Modeled and Metered Energy Savings from Exterior Wall Insulation

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Millions of single-family masonry (block) houses with slab foundations exist in the southern United States. In fact, approximately 50% of Florida's six million residences are of concrete block construction. The block walls in these homes are usually uninsulated, and the technology for retrofitting wall insulation is not well developed.

Two field tests were performed—one near Phoenix, Arizona and one in Cocoa, Florida—to measure the air-conditioning energy savings and demand reduction impact of applying an exterior insulation and finish system (EIFS) to the exterior of the block wall, and gain practical experience with retrofit application techniques and costs. One field test used a ''site-fabricated'' insulation system, while the other field test used a commercially available system. The field tests measured a savings of 9% in Arizona and less savings in Florida, and emphasized the impact indoor temperature settings have on cooling energy savings: exterior wall insulation on block homes will produce energy savings in Florida houses only if a low cooling thermostat setting is desirable. The field tests also highlighted an improved comfort benefit from the retrofit; namely, elimination of overheating in rooms with south and west exposures.

The DOE-2.1D program was used to analyze the energy savings (air-conditioning and heating) and electric demand impact of applying an EIFS. Air-conditioning energy savings were estimated to be in the range of 8% to 10% in many southern U.S. regions. A 12% savings was predicted for Phoenix, Arizona and a savings of 1% to 4% was predicted for seacoast regions, particularly in Florida. These predictions were in good agreement with the measured values. Peak hour cooling energy savings were predicted to be more uniform throughout the country, generally in the range of 8% to 12%.

This paper summarizes the research results, reviews the installation techniques and their costs, and provides recommendations for future implementation.

INTRODUCTION

One common construction technique for single-family residences in the southern United States (where cooling demands are significant and where termite infestation is a problem) utilizes masonry, or concrete block, walls with a slab foundation. In fact, approximately 50% of Florida's six million existing residences are of concrete block construction. Additionally, basements can be constructed of concrete block and often have exposed walls in states such as Tennessee. Houses having block walls and slab foundations are typically more air-tight than those having wood-frame walls, but are often constructed with little or no wall insulation, particularly those built 15 or more years ago.

A research project in 1990 dealing with the energy performance of buildings in Saudi Arabia evaluated 14 wall system assemblies (Grondzik 1992). Conclusions reported in that study were drawn from a short data collection period of three weeks, but showed that wall system performance can be significantly improved through insulation in an extremely hot climate. Expanded polystyrene insulation (50 mm thick) placed on the exterior surface of a masonry wall reduced the heat flux by approximately 63%.

The technology for retrofitting wall insulation is not as well developed for masonry houses as for framed houses. Installing insulation in the cores of concrete block is not generally practical after the house is built. Interior retrofit insulation can be installed, although occupant inconvenience may be high and costs are not known. Wall insulation retrofit to the exterior of a block house offers a practical alternative to these methods. In addition to slowing the heat transmission rate through the wall system, exterior wall insulation enhances the potential use of the block's thermal capacitance to shift cooling peak demand and minimize interior air temperature fluctuations under certain thermostat set-point strategies.

Proprietary, commercially-available exterior insulation and finish systems (EIFS) are commonly used on new and renovated commercial buildings to enhance the exterior appearance. These systems are used for similar purposes on residential buildings, although their use is usually limited to high-scale homes. Rigid insulation boards are glued and/or mechanically fastened directly to the masonry wall, covered with a mesh, and coated with a polymer-based coating. The insulation boards are, structurally, a necessary part of the system, but offer insulating value as an added benefit.

We performed three separate studies to evaluate the energy savings potential offered by insulating exterior masonry walls. Air-conditioning electricity savings were measured in field tests conducted near Phoenix, Arizona and Cocoa, Florida, and modeling evaluations were performed to better understand field test results and extrapolate results to other southern cities.

ARIZONA FIELD TEST

We monitored eight single-family houses near Phoenix, Arizona throughout the summer of 1991 (Ternes & Wilkes 1993). In the middle of the test period, the exterior walls were insulated. The total electricity consumed by the house and the electricity consumed by the air conditioner were recorded for each residence on a half-hour basis during the entire test period. Indoor temperature was monitored hourly in each house and meteorological data were collected at nearby weather stations.

The homes were occupied, detached, single-story homes with uninsulated exterior masonry walls and having only central electric air-conditioning systems (Figure 1). Walls between the living spaces and unconditioned garages and utility rooms were framed drywall with no insulation. The houses were built between 1960 and 1970 and ranged between 1,120 ft^2 to 1,585 ft^2 in size. All houses had wide front and rear porch roofs, which significantly shaded much of the window area.

The addition of the exterior wall insulation increased the thermal resistance (R-value) of the walls from about 3 h-ft^2-°F/Btu to about 13 h-ft^2-°F/Btu. We used a site-fabricated exterior insulation system (Ternes, Wilkes, & McLain 1995) on the houses in this field test rather than a commercial system as previously described to evaluate cost-reduction and installation techniques. As shown in Figure 2, the insulation was installed by attaching 1.5-inch thick furring strips to the exterior walls, installing inch-thick extruded polystyrene foam insulation boards between the strips and a second layer of insulation boards over the furring strips, attaching a wire lath (Figure 3), and finally, applying a cementitious stucco finish[1]. A finished house is shown in Figure 1. In addition to the exterior wall insulation, interior wood-framed walls between the conditioned living spaces and the garage and utility rooms were insulated with blown-in cellulose to establish a continuous wall thermal barrier.

Total retrofit costs ranged from $3,610 to $4,550 per house, averaging $3.34 per ft^2 of exterior wall area covered with insulation. The cost of installing the furring and exterior insulation was $1,500 to $1,950, and the cost of insulating the interior walls between the conditioned living spaces and the garage and utility rooms with blown-in cellulose was $160 to $200 per house. For aesthetic reasons, garage walls, attic gables, and other features such as walled flower beds were also insulated and/or stuccoed even though doing so offered no energy savings potential. These areas were

Figure 1. *Owner-Occupied, Single-Family Detached Houses Were Chosen for the Arizona Field Test*

Figure 2. *Retrofit Installation on the Arizona Field Test Houses Began by Installing Furring Strips and Extruded Polystyrene Foam Insulation Boards*

Figure 3. A Wire Lath with Flashing, Metal Trim, and Control Joints Was Installed on the Arizona Field Test Houses Before Applying the Stucco Finish

approximately a third of the total area receiving exterior wall insulation.

We estimated cooling energy consumptions and savings for each house directly from measured data using a regression technique. The regression model assumed that daily air conditioning energy consumption was linearly related to the daily average difference between indoor and outdoor temperature. The regression analysis estimated an average annual pre-retrofit air conditioning electricity consumption of 5,499 kWh for the eight houses (see Table 1), and an annual savings of 491 kWh, or 9% of pre-retrofit consumption. Annual savings for individual sites varied from − 106 kWh (− 3%) to 1,319 kWh (16%). Estimated annual consumptions and savings were normalized to a standard indoor temperature of 79° F for all houses (average indoor temperatures measured in the eight houses ranged from 76.5° F to 81.6° F, and changed in some houses following retrofit).

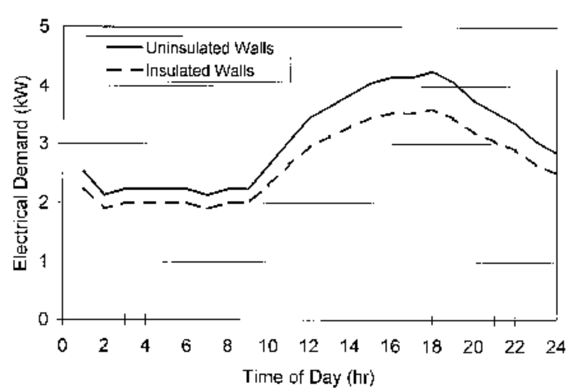
We also used another regression model to analyze the combined electricity demands of all eight houses. We chose the outdoor temperature for the driving force (or independent variable) for this model. Our examination of the data showed thermal mass effects, where variations in the pooled (average) demand lagged variations in outdoor temperature. That is, when the outdoor temperature changed, there was some time delay before the air conditioner responded. To account for this, we used a single lagged outdoor temperature variable. A one-hour delay was determined to be optimal.

Using the pre- and post-retrofit regression curves, average peak-day demand profiles of all eight houses were developed for the pre- and post-retrofit periods (Figure 4). The ambient temperature profile used was that for the hottest day of an average year for Phoenix (the peak temperature was 114° F).

Table 1. Results of Regression Analysis for the Arizona Field Test

House	Annual Pre-Retrofit Air-Conditioning Electricity Consumption (kWh)	Air-Conditioning Electricity Savings (kWh)	(%)
1	8225	1319	16%
2	6955	81	1%
3	4379	539	12%
4	3124	− 106	− 3%
5	4950	306	6%
6	7073	516	7%
7	4387	413	9%
8	4902	861	18%
Average	5499	491	9%

Figure 4. Predicted Pooled Air-Conditioning Electricity Demand with and Without Exterior Wall Insulation for the Hottest Day of an Average Weather Year in Phoenix, Arizona



The peak demands without and with insulation were 4.26 and 3.61 kW, for a demand reduction of 0.65 kW (15% of pre-retrofit demand).

Although we had been concerned about how the houses would look after the retrofits, homeowners generally felt that the property value and appearance of their homes improved after the wall insulation was installed. Additionally, three occupants reported that overheating in rooms with south and west exposures vanished after the retrofits. One occupant had previously installed a second thermostat in the overheated room to try to alleviate the problem.

FLORIDA FIELD TEST

Two occupied, single-family block houses, constructed with uninsulated masonry walls on uninsulated concrete slabs, were monitored from the Spring of 1994 through the Fall of 1994 (Barkaszi & Parker 1995). Site 1 was 1450 ft^2 and had a low-slope built-up roof. Site 2 was 1800 ft^2 and had a conventional truss roof with gable ends. A highly reflective roof coating had been applied to both houses for another experiment to reduce solar gains through the roof system, and ductwork in both houses had also been previously sealed. Fifteen-minute electrical consumptions, house temperatures, and meteorological data were collected at each site.

A local contractor specializing in EIFS work installed a commercially available system on these two houses. The system used 1.5-inch extruded polystyrene rigid foam insulation boards, fiberglass mesh reinforcement in the exterior base coat, and a 100% acrylic finish. The insulation boards were adhered directly to the wall after pressure washing the exterior surfaces to remove any dirt and loose paint. The boards were then rasped and sanded to plane the surface (Figure 5) before the base coat of mastic (Figure 6) and finish coat were applied.

Figure 5. *The Extruded Polystyrene Foam Insulation Boards Were Sanded and Planed on the Florida Field Test Houses to Obtain a Smooth Surface*

Figure 6. *An Acrylic Polymer Finish Mastic Was Applied over the Base Coat of Mastic on the Florida Field Test Houses*

A crew of two required approximately seven working days to complete each installation. The average cost of the retrofits was approximately \$6,800 per home, or \$3.90 per ft^2 of wall area covered.

A matched-days comparison method, using individually paired days with similar weather conditions from the pre- and post-retrofit periods, was used to estimate air-conditioning electricity savings. The matched-days had daily average ambient temperatures within 1° F of each other, solar irradiance within 20 W/m^2, interior temperatures within 1° F, and interior appliance electrical use within 80 Wh. Nineteen matched days were identified for Site 1 and 44 matched days were identified for Site 2. Average values for energy use and the matching parameters are shown in Tables 2 and 3. The matched-days method estimated a 8.9% savings (3.2 kWh/day) in cooling energy use for Site 1 and a 5.5% increase (1.4 kWh/day) in air-conditioner electricity consumption for Site 2. We attributed the difference in performance between these houses to the lower set point temperature maintained at Site 1 (about 73.4° F) compared to Site 2 (79.0° F). This is discussed more thoroughly in the modeling section below.

We estimated cooling energy savings with a second analysis method using composite days. Analysis of composite days utilized long-term averages of continuous data segments with similar weather conditions before and after the treatment. We used a 32-day period before and after retrofit for Site 1, and a 21-day period for Site 2. We selected these continuous periods so that the number of days would be maximized and the variation in selected independent parameters (ambient temperature, solar irradiance, interior temperature, and appliance energy use) would be minimized. Aver-

Table 2. *Matched-Days Comparison for Florida Field Test Site 1 (19 Matching Days Identified)*

	Ambient Temperature (°F)	Solar Irradiance (W/m^2)	Interior Temperature (°F)	Appliance Energy Use (kWh/day)	Air-Conditioning Energy Use (kWh/day)	Savings
Before	81.8	265.9	73.4	13.4	36.0	3.2 kWh per day (8.9%)
After	81.9	261.6	73.5	13.2	32.8	

Table 3. *Matched-Days Comparison for Florida Field Test Site 2 (44 Matching Days Identified)*

	Ambient Temperature (°F)	Solar Irradiance (W/m^2)	Interior Temperature (°F)	Appliance Energy Use (kWh/day)	Air-Conditioning Energy Use (kWh/day)	Savings
Before	80.9	239.6	79.0	10.3	26.4	−1.4 kWh per day (−5.5%)
After	81.0	240.2	70.0	10.4	27.8	

ages and standard deviations of the daily averages are shown in Tables 4 and 5. The standard deviations show that the variation in daily averages was comparable for the pre- and post-retrofit periods at both sites. The composite-days method estimated cooling energy savings of 14.5% (4.6 kWh/day) for Site 1 and an energy use increase of 4.9% (1.3 kWh/day) for Site 2. For each site, these values were consistent with the values determined from the matched-days method.

We developed an average air-conditioning demand profile for each house for the pre- and post-retrofit periods using

Table 4. *Long-Term Periods Comparison for Florida Field Test Site 1*

	Ambient Temperature (°F)	Solar Irradiance (W/m^2)	Interior Temperature (°F)	Appliance Energy Use (kWh/day)	Air-Conditioning Energy Use (kWh/day)	Savings
BEFORE (Julian days 160 to 192)						
Average	80.7	235.3	73.8	15.7	31.7	
Standard deviation	2.4	62.1	1.6	4.3	9	4.6 kWh per day (14.5%)
AFTER (Julian days 214 to 246)						
Average	80	212	73.2	12.8	27.1	
Standard deviation	2	71.4	1.5	4	9.6	

Table 5. Long-Term Periods Comparison for Florida Field Test Site 2

	Ambient Temperature (°F)	Solar Irradiance (W/m²)	Interior Temperature (°F)	Appliance Energy Use (kWh/day)	Air-Conditioning Energy Use (kWh/day)	Savings
BEFORE (Julian days 167 to 188)						
Average	81.4	234	79.2	9	26.1	
Standard deviation	2	56.1	0.4	3.4	5.5	−1.3 kWh per day (−4.9%)
AFTER (Julian days 239 to 260)						
Average	81	208.3	79.1	12.1	27.4	
Standard deviation	2.4	58.5	0.3	3.5	6.3	

the data from the composite-days period. Power use at 5 to 6 pm is about 0.3 kW (14%) less at Site 1 (Figure 7) following retrofit and about the same at Site 2 (Figure 8). This is not the peak demand reduction expected for the season because the profile is based on the composite period which included hot, warm, and mild days.

We analyzed wall temperature data from the composite-day periods to determine changes in wall system performance after retrofit. As expected, interior wall surface temperatures were reduced and had less diurnal fluctuations, while exterior wall surface temperatures were greater.

Figure 7. *Average Air-Conditioning Electricity Demand Profile for the Pre- and Post-Retrofit Periods of Florida Field Test Site 1*

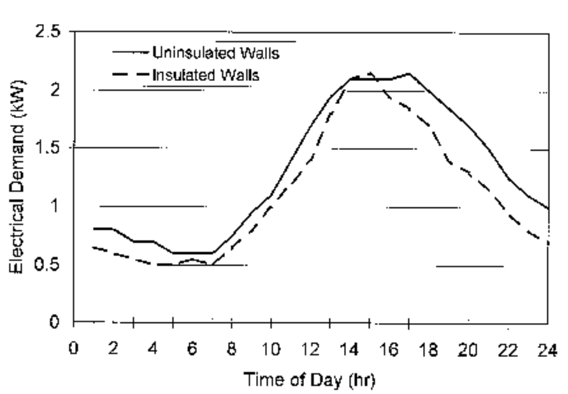
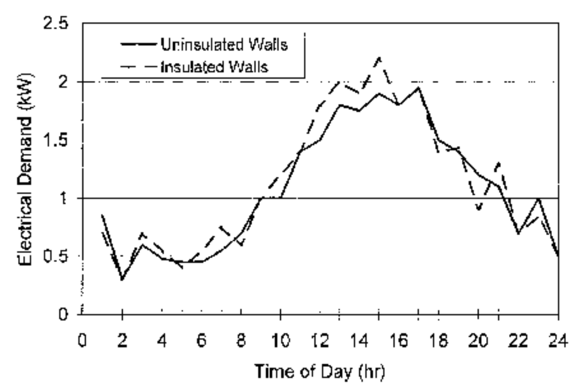


Figure 8. *Average Air-conditioning Electricity Demand Profile for the Pre- and Post-Retrofit Periods of Florida Field Test Site 2*



MODELING STUDIES

We performed several modeling studies in conjunction with the field tests using the DOE 2.1D building simulation program (LBL 1989). Each of the eight houses tested in Arizona were modeled using DOE-2 (McLain 1992), modified by an attic simulation model (Wilkes 1991). We adjusted selected input parameters (e.g., internal loads and window shading) in the DOE-2 models, within reason, and developed calibration factors to match DOE-2 estimated air-conditioning electricity consumptions with pre- and post-retrofit measured consumptions. We then used these calibrated models to estimate annual cooling energy savings for each house for an average weather year. An average savings of 11% was predicted by DOE-2 for the eight houses, which compares favorably with the 9% estimated directly from measured data using a regression technique. The peak demand reduction of 0.65 kW (15%) estimated previously was also in good agreement with the reduction of 0.70 kW (14%) estimated by DOE-2 modeling.

We examined the effect of adding external wall insulation for a number of cities in the southern region of the United States using the DOE-2 model and a prototypical house similar to the Arizona test houses. The cooling set point temperature was assumed to be 78° F. Predicted annual air-conditioning electricity savings were the greatest, 450 to 700 kWh (10% to 14%), for houses located in Las Vegas and Phoenix. In contrast, they were less than 50 kWh for a house located in Miami or southern California, a value consistent with the measurements made in the Florida field test. For the peak hour, the percentage demand reductions were more uniform, generally in the range of 8% to 12% (or 0.25 to 0.7 kW).

Modeling showed that heat gains through exterior walls were much less in most southern climates (especially coastal regions) compared to an extremely hot, dry climate like the southwest. Heat gains from internal loads and solar loads through the glazing contributed significantly to the house's total cooling load in all climates. Insulating the walls did result in much lower heat transfer rates through the walls in all cases. However, the insulated walls also caused a greater retention of heat generated within the house, which added to the cooling loads. The impact of this was apparent in Miami during the spring and fall months, when there was a relatively small amount of heat transfer through the house envelope. The addition of wall insulation resulted in a cooling load increase during these months.

A DOE-2 parametric study (Barkaszi & Parker 1995) of a 1,500 ft^2 prototypical home located in central Florida was performed to determine the effect of the following variables on wall system performance: insulation location (interior or exterior), constant cooling set point (70° or 80° F), natural ventilation option[2] (ventilation or no ventilation), and wall solar absorptance (0.3, 0.4, 0.5, or 0.6). Insulated walls provided a maximum cooling energy savings of 4.3% when the interior temperature was 70° F and ventilation was provided. The addition of insulation provided little benefit and often produced increased energy use with the higher cooling set point and non-ventilated configurations. Exterior insulation generally performed better than interior insulation with the constant set point strategy assumed. Savings were greater for higher wall solar absorptances (associated with darker exterior colors) because the initial heat flow through the wall was greater.

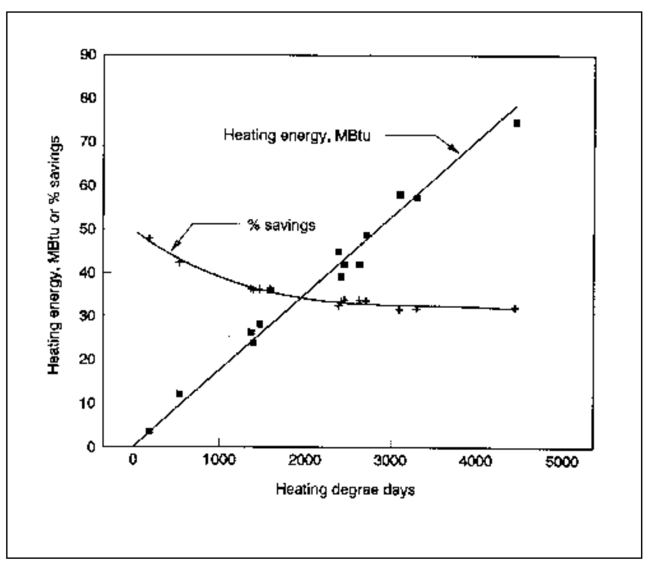
Using the 1,500 ft^2 prototypical home, simulation of Florida field test Site 1 predicted an annual cooling energy savings of 293 kWh (3.5%), and simulation of Florida field test Site 2 predicted a cooling increase of 35 kWh (1.8%). The major difference between these simulations was that the cooling set point temperature was lower for Site 1 compared to Site 2. These results support the performance changes observed from analysis of the measured data.

Our two modeling studies of prototypical homes showed that heating energy savings can be significant and of greater economic value than the cooling energy savings in many climates. For the modeling of the Arizona prototypical house, we estimated that about a third of the heating energy could be saved (see Figure 9) assuming a constant 70° F setpoint. A significant reduction in heating energy use (approximately 1000 kWh) was predicted by the modeling of the Florida prototypical house, assuming an electric resistance furnace (which is typical for Florida homes) and a constant 69° F setpoint.

RETROFIT ECONOMICS

From the consumer's viewpoint, benefits from the installation of exterior wall insulation include reduced air-conditioning electricity costs as well as reduced space-heating costs. Space-heating fuel savings of 14 MBtu/year were estimated using the DOE-2 model for a prototypical house in Phoenix equipped with a central, forced-air gas furnace. The simple payback period for an average $3900 investment cost is 32 years considering the measured cooling savings and estimated heating savings in Phoenix. If the house exterior is

Figure 9. Predicted Annual Heating Energy Use and Retrofit Energy Savings for the Arizona Prototypical House at Selected Geographic Locations



to be stuccoed to improve its aesthetic appearance, the simple payback period for adding insulation costing $1,500 to $1,950 is 12 years. The relatively lower level of savings produced by the retrofits in the Florida homes pose considerably less advantageous economics.

A major benefit obtained from the exterior wall insulation retrofit is a peak electrical demand reduction. Although consumers could benefit from this reduction if they used a time-of-day rate schedule, this demand reduction most directly benefits the electric utility. Examination of the economics of the measured demand reductions from a utility perspective was beyond the scope of our study. However, a 15% demand reduction is comparable to demand reductions achieved from installation of high-efficiency air conditioners, which are often supported by utility subsidies of several hundred dollars.

One benefit that is not captured in these economic analyses is the improved comfort resulting from more moderate wall temperatures after retrofit. The savings analyses assumed constant indoor temperature conditions before and after retrofit, whereas occupants may choose a higher setpoint during the summer after retrofit because of the lower mean radiant temperature of the exterior mass walls. Three occupants reported that overheating in rooms with south and west exposures vanished after retrofits in the Arizona field test, an additional benefit that is difficult to quantify.

SUMMARY AND CONCLUSIONS

Exterior wall insulation installed on masonry-constructed houses produces the greatest air-conditioning electricity savings and peak demand reductions in hot, dry climates similar to Phoenix, Arizona. Modeling estimated savings of 10% to 14% and demand reductions of 8% to 12% are possible in these climates, which were confirmed by measured data from eight tests houses in Phoenix.

Appreciable reduction in air-conditioning electricity use in milder climates will most likely be realized only in cases with low cooling thermostat settings. Modeling indicates that wall insulation impedes the natural cooling that occurs at night in milder climates, such that air-conditioning electricity consumption can actually increase following retrofit if higher indoor temperatures are maintained.

Modeling suggests that heating energy savings can be substantial in many southern climates, even being greater than cooling energy savings. Although concrete block houses are not prevalent in northern climates, any such residences would likely benefit greatly from this retrofit. Additionally, this technique could be used on houses in heating climates with exposed basement walls. Care must be taken to prevent ground contact in moderate to heavy termite infestation areas, and installation details must be followed to avoid moisture problems.

Conservation programs in hot, dry climates should consider including exterior wall insulation as a retrofit option based on the potential to reduce peak demand. From a consumer perspective, high installation costs are likely to prohibit this measure from being cost-effective in southern climates if the total investment cost must be recovered from air-conditioning and space-heating energy savings. The economics are significantly improved if considered within the context of a renovation program, where exterior improvement work is already being performed. Benefits that cannot be easily quantified include improved house appearance, savings from higher thermostat set points in the summer (and lower in the winter), and elimination of overheated rooms.

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ENDNOTES

1. A 0.5-inch air gap between insulation layers results from this installation. This gap is sealed at the bottom by a weep-screed and may be sealed at the top by flashing or installation flush to the eave of the roof. A 1.5-inch-thick insulation board placed between the furring strips instead of an inch-thick board would effectively eliminate the gap, with no difference in performance expected.

2. Natural ventilation was modeled so that windows were opened and the interior ventilated whenever the outside temperature fell more than two degrees below the cooling set point and remained above the heating thermostat set point. Windows remained in their set position (opened or closed) between midnight and 7 a.m.

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