RETROFITTING FRAME HOUSES WITH RIGID FOAM INSULATION: FIELD APPLICATIONS

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ABSTRACT

The standard resistance level of insulation installed in houses from about the 1950s through the early 1970s was typically R-11 to R-19 (R-1.9 to R-3.3) in ceiling assemblies below attics, R-11 (R-1.9) in cavities of exterior walls, and R-0 on exterior foundation walls and between floor joists over crawl spaces. Owners of these buildings have felt the pressures of fuel price increases over the years since 1973 and many have sought ways of improving the thermal integrity of the exterior envelope of their homes.

First priority has been given to increasing the thermal resistance (R-value) of the ceiling-to-attic section. Walls constructed with conventional 1.5 in (38 mm) by 3.5 in (89 mm) wood framing members and R-11 (R-1.9) fibrous insulation in exterior wall cavities offer more of a challenge to retrofitting than most attics, while the insulation of foundations ranks lower on homeowners' priority lists.

A number of houses have benefitted from some form of retrofitting at the same time they were re-sided. However, many of these installations have suffered from improper or inadequate workmanship and have utilized metal or vinyl sidings offering little or no additional thermal resistance to the wall assembly. Also, homeowners in some geographical areas have shown a reluctance to cover more traditional appearing wood exterior surfaces with these sidings. This paper describes how these concerns were met in an actual field application, using extruded polystyrene and wood clapboards. The installation is located in northern New England; after three years, no siding or other problems have developed.

INTRODUCTION

The absentee owner of an electrically heated, precut vacation home built on a mountainside in northern Vermont and exposed to strong winds from the north, west, and south, was very concerned with potentially high electric bills in periods when the home was not rented. When the tenants moved out, he decided not to rent the home again, in order to use it himself in the summers. The house has a cathedral ceiling constructed of 1.5 in (38 mm) by 7.4 in (187 mm) tongue-and-groove "V-joint" decking nailed over heavy beams, which also serves as a nailing base for the roof shingles.

The foundation is poured concrete with finish grade on the road-facing side (east) essentially at the top of the wall. The view-facing rear side (west) is essentially entirely above grade, sloping downward along the side walls. Dry stone retaining walls butting against the side walls create a terraced effect. Exposed portions of these side walls are coated with a thick, rough cement-based stucco. As the stucco proved very difficult to remove, it was left as is and retrofitted as described later.

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Exterior walls above the foundation consist of 1.5 in (38 mm) by 3.5 in (89 mm) wooden studs with R-11 (R-1.9) fibrous glass insulation in the cavities. The presence of an integral kraft or aluminum laminate vapor retarder was assumed. The existing siding was 5/8 in (16 mm) plywood with grooves 8.0 in (200 mm) apart. Inside, the walls are finished with thin, plastic-faced plywood paneling.

Wooden decking surrounds the principal living level on three sides, with cantilevered floor joists projecting through the exterior walls supporting the decking on two sides. Roof beams also project through these walls with none of the exposed, room-facing inverted "V-joints" sealed. The joints thus provided a direct air leakage path to the outside.

Additionally, at the time of retrofit, the finished bedroom, bathroom, and utility room floors on the lower level were periodically wet from leakage of the foundation wall on the higher graded road-facing side.

PROJECT GOALS

Three specific goals were established in the retrofit. They were:

1. To solve the foundation leakage that wet the wall-to-wall carpeting in the lower bedroom and caused a constant musty smell on the lower level.
2. To insulate the 8.0 in (200 mm) thick concrete foundation, both above and below grade.
3. To improve the thermal performance of the exterior frame walls while simultaneously reducing air infiltration.

CONSIDERATIONS RELATING TO THE GOALS

Foundation Leakage

Under normal circumstances, the first recommendation would be to repair any grade deficiencies around the exterior of the house, create a slope from the foundation to move water away from it and provide a healthy stand of grass or other ground cover to minimize erosion. However, in this case, it was obvious that underground water traveling down the mountain slope from higher elevations was responsible. Therefore, replacement of what appeared to be a non-functioning footing drain was in order.

Insulation of Concrete Walls

The need to excavate at the outside of the foundation walls was the deciding factor as to whether the inside or outside should be insulated. The existence of an interior finish and the small sizes of the rooms also entered into this decision. If replacement of the faulty drain and the heavy native clay soil used as backfill was not required, exterior insulation would not be recommended.

Improving the Thermal Performance of the Exterior Frame Walls

The owner did not like the exterior "chalet" appearance of the house and requested the removal of all shutters and extraneous trim. Further, he would not consider the use of metal or vinyl sidings as a new exterior finish.

PROCEDURES EMPLOYED IN THE RETROFIT

Foundation Leakage and Insulation

The front of the house was insulated down to the bottom of the footings. As anticipated, the existing perforated pipe was completely silted, and the pipe, silted crushed stone, and heavy clay backfill were removed and hauled away.

The area was very wet, and running water could be seen coming through the old natural forest floor buried under the backfill and gravel driveway.

Porous filter fabric was pinned against the bottom 4 feet (1.2 m) of the dirt of the excavation; 6 mil (0.15 mm) polyethylene applied against the concrete foundation, including the projection and exposed side of the footing; and 1.0 in (25 mm) thick extruded polystyrene placed over the polyethylene and against the foundation. It was held in place with rough sawn wood stripping tacked to the house siding above.

A bed of crushed stones about 12 in (300 mm) thick was installed at the bottom of the excavation, encasing a perforated plastic drainpipe. Solid pipe was attached to the drain and run downhill to daylight. The filter fabric was then folded over the crushed stones and up the foundation wall insulation. Bank run gravel was then gently placed over the fabric to complete the backfilling.

Since the stucco on the exposed foundation walls on either side of the house could not be removed by reasonable means, 1/2 in (13 mm) C-D Exterior (CDX) plywood was fastened to it with power pins (fasteners actuated by powder charges). The CDX was, in turn, covered with 1.0 in (25 mm) thick extruded polystyrene.

On the rear wall of the house, the edge of the lower level concrete slab was exposed to the elements. The frost wall below was hand excavated down 2 feet (0.6 m) and rigid insulation applied against it.

All rigid insulation, both above grade and below the new siding, was covered with 0.5 in (13 mm) pressure treated plywood.

Frame Walls

All extraneous molding and trim, as well as the window shutters were removed. Softwood (pine) extension jambs were fabricated on the job site and installed at all window and door openings in order to accommodate the thickness of the rigid insulation. All exterior electric boxes were brought out 1.0 in (25 mm) for the same reason.

The rigid extruded polystyrene boards were nailed directly over the original plywood siding and all joints were filled with expanding polyurethane sealant. These included joints between insulation and cantilevered joists and beams, new extension jambs, electric boxes, and where the inverted "V-joint" decking penetrated the exterior walls.

Typical square-edged New England wooden casings were applied at all windows and doors and the walls were covered with narrow spruce clapboards, using 10 penny (10d) galvanized box nails. The nails were snugged but not driven home, as would normally be done to tighten the clapboards. All nail holes near the ends of the clapboards were predrilled to avoid the inevitable splitting that occurs when nailing over soft material.

A light earth-tone color was chosen to minimize the effect of the strong sunlight at the altitude of the site. This color also permitted the house to fit harmoniously into the adjacent forested landscape.

After three years (two winters), there are no signs of distress, cupping, or splitting of the siding application.

ADDITIONAL DISCUSSION

The owner was advised that the aluminum sliding windows are of poor thermal quality due to poor fit and the lack of a sash thermal break, thus resulting in high transmission and infiltration heat losses. In lieu of replacing them at the time of wall retrofit, it was suggested that since the house is unoccupied during the winter, with only minimal heat supplied to keep the interior above freezing, he install R-11 (R-1.9) fibrous glass insulation between the windows and the interior shades.

Although the condensation potential within the retrofitted wall assembly--due to the installation of extruded polystyrene at the exterior in relation to a vapor retarder of unknown permeability adjacent to the interior finish--was considered, it was concluded that because of the significant increase in wall thermal resistance, combined with reduced inside-to-outside temperature differences resulting from a minimal heat supply to the unoccupied house during the winter, its probability was slight. In addition, the impracticality of adding an effective interior vapor retarder to the existing interior paneling was an additional consideration.

CONCLUSION

Since the house was occupied prior to the retrofit and has been vacant during the two subsequent winters, no comparable "before" and "after" space-heating consumption data are available.

A procedure shown in the Appendix roughly approximates the effect of the combined retrofit, window treatment, and air infiltration measures taken, based on the energy usage shown in Table 1. It is important to emphasize that the calculations in the Appendix utilize imperfect assumptions, in that they involve changes in occupancy as well as the building envelope. Also, micro-climate data are not available in the area of the site. Nonetheless, regardless of the balance temperature assumed with occupancy and the effects of the living habits of the occupants, it would appear that the combined retrofit has had a significant influence on the thermal integrity of the house.

Since the house is adjacent to that of one of the authors, it will continue to be monitored to whatever degree acceptable to the owner. Results will be made available when appropriate.

APPENDIX

From the metered electrical usage shown in Table 1, a very rough estimation of the overall thermal performance of the house, both before and after retrofit, in terms of Btu/h.F (W/°C), may be made. It must be stressed that the calculations are quite approximate since periods of no occupancy, tenant occupancy, and owner occupancy are employed. Additionally, weather data for a station about 30 miles (48 km) away (Burlington, VT) for a representative year as shown in the ASHRAE Handbook--1981 Fundamentals were used.

The procedure is as follows (pre-retrofit):

1. Calculate the average energy usage per hour for the seven-month period of owner occupancy, with no space heating use.

2. Calculate the average energy usage per hour for the six-month period of tenant occupancy, including space heating.

3. Subtract (1) from (2) to estimate the hourly space heating required.

4. Using the weather data, sum the heating degree-hours below selected base temperatures.

5. Calculate the average outside temperature for each base temperature selected in (4).

6. Calculate the house heat loss in terms of Btu/h.F(W/°C) by dividing (3) by the base temperature minus (5).

For the unoccupied period (post-retrofit):

1. Calculate the average energy usage per hour for the 18 months (10/82-4/83, 10/83-4/84, 10/84-4/85) of no occupancy and inside temperature settings of 50 F (10°C)

2. Calculate the average outdoor temperature for the same period using the weather data.

3. Calculate the house heat loss in terms of Btu/h.F (W/°C) by dividing (1) by the difference between 50 F (10°C) and (2).

Results of the above are shown below:

1. Average energy usage with occupancy and no heating, = (8326 kWh)(3413 Btu/Wh)/(216 days)(24 h/day) = 5482 Btu/h [1606 W]

2. Average energy usage with occupancy and space heating, = (19780 kWh)(3413 Btu/Wh)/(181 days) (24 h/day) = 15541 Btu/h [4553 W]

3. Average energy usage assigned to space heating, = (2) minus (1) = 10059 Btu/h [2947 W]

4, 5, and 6 are tabularized as Table 2.

For the post-retrofit period with no occupancy with 50 F maintained inside;

1. Average energy usage with no occupancy, = (16700 kWh)(3413 Btu/Wh)/(544 days)(24 h/day) = 4366 Btu/h [1279 W]

2. Average outdoor temperature (11/1-4/30), = 65 F - (6987 Heating Degree-Days)/(181 Days) = 26.4 F [-3.1°C]

3. Winter heat loss, Btu/h.F, with no occupancy, = 4366 Btu/h/(50 F - 26.4 F) = 185 Btu/h.F [98 W/°C]

TABLE 1
Whole House Metered Electrical Use, kWh (MJ)

	1985		1984		1983		1982		1981	
January	2352	(8467)	2070	(7452)	1840	(6624)	5240	(18864)a	--	--
February	1851	(6664)	1167	(4201)	1720	(6192)	4050	(14580)a	--	--
March	1349	(4856)	1471	(5296)	1110	(3996)	2330	(8388)a	--	--
April	750	(2700)	540	(1944)	480	(1728)	1670	(6012)a	--	--
May	163	(587)	158	(569)	180	(648)	220	(792)	--	--
June	9	(32)	36	(130)	110	(396)	1560	(5616)b	--	--
July	192	(691)	0	(0)	1470	(5292)b	990	(3564)b	--	--
August	1204	(4334)b	1112	(4003)b	810	(2916)b	1180	(4248)b	--	--
September	--	--	85	(306)	100	(360)	160	(576)	--	--
October	--	--	157	(565)	140	(504)	210	(756)	--	--
November	--	--	891	(3208)	590	(2124)	690	(2484)	2870	(10332)a
December	--	--	1412	(5083)	1590	(5724)	1270	(4572)	3620	(13032)a

a. Tenant occupied
b. Owner occupied

TABLE 2
Calculated Winter Heat Loss, Btu/h.F (W/°C), with No Occupancy

Base Temp. Selected	Annual Deg. Hrs. Below Base Temp.	Annual Hours Below Base Temp.	Avg. Outdoor Temp.	Heat Loss Btu/h.F
70 F	227488	7586	40.0 F	335
65 F	190898	6916	37.4 F	364
60 F	157224	6213	34.7 F	398
55 F	128047	5519	31.8 F	434
50 F	101762	4864	29.1 F	481