MASONRY WALLS—FOR INDUSTRIAL BUILDINGS ONLY?

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ABSTRACT

Five modules on one site were used to evaluate losses through residential type of above-grade walls, in a heating climate. Four of the walls were of wood-frame construction, with nominal resistances varying from R-10 (RSI 1.76) to R-40 (RSI 7.04), while the fifth was a masonry cavity wall. The masonry wall has a face brick exterior and a concrete block interior with either foamed-in-place polyurethane or loose fill vermiculite in the 2.5 in (64 mm) wide cavity.

Heat flux measurements show that the wood-frame walls perform as expected, while polyurethane-filled masonry wall has a larger than expected thermal resistance, R-28 (RSI 5), compared with the nominal calculated value of R-15 (RSI 2.6). The module constructed with the cavity wall has a natural air infiltration rate of 60% of that of a wood-frame module of similar thermal specification. No deterioration of the thermal performance of the masonry wall has been detected in two years of study.

The impact of the large above-grade mass on hour-by-hour energy requirements is also discussed.

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INTRODUCTION

Concern over energy consumption in residences has resulted in new construction having higher levels of insulations in all components of the building envelope. In this experimental study, five different levels of insulation were utilized in the above-grade walls of five test modules to gauge the effectiveness of varied insulation levels in the reduction of envelope losses. Included are four wood-framed constructions and one masonry cavity wall construction. Load-bearing masonry cavity walls are not normally used in residential construction due to their high initial cost and perceived poor energy-saving capability. They do, however, offer a large above-grade thermal storage capability and the potential for reduced maintenance costs.

The experiments were performed by using five modules at the Alberta Home Heating Research Facility. This project is an experimental facility consisting of six single-story modules each 22 ft x 24 ft (6800 mm x 7400 mm) in plan, with full 8 ft (2440 mm) concrete basements and 8 ft (2440 mm) high walls. The uninhabited modules are located in a single east/west row at latitude 53.5°N where the long-term average heating degree-days are about 10500 F days (5800°C days). Each module was designed to study a conservation and heating strategy different from the others. All are electrically heated and with the exception of the masonry module all are wood framed. Figure 1 shows the masonry module constructed during the fall of 1983.

The nominal resistance values of the insulation used in all of the modules are listed in Table 1, and other construction details relevant to the modules performances are listed in Table 2. Complete construction details of the facility have been reported previously (Ackerman et al. 1983)[1].

The philosophy used throughout this project has been to make changes to the modules only on an annual basis and, through comparison with the reference module, quantify the effect of the changes. In addition, detailed comparisons will be made between Module 1, the masonry module, and Module 5, the reference module. The reasons for selecting Module 5 for comparison are that it has not been modified since the beginning of the project (1979), it has identical ceiling and basement construction, identical windows and doors, and differs only from Module 1 in the above grade wall construction.

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[1]Numbers in brackets refer to references.

The results reported here will focus on four areas:

1. The overall performance of the modules relative to the reference module.
2. The thermal performance of the above grade walls with particular emphasis on the masonry module.
3. Air infiltration.
4. Temperature decay testing (overnight cool down).

CONSTRUCTION DETAILS AND DATA ACQUISITION

The modules have the same overall dimensions. Other common features include gable roofs on elevated roof trusses and full concrete basements. The elevated roof trusses permit varying thicknesses of insulation (fiberglass batts in all modules at present) to be installed without structural modification. The basements extend 6 ft (1800 mm) below grade and have drainage pipe around the foundation perimeter. All modules, except Module 3, have a 6 in (152 mm) diameter class B vent terminating 4 ft (1300 mm) above the basement floor. These vents are used to induce pressure distributions similar to those found in residential structures.

The above-grade walls of the masonry module are commonly known as a cavity wall type construction. Figure 2 shows the cavity wall in cross section, while Table 3 lists the physical dimensions of the module and wall. This type of wall was selected for study because it contained a significant amount of mass inside the main insulating layer and it could be fitted to an existing 8 in (200 mm) thick concrete basement wall. The exterior facing bricks are dark colored common brick, and the interior blocks are standard 4 in (100 mm) thick concrete blocks. A 1 in (25.4 mm) air gap was built in by using metal furring to stand off standard 1/2 in (13 mm) gypsum wallboard, which was used to provide a conventional interior finish. Two types of insulation were used in the 2.5 in (64 mm) gap between the facing bricks and the load-carrying concrete blocks. The east, west, and south walls were insulated solely with foamed-in-place polyurethane. One-third of the north wall was insulated with poured-in-place vermiculite, as indicated in Table 1 and Figure 1, and the remainder of the north wall was filled with foamed-in-place polyurethane.

During construction, care was taken to insure that the cavity was kept clear of mortar so that it could be filled as completely as possible. No interior drip space was provided in any section of the wall. In addition, a total of 12 thermocouples were installed within the cavity wall at three locations. Two sets of thermocouples were located inside the north wall, one in the vermiculite section and one in the polyurethane section. A third set was installed within the south wall. Figure 3 shows the positioning of a typical set of thermocouples in a wall.

Modules 2, 4, and 5 have conventional above-grade wood-frame construction with nominal 2 in x 4 in (50 mm x 100 mm) studs on 16 in (406 mm) centers with fiberglass batt insulation between the studs. To increase the insulation of Module 4 from nominal R-10 to R-20 (RSI 1.76 to RSI 3.52), rigid polystyrene insulation was installed on the exterior of the wood studs. The same exterior sheathing and interior gypsum board was used in all these modules. The polyethylene air-vapor barrier was installed on the inside of the wood stud wall and ceiling joists in these modules, overlapped one stud spacing, without sealant, and pierced with electrical outlets. In Modules 4 and 5 this barrier was run continuously down the wall and under the wall bottom plate out to the exterior of the structure and vertically down over the joist header plate and the concrete exterior. The above-grade concrete wall was then covered with rigid insulation and a plywood sheathing. In Module 2 the air-vapor barrier was terminated at the base of the wood-frame wall and not run to the outside of the structure as was done in Modules 4 and 5. The basement of Module 2 does not have any insulation.

Module 3 has a double-wall-type construction. All of the insulation is rigid polystyrene added to the exterior of a conventional wood stud wall. A continuous, overlapped sealed air-vapor barrier was added to the exterior of the stud walls and ceiling before the insulation was added, thus it was not pierced with any electrical outlets when gypsum wallboard was installed. In order to further minimize punctures of the air-vapor barrier, this module was not equipped with a furnace flue.

Two on-site computers were used to gather data. The main system, which is used to record data about the thermal performance of the modules,reads 125 channels once every two minutes and temporarily stores this information. At the end of an hour, the stored signals are averaged and transfered to magnetic tapes. The magnetic tapes are then removed and taken to the mainframe computer at the university for analysis. The information recorded by this system includes the electrical power input to each of the modules, the indoor, attic, and basement temperatures, the output from heat flux gages mounted on the ceilings, walls, and below grade portions of the basements, temperatures inside the masonry walls, exterior soil temperatures, environmental temperatures, wind speed and direction, and direct and diffuse solar radiation.

The second computer is used solely to control and monitor the natural air infiltration experiments. The measurement of air infiltration rates is done once every 7.5 minutes in each of the modules and recorded as an average rate over one hour. The unit functions by injecting discrete volumes of sulfur hexafluoride (SF6) to maintain the indoor concentration at a constant level of 5 ppm. Concentration within the module is monitored using an infrared concentration detector. Detailed results using this system have been reported previously (Wilson and Pittman 1983).

RESULTS

Relative Energy Consumption

The year-to-year variations in climate make it difficult to evaluate in isolation the impact physical changes can have on reducing energy consumption in housing. By using the on-site reference module, one can normalize the year-to-year variations in climate that influence the envelope losses in houses. This is shown in Table 4 where the relative positions of Modules 1 through 5 for two heating seasons are presented. For each heating season, Module 5 is given 100 units. The energy consumed by each of the other modules is ratioed to the total energy consumed in Module 5, accounting for differences in the heating degree-days that occur due to slightly different thermostat setpoints.

Examination of Table 4 shows that the relative position of Module 2 was unchanged during this period, while those of Modules 1, 3, and 4 show small changes. Module 2, which like Module 5 has no south-facing windows, was not modified during this period. Its high relative position is due in part to the lower insulation levels listed in Table 1. Modules 3 and 4 also were not modified during this period, but because they have large south-facing windows, variations in the amount of radiation and window shutter effectiveness do alter their relative positions.

The relative position of Module 1 for 1983-84 heating season is shown to be 79%. Considering that only the walls are significantly different from the reference module, this is an important result. The reasons for this are the higher than expected thermal resistance of the wall and a lower natural air infiltration rate produced by the construction. The increase in the relative position of Module 1 to 83% during the 1984-85 heating season was due to the installation of 32 ft^2 (2.97 m^2) of south-facing sealed double-pane glazing during the summer of 1984. The windows result in larger nighttime losses and thus are a detriment to the thermal performance of this module in a heating climate.

Thermal Performance of Walls

In order to quantify the thermal performance of all the above-grade walls, the output from the heat flux plates mounted on these walls and the indoor-outdoor temperature difference can be used to determine the in-situ resistance of the wall. Figure 4, for example, shows the measured rates of heat transfer plotted against the temperature difference for both the north-facing vermiculite and polyurethane sections of the masonry wall. The data points shown in this figure are 48-hour averages. The inverse of the slopes of Figure 4 are the effective overall thermal resistances of the wall sections.

Table 5 lists results of the measurements of thermal resistances for all the walls, where they are compared with predicted values using ASHRAE property values and techniques (ASHRAE 1985). First note that the values for Modules 2,3, and 5 show good agreement between measurement and theory. Module 4 shows a large discrepancy, which is thought to be due to large swings in interior temperature due to the large south-facing windows in this module. The values given for the polyurethane and vermiculite sections of the walls in Module 1 show good agreement with ASHRAE predictions, but note that these predictions are significantly different from the nominal values given in Table 1.

The predicted resistances for the polyurethane section of the masonry walls listed in Table 5 are based on the unaged value of thermal conductivity for this insulation, while those in Table 1 are based on fully aged values. Other researchers (Bomberg 1980; Dechow and Epstein 1978) report that the thermal conductivity of foamed-in-place polyurethane can change with time as the insulation naturally "ages" and/or comes in contact with water. This has not been the case with the insulation at this site. As shown in Figure 5, over the two heating seasons the measurement of resistance for the polyurethane section of the wall shows essentially no change in value. An in-situ measurement of the thermal conductivity of the polyurethane using the transient-heated line source method produced a value of 0.0103 $\frac{\text{BTU}}{\text{hr}\cdot\text{ft}\cdot{}^\circ\text{F}}$ (0.018 $\frac{\text{W}}{\text{m}\cdot\text{k}}$), which is in agreement with published values for unaged material. Also shown in Figure 5 are the measured resistances for a typical wood frame.

The annual rainfall measured near the test site during the two-year study has been approximately 14% above normal at 11.5 in (290 mm). Snowfall, expressed as water equivalent, would add 20% to the rainfall totals.

The calculated resistance shown in Table 5 for the vermiculite section uses the minimum value of thermal conductivity listed in the ASHRAE Handbook. This minimum value is typical of those obtained for this product with present manufacturing processes.* Comparison of the values in Tables 1 and 5 show that over time improvements in the process of manufacturing vermiculite have resulted in a substantial reduction in its thermal conductivity. Visual inspection of the vermiculite section shows that a 10% settlement has taken place. Heat-flux measurements have not yet been conducted on the voided section.

Diurnal Variation of Temperatures in Masonry Walls. The use of the masonry in the above-grade walls adds significantly to thermal capacity of the structure. This added thermal capacity should manifest itself by a phase-lag or time-lag in the interior wall temperature as changes occur in the ambient temperature and by producing a slower cool-down rate when the heating system is shut off. By observing the daily variations of temperature within the wall section, properties associated with the walls thermal mass can be evaluated.

Figures 6 shows a trace of the temperature changes in the cavity wall over a two-day period. Plotted concurrently on this figure are the ambient, room, and sol-air temperatures. The sol-air temperature shown here is the temperature recorded on the exterior surface of the south wall of Module 2. Though this sol-air temperature is not directly applicable to the masonry module, due to different materials on the exterior of Module 2, it does give a good indication of temperatures experienced by the exterior of south-facing walls.

By comparing the times that the peaks or troughs occur in the different temperature lines, the development of the wall's time lag can be seen in Figures 6. The time lag of a wall section is defined in terms of the heat flux at the interior wall surface lagging behind the outdoor temperature changes. Figure 7 shows the measured hour-by-hour heat flux at the interior surface of the masonry wall for the same days as Figures 6. Comparison of these figures indicates that the time lag for the north wall of the module is approximately 8 and 10 hours for the vermiculite and polyurethane sections respectively. Standard wood-frame walls have a time lag of about one hour.

As a result of this time lag, the time of the greatest wall conductive heat loss and coldest ambient temperatures no longer coincide for this module. For the two-day period shown here, the largest conductive loss occurs at about 16:00 hours, while the smallest occurs at 4:00 hours. This time lag can help in leveling out the total heating load on the module as

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*Personal Communication. W.R. Grace Co. of Canada Ltd., 1985 other elements in the envelope, which have lower thermal capacities, respond in phase with the changing ambient temperatures. Thus, one would expect to have a more uniform heating load over a 24-hour period. This is confirmed in Figure 8, which shows hour-by-hour electrical power consumption of Modules 1 and 5 for the same time period as shown in Figures 6 and 7. In Figure 8 a substantial reduction in the amplitude of the heating energy requirement is evident. The minimum values shown in Figure 8 are the power requirements for the furnace fans, which run continuously.

The results shown in Figure 8 are for the period when Module 1 did not have any south-facing glazing. Installation of the glazing produced a lower daytime heating requirement but also resulted in higher nighttime losses, producing a higher relative energy consumption as was shown in Table 3. The higher nighttime losses and lower daytime heating requirements produce a larger swing in the hour-by-hour power requirements, producing a result more like that of Module 5 shown in Figure 8. The windows, in effect, negated the thermal capacity influence of the masonry wall on the modules' hour-by-hour power requirements.

Temperature Decay Tests

Temperature decay tests are used to determine the effective thermal capacity of the modules. The decay tests are done simply by shutting off the modules heating system and measuring the decay of interior temperature with time. The circulating fans are left on to maintain a uniform temperature within the modules. One can also monitor the internal wall temperatures during a decay test to ascertain whether significant energy recovery is occurring from the energy stored in the wall.

Figure 9 shows the variation of the internal wall temperatures of a polyurethane section of the masonry wall during such a cool down test. Note that during this particular test, the temperature gradient throughout the wall is in such a direction that heat is constantly transferred from the interior of the module to the exterior. Thus, no energy recovery is obtained from the wall directly back to the room air. This can only occur if the wall temperature is higher than the air temperature in the room. Note that these walls are not directly heated by sunlight and thus are not acting as direct gain walls. The implication is that in a heating climate, energy stored in the exterior walls cannot be effectively recovered to the interior air space. This does not mean that the masonry has no influence in the cool-down process, as this is a function of both the resistance and thermal capacity of the structure.

From the rate of decay of interior air temperature with time, one can determine effective time constants of the modules. Typical results of these tests are shown in Table 6. The time constants identified in this table were determined from the slope of the temperature decay test at the 1/2-hour and 6-hour times after intitiating the tests, taking into account the energy input from the fans. One interpretation of the rapid intital decay is that it is due to the lower thermal capacity elements losing their stored energy first (i.e. air), while the slower decay at 6 hours is due to the larger thermal capacity elements losing their energy. Module 3 has the largest time constant at both the 1/2-hour and 6-hour times. These are due to the lower natural air infiltration rate and high thermal resistance designed into the structure. Of the remaining modules, Module 1 has the highest time constants. Recall that Module 3 is the only module without a flue, so that a comparison between Modules 1 and 3 may not be appropriate. Module 1 would be more properly compared with the other modules which have flues.

Air Infiltration

Monthly average air infiltration rates are shown in Table 7 for the five modules. As one would expect from the construction details, Module 3 has the lowest air infiltration rate of all of the units. Of the remaining modules, Module 1 has the lowest natural rate, just marginally lower than Module 4.

Another method of rating structures for air infiltration is to measure the effective leakage area through fan pressurization/depressurization tests. The results of a series of depressurization experiments on the five modules is shown in Table 8, where the effective leakage area is given at a pressure differential of 4 Pa. Note that there are two values listed, one for the flue open and one for which the flues were blocked. In the flue open case, Module 1 had the lowest effective leakage area of all the units with flues. With the flues blocked, Module 1 also had the smallest effective leakage area. Notice that Modules 3, 4, and 5 have very similar effective leakage areas, while that for Module 2 is significantly larger than all of the rest. These results would imply that the use of the double-wall construction was not really effective in increasing the airtightness over the much simpler wall construction used in Modules 4 and 5 and that running the air-vapor barrier out under the wall over the joist header on the exterior side of the basement wall was very effective in reducing the leakage of the house. This can be seen by comparing the results from Module 2 with those of the other wood-frame modules.

The fan system was not used as an aid to locate leaks during construction; however, it was used to try to evaluate the locations of air leaks in Modules 1 and 5 after the first year's testing. Smoke tests with the flues blocked showed that Module 5 still had some leaks around the rim joist, while Module 1 had a very effective seal where the cavity wall was mortared to the concrete basement wall. Leaks were observed at the base of the vermiculite section in Module 1.

CONCLUSION

Based on the two years of monitoring the field performance of five modules, four wood framed and one with a cavity wall with foamed-in-place polyurethane and loose fill vermiculite insulations, the following conslusions are drawn.

1. The measured rates of heat transfer through the above-grade wood-framed walls agree well with ASHRAE predictions.

2. For the polyurethane-insulated section of the masonry wall, the thermal conductivity of the material is its "unaged" value and no deterioration in this value has been observed.

3. For the vermiculite-insulated section of the masonry wall, the thermal conductivity of the material reflects the minimum expected for this product. A settlement of about 10% has occured in this section.

4. The cavity wall construction produced a time lag of 8 to 10 hours between minimum outdoor temperature and measured maximum heat flux at the interior surface.

5. The large time lag resulted in a reduction in the amplitude of the hour-by-hour heating energy requirements of the module compared with a wood-frame module, both of which were without south-facing windows.

6. With the particular construction used and with no direct sunlight gains to the masonry wall, in a heating climate, the energy stored in the wall could not be effectively recovered to the room air.

7. Overnight cool-down tests showed that the masonry cavity wall construction had a significant effect on the modules' time constant or thermal capacitance.

8. The module constructed with the masonry cavity wall produced a tighter construction than any of the wood-frame modules.

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ACKNOWLEDGMENTS

Financial support for this project was provided jointly by the Alberta Masonry Institute and the Alberta/Canada Energy Resource Research fund (A/CERRF). A/CERRF is a joint program of the Federal and Alberta governments, which is administered by Alberta Energy and Natural Resources. Materials for the construction of the masonry module were provided by I-XL Industries Ltd., and Consolidated Concrete Ltd., Masonry and Building Materials Division. The support of the Alberta Masonry Institute, A/CERRF, and I-XL Industries Ltd. is gratefully acknowledged.

TABLE 1

Nominal Insulation Values for Modules (R (RSI))

Module	Ceiling	Walls	Basements
1. Masonry	12 (2.11)	14.7 (2.59)[a] 6.0 (1.06)[b]	10 (1.76) to 2 ft (610 mm)[c]
2. Retrofit	32 (5.63)	8 (1.41)	none
3. Conservation	80 (14.08)	40 (7.04)	20 (3.52) full height[c]
4. Passive	40 (7.04)	20 (3.52)	10 (1.76) full height[c]
5. Reference	12 (2.11)	10 (1.76)	10 (1.76) to 2 ft (610 mm)[c]
6. Active Air	32 (5.63)	10 (1.76)	10 (1.76) to 2 ft (610 mm)[c]

(a) Polyurethane section (90% of wall area), based on conductivity of fully aged foamed-in-place polyurethane from ASHRAE Handbook - 1985 Fundamentals.

(b) Vermiculite section (10% of wall area).

(c) External, depth below grade.

TABLE 2

Construction Details for the Modules

Module	Flue Diameter in (mm)	Air-Vapor Barrier Thickness mils (mm)	Total Double-Glazed Windows (% floor area)	South-Facing Windows (% floor area)
Masonry	6 (152)	6 (0.152)	13.6,[a] 20.6[b]	0,[a] 6.9[b]
Retrofit	6 (152)	4 (0.102)	11.9	0
Conservation	none	6 (0.152)	13.7	11.3
Passive	6 (152)	6 (0.152)	25.0	22.6
Reference	6 (152)	4 (0.102)	11.9	0
Active Air	6 (152)	4 (0.102)	11.9	0

(a) 1983-84 Heating season

(b) 1984-85 Heating season

TABLE 3A

Specifications - Module 1 - Masonry Module (Inch-Pound Units)

Exterior Dimensions	22.3 x 24.2 feet
Interior Dimensions	20.5 x 22.5 feet
Main Floor Wall Height	8 feet
Basement: Wall Height	8 feet
Wall Thickness	8 inches
Floor Thickness	4 inches

Ceiling Construction
- standard truss with 2-foot bobtail
- 2 x 4 inch rafters on 24-inch center
- fiberglass insulation, R-12
- 6-mil polyethelene air-vapor barrier
- 1/2-inch gypsum wallboard

Wall Construction
- 3-inch (nominal) burn clay brick
- 2.5-inch insulating layer (foamed-in-place polyurethane - 90% of wall area, poured-in-place vermiculite - 10% of wall area)
- 4-inch (nominal) concrete block
- 6-mil polyethelene air-vapor barrier
- 1-inch air space
- 1/2-inch gypsum wallboard

Windows
- North Wall - 40 x 76 inch sealed unit (double glazed)
- South Wall - none, 1983-84 ; 2 - 48 x 48 inch sealed units, 1984-85
- East Wall - 40 x 76 inch horizontal slider, aluminum frame
- West Wall - 40 x 76 inch horizontal slider, aluminum frame

Door
- 36 x 80 inch solid core fir

Basement Insulation
- 2 inches polystyrene extending 2 feet below grade, R-10
- 1/2 inch pressure-treated plywood insulation covering

Auxiliary Heating
- 10 kW electric duct heater

Interior Finish
- painted walls
- carpeted floor

TABLE 3B

Specifications - Module 1 - Masonry Module (SI Units)

Exterior Dimensions	6800 x 7400 mm
Interior Dimensions	6250 x 6860 mm
Main Floor Wall Height	2440 mm
Basement: Wall Height	2440 mm
Wall Thickness	200 mm
Floor Thickness	100 mm

Ceiling Construction
- standard truss with 610 mm bobtail
- 38 x 89 mm rafters, 610 mm on center
- fiberglass insulation, RSI = 2.11
- 0.152 mm polyethelene air-vapor barrier
- 13 mm gypsum wallboard

Wall Construction
- 76-mm (nominal) burn clay brick
- 64-mm insulating layer (foamed-in-place polyurethane - 90% of wall area, poured-in-place vermiculite - 10% of wall area)
- 100-mm (nominal) concrete block
- 0.152 mm polyethelene air-vapor barrier
- 25.4 mm air space
- 13 mm gypsum wallboard

Windows
- North Wall - 100 x 1950 mm sealed unit (double glazed)
- South Wall - none, 1983-84 ; 2 - 1220 x 1220 mm sealed units, 1984-85
- East Wall - 1000 x 1950 mm horizontal slider, aluminum frame
- West Wall - 1000 x 1950 mm horizontal slider, aluminum frame

Door
- 910 x 2030 mm solid core fir

Basement Insulation
- 51 mm polystyrene extending 610 mm below grade RSI = 1.76
- 13 mm pressure treated plywood covering

Auxiliary Heating
- 10 kW electric duct heater

Interior Finish
- painted walls
- carpeted floor

TABLE 4

Relative Energy Consumption for Modules for two Heating Seasons
(Oct. 1 - March 31)

Heating Season	Module				
	1	2	3	4	5
1983 - 84	79	127	39	60	100
1984 - 85	83	127	42	62	100

TABLE 5

Measured and Calculated Thermal Resistance of Above-Grade Walls and Ceilings (R (RSI))

Module and Component	Measured	Predicted
1. Masonry Walls		
- north polyurethane	27.1 (4.76)	26.3 (4.62)
- south polyurethane	27.3 (4.81)	26.3 (4.62
- vermiculite	11.9 (2.1)	11.7 (2.06)
- west wall[(a)]	15.7 (2.77)	—
Ceiling	12.5 (2.20)	12.7 (2.73)
2. Retrofit		
Walls	10.3 (1.8)	9.0 (1.59)
Ceiling	—	—
3. Conservation		
Walls	38.3 (6.74)	42.7 (7.52)
Ceiling	84.4 (14.9)	82.5 (14.5)
4. Passive		
Walls	16 (2.8)	21.3 (3.75)
Ceiling	20.1 (3.54)	42.9 (7.56)
5. Reference		
Walls	13.5 (2.38)	10.5 (1.85)
Ceiling	11.4 (2.01)	12.9 (2.27)

(a) Does not include wallboard, void in insulation discovered heat flux transducer

TABLE 6

Measured Time Constants from Temperature Decay Tests

Module	1/2-hour time constant	6-hour time constant
1	15.3	58.3
2	8.8	23.3
3	26.5	69.3
4	13.4	42.7
5	11.1	38.7

TABLE 7

Monthly Average Natural Air Infiltration Rates
for Modules for 1984

Module	1	2	3	4	5
January	.32	.48	.11	.25	.36
February	.19	.46	.11	.22	.32
March	.21	—	.11	.22	.34
April	.16	.34	.09	.20	.28
May	.17	.36	.08	.21	.29
June	.10	.22	.05	.13	.17
July	.10	.19	.04	.13	.17
August	.14	.22	.05	.14	.20
September	.16	.28	.06	.18	.26
October	.28	.40	.09	.21	.31
November	.28	.38	.09	.21	.34
December	.30	.44	.10	.20	.36

TABLE 8

Fan Depressurization Test Summary
Effective Leakage Areas
at 0.0162 in of H_2O (4 Pa), in^2 (cm^2)

Module	1	2	3	4	5
AL4 flue open	17.8 (114.9)	33.5 (215.9)	—	19.8 (127.7)	19.0 (122.3)
AL4 flue closed	6.8 (43.9)	21.9 (141.2)	8.6 (55.2)	8.2 (52.9)	8.7 (56.2)

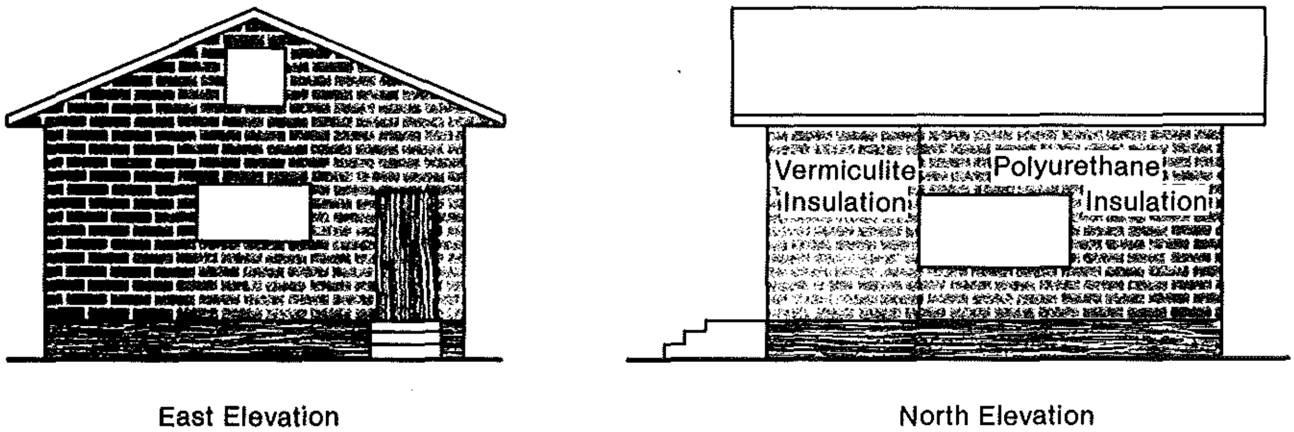


Figure 1. Masonry module

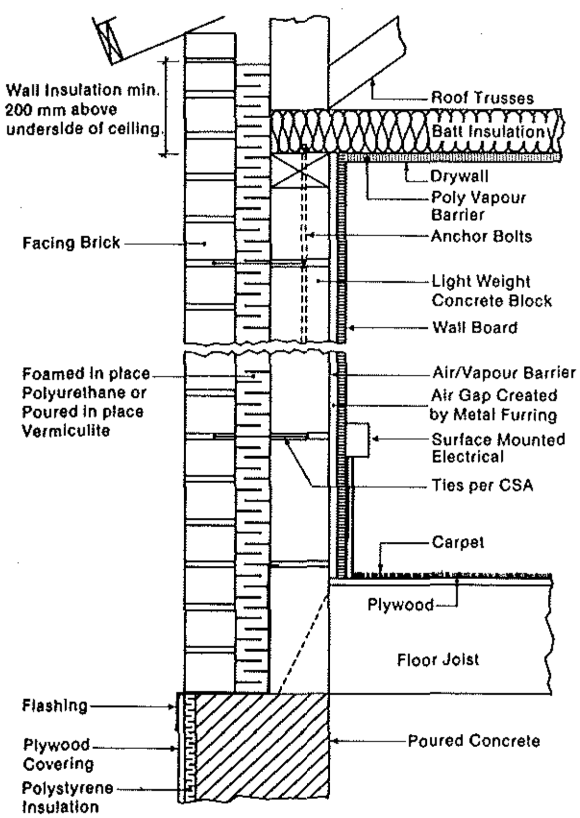


Figure 2. Schematic of cross section of cavity wall

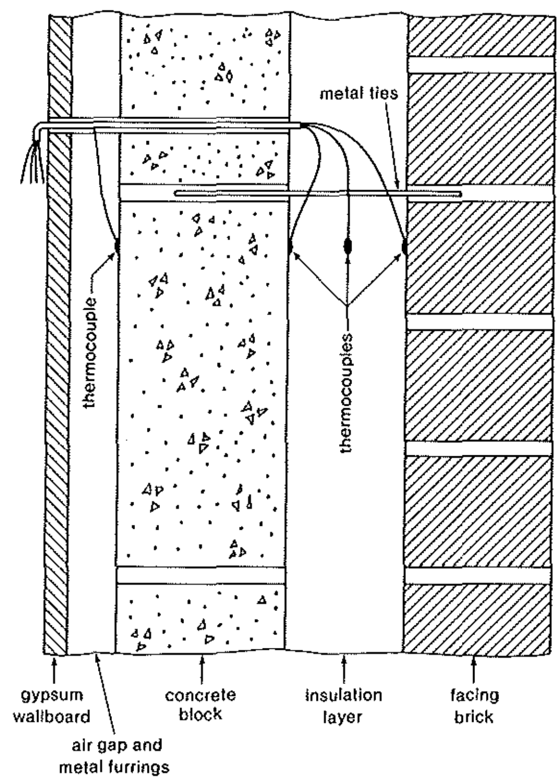


Figure 3. Wall section showing position of internal thermocouples

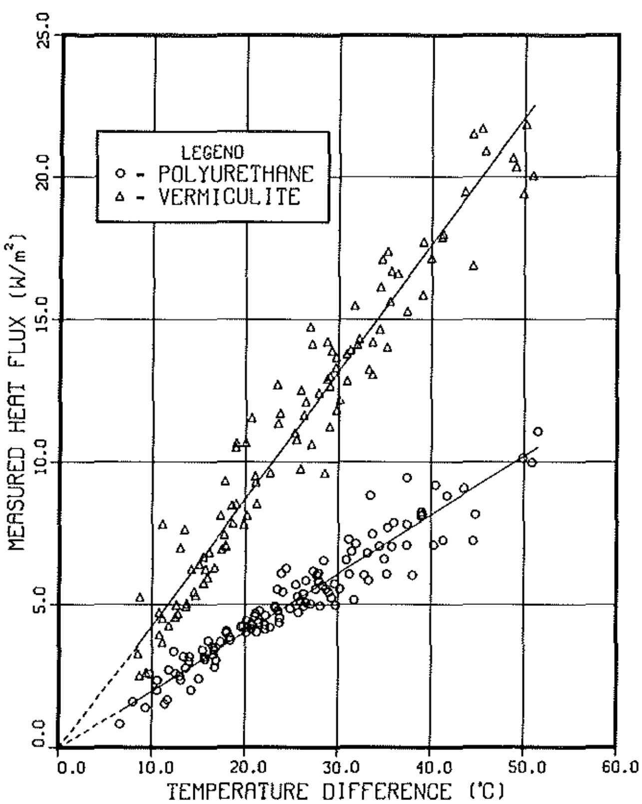


Figure 4. Measured rates of heat transfer through north wall of module 1

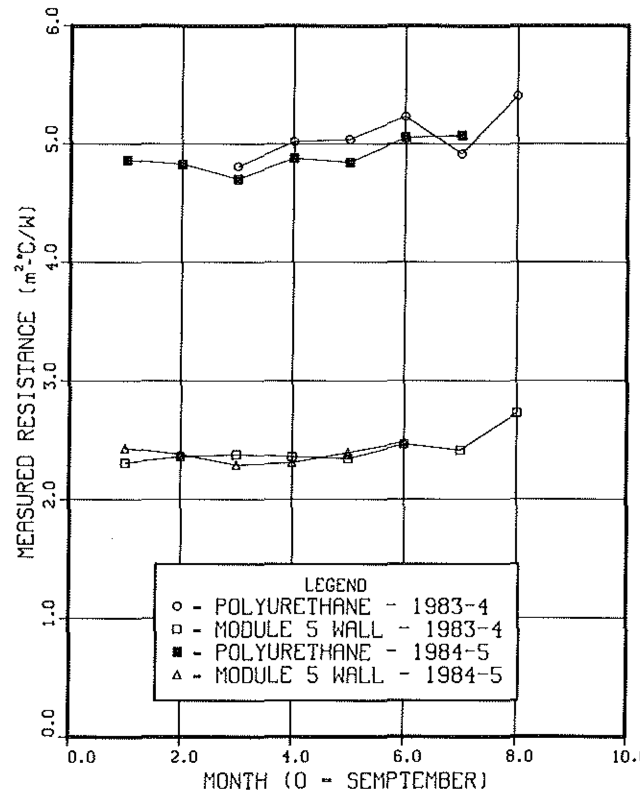
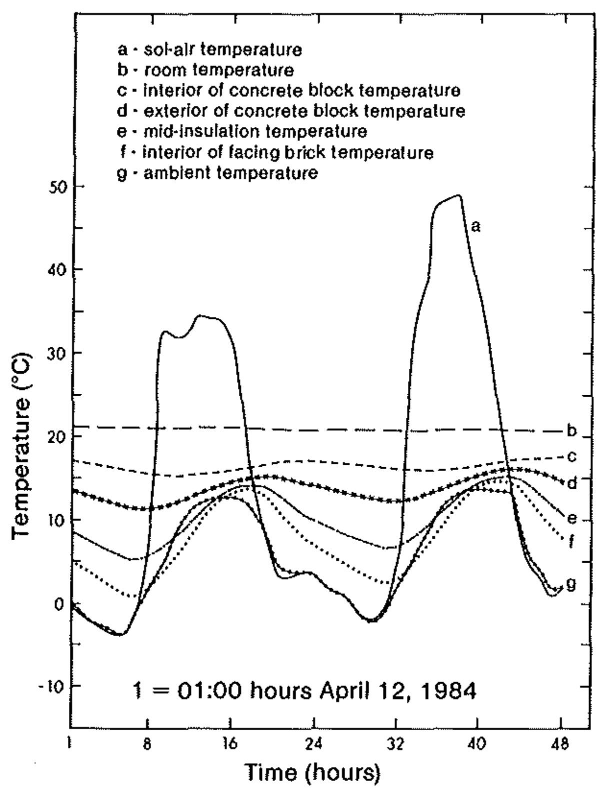


Figure 5. Measured resistance of walls in modules 1 and 5 for two heating seasons



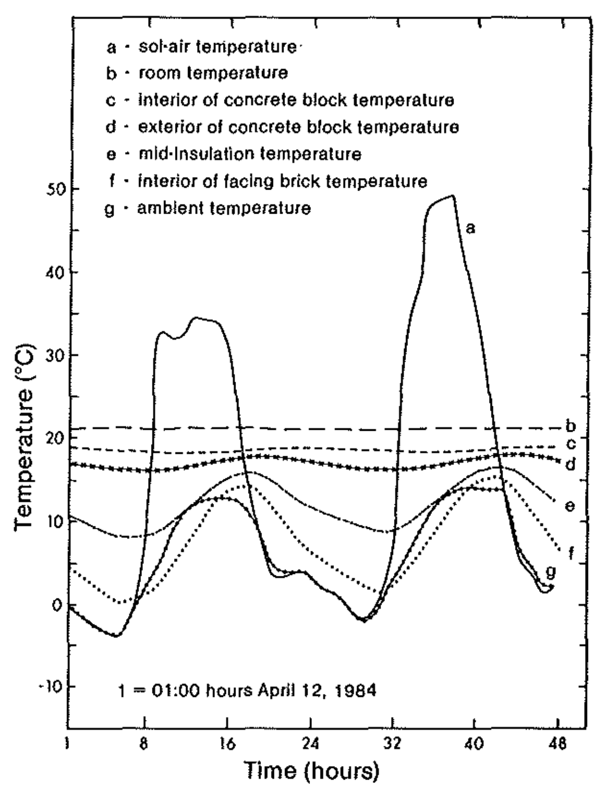


Figure 6. Internal wall temperatures for north polyurethane (left) and vermiculite (right) sections

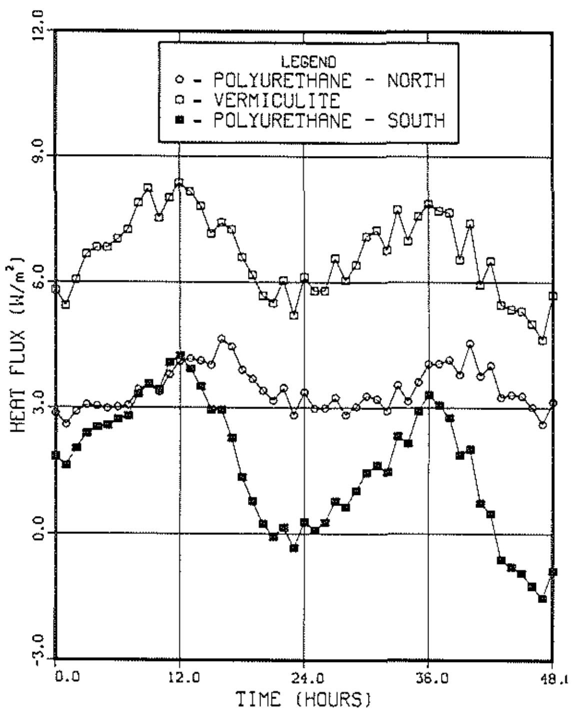


Figure 7. *Measured wall heat flux for April 12-13, 1984*

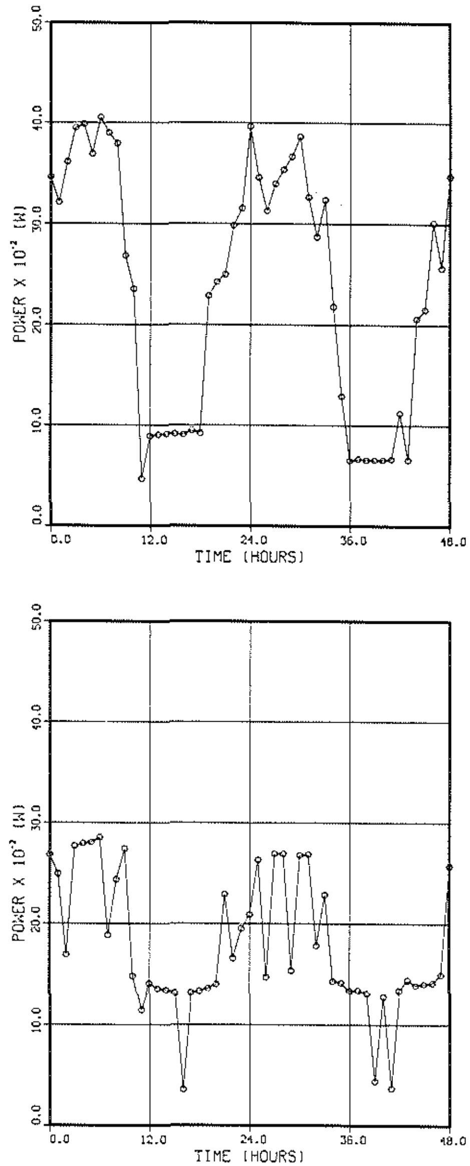


Figure 8. *Measured power consumption for modules 1 (top) and 5 (bottom) for April 12-13, 1984*

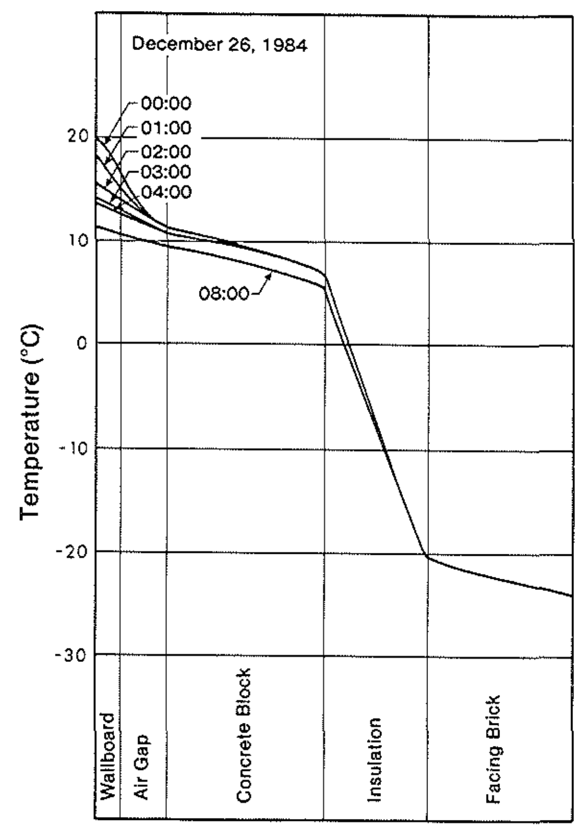


Figure 9. *Internal wall temperatures during an overnight cool down test*