof Blow	Belly Blow	Wall Blow
Infiltration	79	73	40	20	13	11
Conduction	337	297	297	261	221	183
Total	415	370	337	281	234	194

■ Conduction ■ Infiltration

4/5/90 Post Belly Blow (43.6%) Post Wall Blow (53.2%)

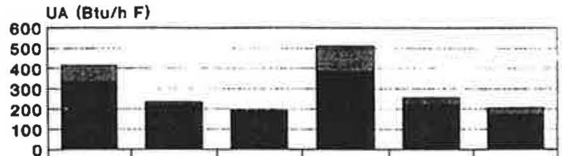
The wind emulator consists of 28 18", ⅙ horsepower, 9,400 cfm (cubic feet per minute) fans arranged in a bank of alternating floor-mounted and stand-mounted units extending the entire length of the mobile home (see photo). It is impossible to exactly replicate an outdoor free-stream wind condition around a mobile home in an enclosure of this size and geometry. However, with one mobile home in the warehouse, the wind emulator does produce a repeatable lateral pressure difference across the home. This pressure difference is similar in magnitude and distribution to what a 3.5 mph wind would produce. Average winter wind speeds are greater than 3.5 mph in most climates.

Test Results

Figure 1 shows the building heat-loss coefficient (BLC) associated with a series of weatherization measures installed on mobile home 4. The bottom and top portions of each bar represent, respectively, the conduction and infiltration portions of the heat loss as measured under still-air conditions. The installation of all weatherization measures except the wall blow resulted in a 44% reduction in the heat-loss coefficient due to storm windows, blower-door directed air sealing and duct repair, roof blow, and belly blow (taken as a percentage of the base-case, pre-weatherization heat-loss coefficient). This is similar to the results shown in the previous article for mobile home 1 where the reduction in heat loss was 44% due to installation of the same set of measures. In addition to these measures, mobile home 4 also received wall insulation via a new technique discussed later. The wall insulation reduced the heat-loss coefficient by another 10% making a total reduction of 53% with no wind.

Figure 2. CMFERT Mobile Home #4 Invader

Measured BLC Overall
Wind vs. No Wind



	Base No Wind	Final 1 No Wind	Final 2 No Wind	Base Wind	Final 1 Wind	Final 2 Wind
Infiltration	79	13	11	124	33	30
Conduction	337	221	183	387	224	177
Total	415	234	194	511	257	207

■ Conduction ■ Infiltration

reduction no wind = 43.6% (53.3%) Final1 = storms/air seal/roof/belly
reduction 3.5mph wind = 49.7% (59.5%) Final2 = Final1 + Wall Blow

Figure 2 shows the initial and final building heat-loss coefficients for mobile home 4 measured with and without wind. "Final 1" designates the post-weatherization case containing all retrofits except the wall insulation. "Final 2" contains all retrofits including the wall insulation. For both cases the reduction in the heat-loss coefficient was, respectively, 40% and 38% greater under windy conditions than under non-windy conditions. For example, [(Base Wind – Final 1 Wind)/(Base No Wind – Final 1 No Wind)] = [(511 - 257)/(415 - 234)] = 1.4. In other words,

Development and Testing of New Wall Insulation Methods

Many of the mobile homes treated under the Weatherization Assistance Program were manufactured prior to implementation of the 1976 HUD Standards. These older units show great variability in the thickness of the walls, and in the amounts of insulation in the walls. The most common walls are 2" x 2", 2" x 3", and 2" x 4" construction. Insulation is sometimes nonexistent, but more frequently consists of 1" fiber-glass batts or blankets. Occasionally units of this vintage are found with insulation completely filling the wall cavities. Generally, though, mobile home walls in these older units are a major source of heat loss and occupant discomfort. This is because of the relatively large surface-area-to-volume ratio in single-wide units, wall thinness, lack of insulation, and proximity of the radiantly cold interior wall surfaces to occupants. Also, the so-called "ventilated wall" design—corrugated siding that allows vertical air passages—probably encourages convective bypassing of the insulation (especially in loosely packed cavities), further reducing the effective resistance to heat flow. More research is needed on the magnitude of this effect.

Weatherization crews commonly insulate walls and attics of site-built structures by blowing loose fiber-glass or cellulose into the cavities. For mobile homes, similar techniques have been developed to insulate the under-floor area (belly), and the ceiling (bow-string truss area). Unfortunately, no such analogous technique existed for insulating the walls of older mobile homes, many of which are inadequately insulated. The main reason for this originally appeared to be the belief among weatherization personnel that mobile home walls are too thin, complex, and fragile to allow the use of normal blowing techniques. Several individuals, including Wyoming weatherization trainer Jim Kleyman, had tried an alternative method called a "wall peel," which requires removal of the doors, windows, exterior trim, and exterior wall panels to allow installation of insulation batts and a Tyvek air barrier. We had measured about a 10% reduction in the building heat-loss coefficient after application of this method during a training workshop at Colorado Mountain College in 1987. However, this method, though thermally effective, was not judged to be practical, and was not widely adopted by weatherization crews because of the complexity of the procedure and the risk of damage to the disassembled unit from high winds or rain.

In late 1989, an impromptu brain-storming session among John Krigger of the National Center for Appropriate Technology, Cal Steiner of the North Dakota Weatherization Program, and myself resulted in the idea that with some modifications to current techniques, a method for insulating mobile home walls without removing wall panels could be developed. Krigger and Steiner made a first attempt to do this at the Region VIII Weatherization Conference in Kalispell, Mont., in June of 1989. However, there was not sufficient time, equipment, or material necessary to fully develop the method. In early 1990 SERI made its facilities available to these two weatherization trainers to develop a practical method for insulating mobile home walls.

The work included building two types of model walls typical of older mobile homes, and then using two methods to fill the walls with insulation. The walls were constructed with a plexiglas viewing panel to allow direct observation of voids, inconsistencies, and other problems. The walls were also designed to allow easy emptying and re-filling for multiple trials. The walls were weighed before and after to determine the density of installed insulation. After the method had been developed on the model wall sections, it was further refined by applying it to ten cavities of a real mobile home. The method consisted of two techniques that work well in combination. The first technique consists of detaching the bottom lip of the wall panel from the rim joist and blowing chopped insulation up from the bottom with a fill-tube. The second method involves sliding insulation batts up from the bottom of the wall using a specially designed sheet-metal tool.

Finally, the two techniques were applied to an entire mobile home (except for some small inaccessible areas above the windows). We measured the effect of the retrofit (about ⅔ done with blowing and ⅓ with stuffing). The wall insulation reduced building heat-losses by about 10%, or 45 Btu/hr-°F. The total job cost about $490, equivalent to $0.60 per square foot for the area insulated. It is probable that costs will be reduced as crews gain experience with the method, and develop their own modifications and "tricks" to increase installation efficiency. We expect that the blow technique will result in slightly greater savings than the "stuff" method. However, we have not tested these methods separately.

A survey was also conducted to inspect the wall insulation and construction detailing in 40 mobile homes at a mobile-home storage lot. Twenty-two of the homes, or 55%, could have allowed their walls to be insulated by the methods developed in this study. The other 18 either had insulation-filled wall cavities, were deteriorated from moisture problems, or had difficult access.

all things being equal, weatherization of a house in a windy climate will save more energy than weatherization in a non-windy climate. This indicates that the results obtained from warehouse tests under still air conditions are conservative in the sense that even greater reductions in heat loss would result under windy conditions such as those which exist in most real climates.

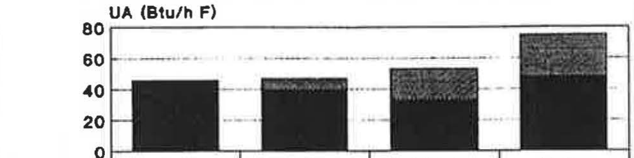
Figure 3 shows the results from a series of tests comparing the savings possible from insulated skirting to that using blown-in belly insulation. Previous indoor tests to investigate this issue had been inconclusive due to the lack of a wind emulator, and lack of control over the warehouse floor surface temperatures. In this test, the wind emulator was used to create a repeatable effective wind condition of about 3.5 mph, and the warehouse floor was thermally de-coupled from the mobile home by covering it with a 6" blanket of vinyl-backed fiber-glass insulation. The skirting system had 1" bead-board insulation and was tightly fitted to the mobile home and warehouse floor. No ventilation of the skirting was allowed during the test even though many local codes require crawlspace ventilation. The test gave the "benefit of the doubt" to skirting, that is, uninsulated or vented skirting would produce less savings than the skirting system used in the test. The tests were sequenced as follows:

- No-wind test of the pre-weatherization base case.
- Wind test of the pre-weatherization base case.
- Install non-vented insulated skirting.
- No-wind test of skirting case.
- Wind test of skirting case.
- Remove skirting, blow belly.
- No-wind test of belly blow.
- Wind test of belly blow.

Figure 3. CMFERT Mobile Home #4 Invader

Reduction in Overall BLC

Skirt vs. Belly Blow Wind & No Wind



	Skirt No Wind	Belly No Wind	Skirt Wind	Belly Wind
Infiltration	0	7	20	27
Conduction	46	40	33	48
Total	46	47	53	75

■ Conduction ■ Infiltration

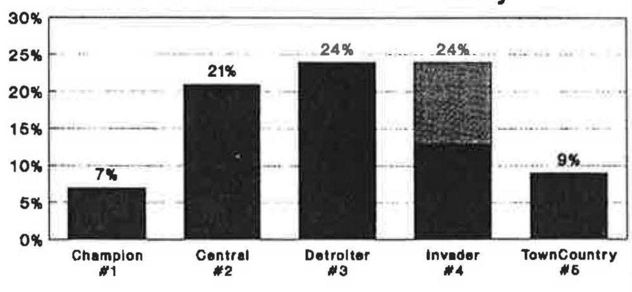
Belly savings 41% > Skirt (with wind)
Floor thermally de-coupled using insulation blanket

Figure 3 shows the reduction in building heat loss due to the skirting and the belly blow under still-air and windy conditions. Under still-air conditions, the reduction or savings from the belly blow was slightly greater than for skirting. Under windy conditions, the savings from the belly blow was 42% greater than from the skirting. The installed cost for insulated or uninsulated skirting in the Denver area is greater than that for a belly blow. Thus the data suggest that belly insulation is much more cost-effective than skirting in calm *or* windy climates.

Proponents of skirting could argue that the test did not properly account for ground coupling. This is true in the sense that we could not replicate the long-term ground-surface temperatures that exist under mobile homes in the outdoor environment. However, there is no evidence to date indicating that this effect would reverse the overall finding that a belly blow is more cost-effective than skirting. Outdoor tests conducted by the New York State Energy Research and Development Authority (NYSERDA) did not find skirting to be cost-effective.[1] Temperature data collected from beneath skirted and unskirted mobile homes in the field by the National Center for Appropriate Technology did not show significantly different temperatures. In both the skirted and unskirted homes the crawl-space and ground-surface temperatures were quite close to the ambient temperatures, according to John McBride, scientist with the center.

Figure 4. CMFERT Mobile Home #1 Thru #5

Increase in Measured Combined Furnace and Duct Efficiency



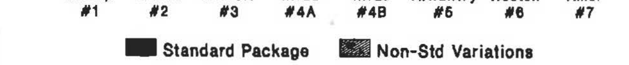
Efficiency = Qcoheat/Qgas + Qfan)
Avg Efficiency Increase = 15% (no wind)
Additional increase with wind = 11%

Furnace Efficiency and Duct Losses

Some retrofits such as furnace tune-ups, sealing of duct leaks, and belly insulation (where heating ducts are in the belly) directly effect the combined furnace and duct efficiency, often called "delivered heat" efficiency. Other retrofits such as general air sealing, wall, floor, and ceiling insulation, and storm windows indirectly effect delivered heat efficiency in combustion furnaces by reducing loads, thereby causing the furnace to become relatively oversized for the load, and thus increasing cycling losses. Figure 4 shows the increase in delivered heat efficiency due to all weatherization measures installed on five of the mobile homes tested in the warehouse under still-air conditions. The average increase in efficiency was 15 percentage points. However, the wind emulation data from unit 4 suggest that in windy climates even greater improvements in delivered heat efficiency are likely. For unit 4, delivered heat efficiency increased by 11% beyond the non-wind improvement of 13%, to make a total increase of 24% under windy conditions. This supports the hypothesis that without wind, much of the heat that escapes from leaky ducts seeps back up into the unit. With the wind emulator running, less of the heat is recovered because of exfiltration from the belly cavity. This is also what would generally occur in the outside environment, because for most locations average winter wind speeds exceed 4 mph. Again, sealing duct leaks saves more energy in a windy climate than in a non-windy climate, all else being equal.

Figure 5. CMFERT Mobile Home #1 Thru #7

Measured % Reduction in BLC Per Home Due To All Measures (No Wind)



#3 got Roof Cap & Belly Wrap #4B got Standard Package + Wall Blow
#7 got Wall Blow & no Belly Blow

Figure 5 shows the percent reduction in building heat-loss coefficient due to all weatherization measures installed on each of the 7 mobile homes tested to date under still-air conditions. Units 1, 2, 4A, 5, and 6 all received the same retrofits: blower-door-directed air sealing and duct repair, interior storm panels, belly blow, roof blow, and furnace tune-up (furnace tune-up affects

The Wall Insulation Techniques

Two methods were used. The first involved chopped fiber glass using a fill tube, and the second involved stuffing fiber-glass batts using a fabricated, galvanized-steel batt stuffer.

Blown Fiber-Glass

In the first method, a clear plastic fill tube with an inside diameter of 1.25" was inserted under the exterior siding and pushed up against the interior paneling to within 6" of the top plate (Figure 7). Plastic fill tubes like the one we used have a naturally bowed shape and it is important to insert the tube so that the bow of the tube presses the tip against the interior paneling. When the tip of the tube is pressed against the paneling, it is least likely to snag the insulation or cross-bracing on its way up the wall.

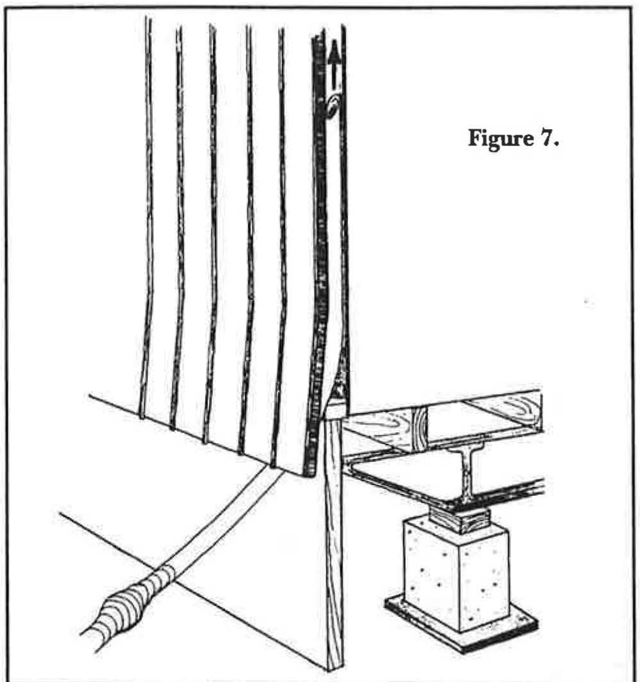


Figure 7.

Fiber-glass insulation (Johns Manville Rich R, Certainteed Insulsafe III, and Owens Corning Thermoglass) was then blown into each cavity from top to bottom using a Promax 218 blowing machine. The bottom row of screws was removed from the siding, and the interlocking joints of the siding were screwed together to help to keep the siding as a one-piece barrier for the insulation at the bottom of the wall. Because the fiber-glass tends to cling to wall surfaces and to the existing insulation, the wall was filled and packed from top to bottom. The installer can tell when to withdraw the tube by the sound of the blower lugging down and by the insulation flow slowing down as packing occurs. The installer can observe the exterior siding bulging noticeably if packing exceeds 3.5 lbs/ft^3.

The installed density and the speed at which the cavities fill depend on the blower's feedgate setting and speed. If the feedgate is opened too far, the cavity will take inordinately long to fill. With the blower operating at near maximum speed and the feedgate opened just a few holes, the blower will over pack, bulge, or blow off the interior or exterior wall panels. We found that a feedgate setting of 6 holes and a blower speed of 80–100% produced a pack of 3.5 lbs/ft^3 with minimal bulging and blow-off of wall panels. Occasional panel pop-offs were easily repaired with nails, screws, or staples. (Other machines may require different settings. At the beginning of the job, the insulator should carefully experiment to find the appropriate settings for each machine.)

Unless care and judgment are exercised, the bottoms of the insulated wall cavities will overfill because the siding is loose on the bottom. This is not a major problem, but it will waste insulation and slow down re-attachment of the bottom of the wall panel. We found that marking the fill tube in feet and listening to the insulation filling the wall cavity were helpful in withdrawing the tube from the last two feet without overfilling. Two pieces of fiber-glass batt or two rags help to prevent insulation from blowing out of the bottom of the wall cavity. Holding the siding closely around the fill tube helps keep the insulation in and also helps in avoiding overfilling the bottom of the cavity.

The Batt Stuffer

The second method used in the study was stuffing batts into the cavity using an 8' x 1' galvanized stuffer (Figure 8). Sixteen-gauge galvanized steel is folded lengthwise for stiffness and to produce smooth edges. The top and bottom have about two inches folded over for the same reasons. A set of teeth is cut into the top to impale the insulation so that it will not slip off the stuffer as it is pushed into the wall.

The bottom two rows of screws are removed and the joints screwed together to keep the interlocking joints from separating and flapping around. The 14.5" x 8' R-11 batt is loaded onto the

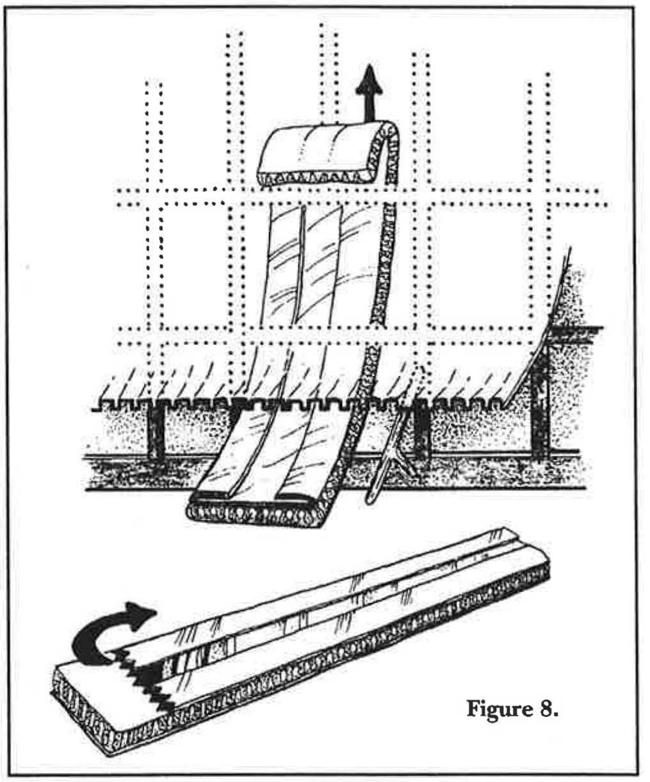


Figure 8.

stuffer by wrapping the top 4–6" of the batt over the teeth. The exterior siding is held away from the wall by L-shaped 1 x 2 holding blocks and the batt is pushed up into the cavity until the stuffer and the insulation bump into the top plate. The stuffer is pulled down and bumped up a couple of times to insure that the insulation is all the way up to the top plate. Then the stuffer is removed and the excess batt cut from the bottom. For 1.5" wall cavities or cavities with obstructions, a 14.5"-wide, full-length piece of 4–6 mil plastic placed over the insulation and slid up the inside of the interior wall will reduce friction and prevent tearing most of the time. Electrical boxes must be loosened from the inside and pulled temporarily out of the wall for stuffing. The stuffing method does not work well near corners or doors because the siding is difficult to loosen in those areas. Sometimes existing insulation must be removed from the wall or compressed by the new insulation as it is stuffed into the wall. The two methods work well together especially at sites where two blowing machines are not available. Even with a single blowing machine, a two-man crew can complete the wall retrofit in one day.

delivered-heat efficiency, not BLC). The average reduction in BLC for these 5 units was about 42%.[4]

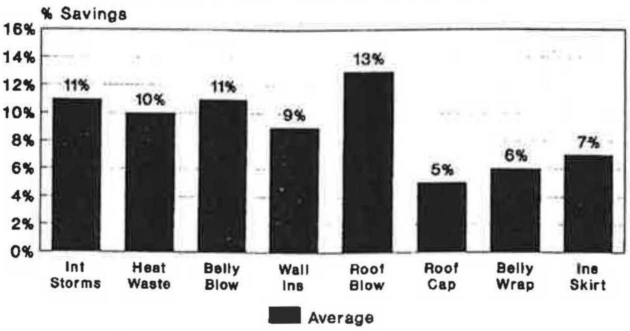
Unit 3 received a belly wrap and a roof cap instead of a belly blow and roof blow. This accounts for its relatively small savings. Unit 4B received a wall blow in addition to the standard package of measures. This accounts for its relatively large savings. Unit 7 received the standard package, except a wall blow was substituted for a belly blow. Units 4A, 4B, and 6 were tested under both still air and wind conditions. In all cases savings increased with wind by 40%, 38%, and 24%, respectively.

Figure 6 shows the average percent reduction in BLC by retrofit measure under still-air conditions for all the mobile homes tested, including one home tested at the Colorado Mountain College.[5]

The individual savings from any single retrofit measure may vary considerably from home to home, but the savings per home, when the entire retrofit package is installed, should be relatively consistent.[6]

Figure 6. CMFERT Mobile Home #1 Thru #7 & CMC

Measured UA Average % Savings
Conduction and Infiltration



Savings with wind:
Skirt = 9.6% Belly = 14.7% Wall = 9.8%

Interpretation of Results

Our data reflect measured changes in the building heat-loss coefficient, and the steady-state heating-system efficiency taken at a 30°F temperature difference. The BLC is a characteristic of the building itself and is independent of climate and occupant behavior. It is useful for comparing one building to another, or a pre- and post-retrofit building. A reduction in the BLC indicates the *potential* for energy savings. Actual energy savings, of course, depend on climate and occupant behavior. Client education should therefore be a key feature of any weatherization program.

Once we know the change in BLC, infiltration rate, and heating system efficiency, we can model the potential energy savings in different climates. This is how we determined the cost-effectiveness of the retrofits. (See *HE*, Jan/Feb '90, p.27, Figs. 5–7.) The paybacks and simplified calculation methods presented in the previous article did not change as a result of the new data. Those results were based on the data from mobile home 1 where application of the standard retrofit package reduced the BLC by 204 Btu/hr-°F, or normalized to the surface area of the home, .09 Btu/hr-ft^2-°F. The average normalized reduction in BLC for the five homes that received the standard weatherization package was about 10% less than for mobile home 1. However, we know from the wind experiments that the increases to heating-system efficiency are also greater under windy conditions. A wind of only about 3.5 mph resulted in an additional 11% increase in heating-system efficiency due to the weatherization package. This more than offsets the 10% deficit in the average BLC savings. Thus, we can safely continue to use the cost-effectiveness data and simplified calculation methods from the previous article.

In Our Next Report...

We are now conducting a follow-up study in which we will track utility bills for Colorado mobile homes receiving the standard package of retrofits. The utility bill data will be analyzed using the Princeton Scorekeeping Method (PRISM). Results from this study should be available in December.

Conclusions

The most cost-effective measures for colder climates appear to be: blower-door-directed air sealing and duct repair, furnace tune-up, belly blow, interior storm panels, and roof blow (cost-effectiveness based on data furnished by the Colorado Division of Housing Weatherization Program as described in the previous article). Storm windows are only effective if properly used by the occupants. "Self-Storing" interior storm panels may solve many of the problems associated with seasonal removal and replacement of storms, although we have not yet tested this type. In addition, two new wall insulation retrofit techniques have been developed and have proven to be much more practical and less costly than the previous "wall peel" technique. Belly wraps, skirting, and roof caps appear to be less cost-effective than the other measures. The 21 belly wraps tried in Colorado have shown severe deterioration in only a few years, and we do not recommend this technique. Skirting and roof caps should only be used when special circumstances justify the added costs, such as when a belly blow is not possible, or where a roof is damaged.

Wind does not negate the effects of the retrofits. On the contrary, all else being equal, these weatherization measures will save more energy in windy climates. Skirting, however, does not perform much better in windy climates. A belly-blow outperforms skirting under all circumstances, but even more so under windy conditions.

The savings attributable to any individual retrofit vary considerably from home to home. However, the overall effect of the entire weatherization package results in a mean reduction of the BLC from 38 to 46% at the 95% certainty level. If our sample of eight homes was typical of the population of mobile homes qualifying for low- income weatherization, then these savings can be achieved with a simple list approach. Where agencies are willing to apply more sophisticated audit techniques, even greater savings and cost-

To Save More Energy than the U.S. Gets from Kuwait

There are about 5 million pre-HUD-code mobile homes, and 5 million HUD-code homes.[1] Our measured data shows that for an expenditure of about $1,000–$1,500 per pre-HUD-code home, we can reduce the BLC of an average single-wide by about 200 Btu/hr-°F (with wind). Theoretical computer simulation studies and preliminary measured data on new manufactured homes indicate that, with some further research to develop an appropriate weatherization package for HUD-code homes, we should be able to reduce the BLC in these homes by about 100 Btu/hr-°F.[2,3] Thus the annual savings potential is:

$$\left[\frac{(200 + 100)\text{Btu/hr-°F}}{2}\right] \times 24\text{hrs/day}$$

= 3,600 Btu/HDD per average mobile home.[4]

3,600 Btu/°F-day X 4,000 °F-days X 10,000,000 mobile homes X 1.4
= .2 Quads/year for all mobile homes.[5]

To put .2 quadrillion Btu into perspective:

- .2 Quads represent savings of 36 million barrels of oil per year.
- 36 million barrels of oil exceeds 1988 oil imports from Kuwait and is approximately equivalent to 11% of the 1988 oil imports from Saudi Arabia.
- .2 Quads exceeds the energy produced by six 1,000-megawatt nuclear power plants. (These plants cost about $2.5 billion each to build.)
- .2 Quads would save low-income families about $2 billion per year at 1989 fuel prices.

Notes

1. Conversation with Rob Riebling, Manufactured Housing Institute (MHI).
2. Ecotope, Inc., and Washington State Energy Office, "Manufactured Homes Simulated Thermal Analysis and Cost-Effectiveness Report," 1990, sponsored by Bonneville Power Administration.
3. "Industrialized Housing: Exploring the Potential for Energy Efficiency," *Home Energy*, Sept/Oct '90, p. 9.
4. Heating Degree Days, calculated to a base of 65°F.
5. 4,000 °F-days = the mobile home weighted average degree-days for the United States. 1.4 = the average delivered heat inefficiency across furnace types, i.e., the ratio of furnace input energy to duct register output energy. .2 Quads is a relatively conservative figure in that no credit has been taken for cooling savings.

effectiveness should be possible. Actual energy savings will, of course, depend on climate and occupant behavior.

The blower door is an excellent tool to find air leaks in the building and duct system, and is essential to prevent overtightening. Occupants of low-volume buildings are particularly vulnerable to health and safety problems associated with insufficient ventilation, especially when using unvented appliances. The heating system is an integral part of the home. It is unsafe to weatherize small volume buildings such as mobile homes without proper training on combustion-system safety checks and adjustments.

Recommendations

During the course of this project we have learned a great deal about how to better weatherize pre-HUD-code mobile homes (those built before 1976, when the U.S. Department of Housing and Urban Development building code went into effect) in cold and relatively dry climates. A previous study by Meridian Corporation for the U.S. DOE found that national averages of heating energy savings for mobile home retrofits were about 5% after a weatherization expenditure of $1,000, resulting in a simple payback of about 21 years.[7] This was because most weatherization agencies thought that conservation measures developed for site-built houses could also be applied to mobile homes. The CMFERT study has shown that with retrofits developed specially for mobile homes, the potential for savings is from 30 to 50% for about the same expenditure, resulting in simple paybacks of from 3 to 8 years.

Many questions remain concerning how to properly weatherize mobile homes in cold-moist, hot-moist, and hot-dry climates. For example, we do not yet know if roof blows or air tightening will lead to long-term condensation problems in moist climates. Further research on these issues would lead to greater savings in these climates.

Much of what we have learned by studying pre-HUD-code mobile homes is also applicable to newer manufactured housing. These homes are not much better in energy efficiency than the pre-1976 models (Table 1). Other independent studies have found approximately the same potential for savings as the pre-HUD-code homes studied by the CMFERT project.[8] However, some additional research is required to develop an appropriate weatherization package for the post-1976 group of homes.

The new manufactured buildings of today will be the weatherization headaches of tomorrow, and the problems will be with us for a long time. According to Rob Riebling of the Manufactured Housing Institute, the life-cycle of a mobile home averages about 41 years. Obviously, it is much less expensive and easier to install conservation measures in the factory than in the field. Currently, the national weatherization program spends about 25% of its annual budget, or $40 million per year, on weatherizing pre- and current HUD-code mobile homes. From a societal perspective, it would be much more cost-effective to make sure new mobile homes are energy efficient to begin with than to weatherize them after they are built. Again, some research is required to determine the most appropriate energy-conservation features for newly manufactured homes. The knowledge gained and the test methods developed in this project represent a good start in that direction.

At a time when home ownership is becoming less attainable for a growing portion of the population, manufactured housing is the fastest-growing segment of the residential market and represents the most affordable

Table 1. Mobile Home Construction Before and After 1976 HUD Code

Component	Before	After
Insulation	1" batt/blanket	2"
Wall structure	2" x 2" or 2" x 3" vented	2" x 4" vented
Windows	jalousie/awning no storms	double-hung slider storms
Infiltration	same	same

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housing in America. The occupants of this housing type are low-income families and elderly people, for whom energy bills comprise a disproportionately large share of disposable income. For these residents, the line between home ownership and homelessness is quite thin. The application of cost-effective energy-conservation measures has the potential to reduce mortgage defaults and increase the number of qualified buyers through energy-efficient mortgages. This creates a win-win situation for buyers, lenders, and manufacturers. ■

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2. "Mobile Home Weatherization Measures: A Study of their Effectiveness," Judkoff et al., SERI/TR-254-3440, Dec. 1988; and "Testing the Effectiveness of Mobile Home Weatherization Measures in a Controlled Environment: the SERI CMFERT Project," Judkoff et al., SERI/TP-254-3629, Mar. 1990.
3. A coheating test measures the overall U-value (or R-value) of a building by heating it with metered electric-resistance heaters to a constant temperature and and measuring the amount of time it takes to achieve the warm-up, the amount of energy it takes to maintain the constant indoor temperature, the amount of time it takes to cool down the building afterwards, and the outdoor temperature. In the warehouse, we are able to conduct the coheating tests while maintaining a near constant "outdoor temperature—the temperature inside the warehouse but outside the mobile home. This provides a very accurate measure of the building's overall U-value (also known as UA_o, building loss coefficient, or building load coefficient).
4. The average was 42% with a standard deviation of 3%. Assuming a random sample, the mean reduction in BLC for mobile homes receiving this package should be about 42% ±4% at the 95% confidence level.
5. "Testing the Effectiveness of Mobile Home Weatherization Measures in a Controlled Environment: the SERI CMFERT Project," Judkoff et al., SERI/TP-254-3629, Mar. 1990.
6. This is indicated by the fact that the standard deviation for the mean savings per home is much smaller than the standard deviations around the mean savings per individual measure.
7. "Weatherization Evaluation Findings: A Comparative Analysis," CSR Inc., and Meridian Corp. Prepared for U.S. Department of Energy, Contract #DE-AC01-89 CE-10530, Alexandria, VA. 63pp. April 1989.
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