INSULATED CAVITY WALLS
HOW WELL DO THEY PERFORM?

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ABSTRACT

The thermal performance of a residential masonry structure was investigated experimentally by comparing its performance to a structure constructed with conventional wood framed walls. The testing was done by using two electrically heated, uninhabited, identically sized modules on an isolated site. The modules are 7.4 m x 6.8 m in plan with full concrete basements and 2.44 m wall heights. The same insulation levels are used in the basements and ceilings so that the modules differ only in the above grade wall construction.

The masonry module was found to consume 79% of the energy of the wood framed unit, while its natural air infiltration rate was only 60% of that of the wood framed module. The measured rates of heat transfer through the masonry walls were found to be lower than expected from ASHRAE handbook predictions. This is attributed to the insulation have a lower thermal conductivity than expected. Also shown is that the influence of the metal tie bars on the rates of heat transfer through the walls is small for the type of wall section tested.

INTRODUCTION

A study into the thermal performance of a residential masonry structure has been undertaken at the Alberta Home Heating Research Facility. The study involves the experimental testing of two single storey, electrically heated modules, each 7.4 m x 6.8 m in plan, with full concrete basements. These uninhabited modules are located on the same site near Edmonton, Alberta (latitude 53.5°N and the long term average heating degree days are approximately 5800°C days). One of the modules has masonry walls while the other module has wood framed walls. The results of the study often rely on the direct comparison between the two modules. In this way, the module with wood framed walls is used as a "reference" module for the performance of the masonry module. The only essential difference between the two modules are. their above grade walls, as the ceilings and basements are identical in construction.

The thermal resistance values for the insulations used in the two modules are shown in Table 1.

Table 1 Nominal Insulation Values for Test Modules

$(\mathrm{m}^2 \cdot {}^\circ\mathrm{C/W})$

Module	Ceiling	Walls	Basements
Masonry	2.11	2.59(a) 1.06(b)	1.76 to 0.61 m(c)
Reference	2.11	1.76	1.76 to 0.61 m(c)

(a) Polyurethane section (90% of wall area , based on conductivity of fully aged foam-in-place polyurethane from ASHRAE Fundamentals 1981.

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

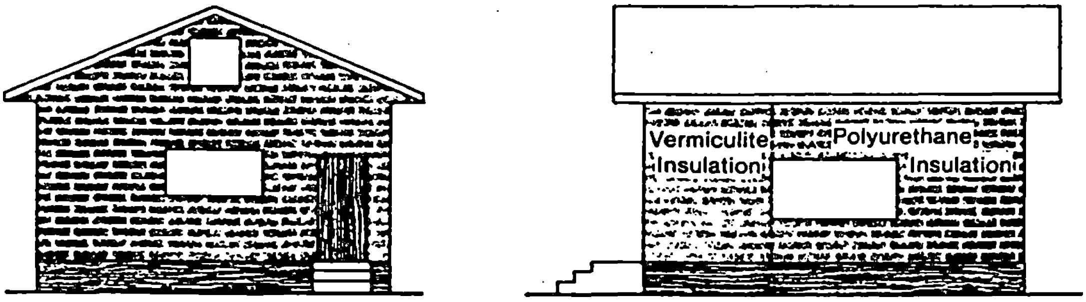
(c) Depth below grade.

The results reported here will focus on four areas:

1. The overall performance of the masonry module relative to the reference module.
2. Thermal performance of the insulations used in the masonry module.
3. Natural air infiltration.
4. Effects of the metal ties in the masonry walls.

Construction Details and Data Acquisition

The masonry module, shown in.Figure 1, has most of the same overall dimensions as the reference module. Common features include their gable roofs on elevated roof trusses and full concrete basements. The basements extend 1.8 m below grade with weeping tiles around their foundations. Both modules have 15.2 cm class B flues terminating 1.3 m above the basement floor. These vents are used to induce pressure distributions similar to those found in residential structures with combustion furnaces.



East Elevation

North Elevation

FIGURE l Masonry Module

The above grade walls of the masonry module are commonly known as double wythe or cavity walls.· Figure 2 shows the double wythe wall in cross section. This type of wall was selected for study because it contained a significant amount of mass inside its main insulating layer and it could be built on an existing 20 cm thick concrete basement wall. The exterior wythe is dark colored facing bricks and the load carrying inner wythe is 10 cm thick light weight concrete blocks. A 2.54 cm air gap was built in by using metal furrings to stand off standard 13 mm gypsum wallboard as interior finish. Two types of insulation were _installed in the 6.4 cm gap between the inner and outer wythes. All east, west, and south walls are solely foamed-in-place polyurethane insulation. One third of the north wall was insulated with poured-in-place venniculite, as indicated in Figure 1. The remainder of the north wall was filled with foamed-in-place polyurethane. During construction, care was taken to ensure that the wall cavity was kept clear of mortar so that the cavity could be filled as completely as possible. No interior drip space was provided in any section of the wall. Detailed specifications for the two modules are listed in Tables 2A and 28.

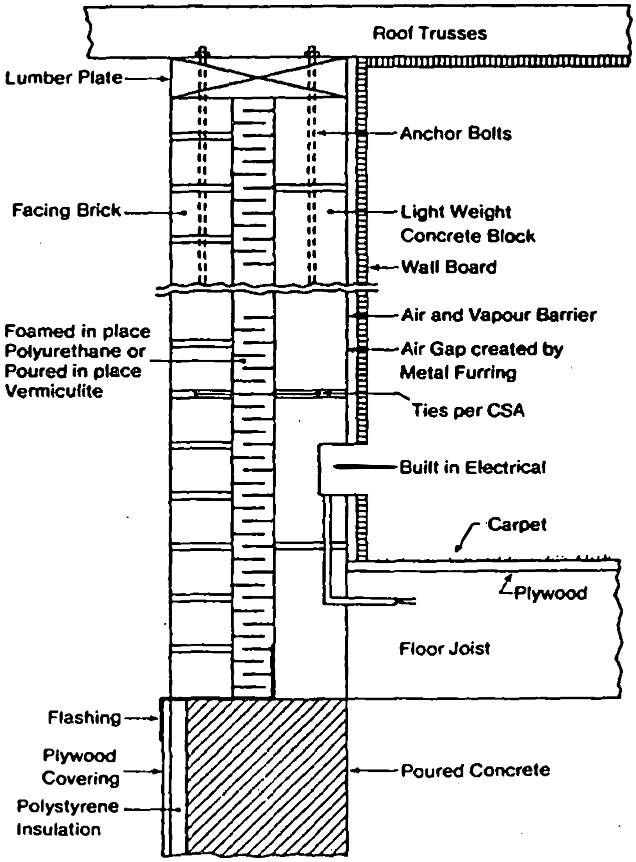


FIGURE 2 Cross Section of Cavity Wall

Table 2A
Specifications - Masonry Module

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 - 1000 x 1950 mm sealed unit (double glazed)
South Wall - none
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 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 2B
Specifications - Reference Module

Exterior Dimensions	6700 x 7300 mm
Interior Dimensions	6500 x 7100 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
- 0.102 mm polyethelene air-vapor barrier
- 13 mm gypsum wallboard

Wall Construction

- 10 mm prestained plywood exterior finish
- 38 x 89 mm framing, 410 mm on center
- fiberglass insulation, RSI = 1.76
- 0.102 mm polyethelene air-vapor barrier
- 13 mm gypsum wallboard

Windows

North Wall - 1000 xx 1950 mm sealed unit (double glazed)
South Wall - none
East Wall - 1000 x 1950 mm horizontal slider (vinyl frame)
West Wall - 1000 x 1950 mm horizontal slider (vinyl frame)

Door

- 910 x 2030 mm urethane foam core

Basement Insulation

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

Auxiliary Heating

- 7.5 kW electric duct heater

Interior Finish

- painted walls
- carpeted floor

Two on-site computers are used to gather data. One system is used solely to control and monitor the natural air infiltration experiments, while the other is used to monitor energy consumption and envelope losses. The pertinent information is read once every two minutes and temporarily stored. At the end of each hour the signals are averaged and transferred to magnetic tape. The magnetic tapes are then removed and taken to the main frame computer at the university for analysis. The information recorded included the electrical power input to each module, the indoor temperature at three different locations, the output from heat flux transducers mounted on ceilings, walls and below grade portions of the basements, soil temperatures, wind speed and direction, and solar radiation at several orientations.

Complete instrumentation details have been reported previously (1)[1] •

RESULTS

Total and Relative Energy Consumption

The simplest measure of a module's overall thermal performance is its total energy consumption over a heating season. The total energy consumed by a module is a function of the severity of the ambient conditions, and the envelope characteristics of that module. The customary measure of the severity of the ambient conditions is the indoor-outdoor temperature differ-ence, expressed in units of heating degree days {HOD}. The heating degree day is a unit, based on temperature difference and time, used normally in estimating energy consumption, and specifying the nominal heating load on a building during the winter. For any one day, when the mean ambient tempera-ture is less than the room temperature, the degree days are equal to the number of Celcius degrees difference between mean ambient temperature for the day and the mean room temperature. It is important that each module have its .own HOD calculated separately, since even a slight difference in thermostat set point over an entire heating season can greatly effect the energy consumption of that module.

The cumulative energy consumed by the two modules is plotted against each module's own HOO in Figure 3. Initially the thermal performance of both of the modules is quite similar, as the two lines follow one another up to about the 2600 HOO point. At this time the masonry module shows a sharp change in slope. It was discovered at that time that the makeup air vent in the masonry module had not been properly sealed after the module's construc-tion. Consequently, the masonry module was severely over ventilated for the first three and a half months of its operation.

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[1] Numbers in brackets refer to references

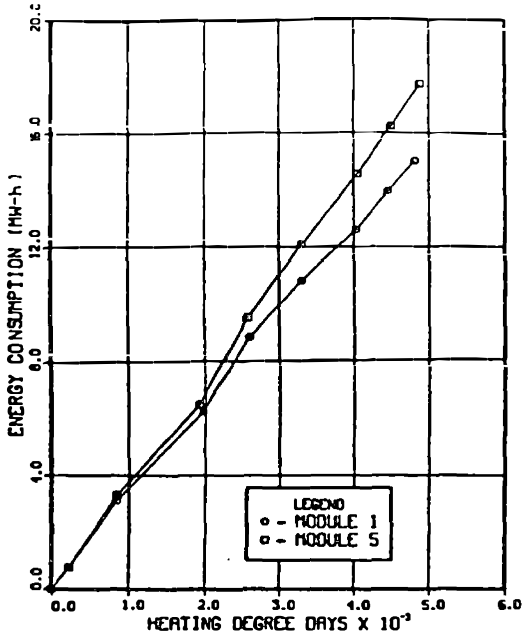

FIGURE 3 Electrical Energy Consumption of Modules

A large degree of -the seasonal variation in results can be removed by defining the masonry module's "relative position" with respect to the reference module. The "relative position" meaning simply the ratio of the perfor-mance of the masonry module to the performance of the reference module, mul-tiplied by 100. In terms of energy consumption, the relative position also implies that any difference in HOD due to different thermostat setting is accounted for between the modules. Figure 4 shows the month by month relative energy consumption for the masonry module. At the start of the heating season, the relative position of the masonry module was greater than unity. This initially high relative energy consumption of the masonry module was caused by the over ventilation problem mentioned .previously. Considering only the periods when the air infiltration rates were reasonably stable, the energy consumption for the masonry module was 79% of the reference module. This lower energy requirement for the masonry module can be attributed to lower than expected heat transfer through the walls and lower air infiltration.

Air Infiltration

The ratio of the natural air infiltration rates between the masonry and reference modules, calculated weekly, is shown in Figures. The ratio shows very clearly the effect of sealing up the makeup air vent in mid January. Originally, the air infiltration rate of the masonry module was 160% of the reference module. It then dropped sharply to only 60% of the reference module after sealing the vent. This dramatic change in air infiltration rate for the masonry module was responsible for the drop in module's relative energy consumption between the months of December and February as shown in Figure 4. The average air infiltration rate for the masonry module after the vent had been sealed was about 0.2 air changes per hour, with the 15.2 cm diameter class B flue open.

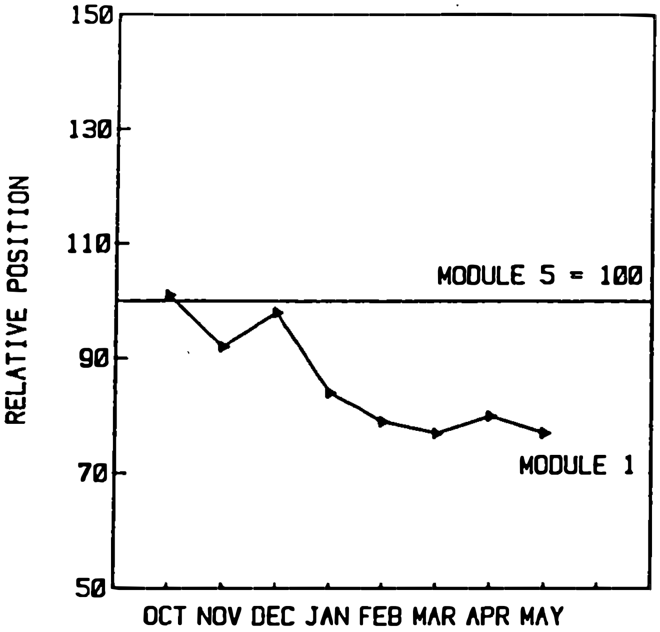

FIGURE 4 Relative Energy Consumption of Modules

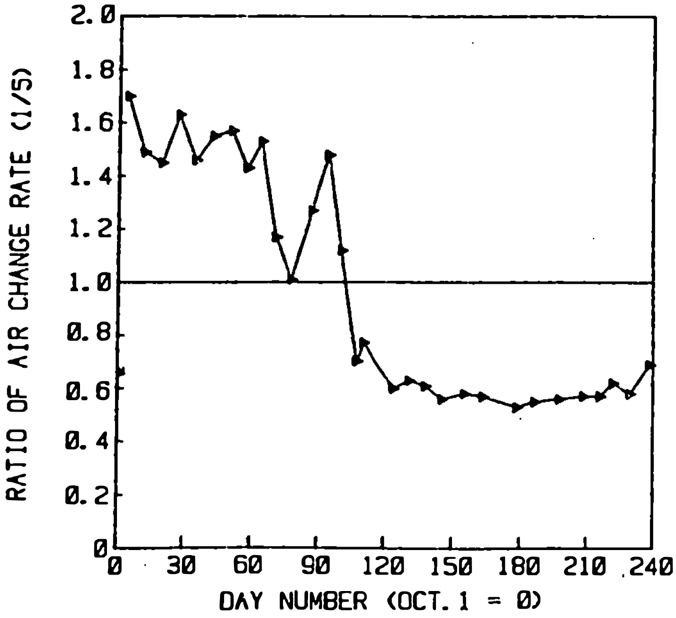

FIGURE 5 Relative Air Infiltration Rates of Modules

Measured Wall Heat Flux

To detennine if the above grade wall sections were performing as well as expected from their desi'gn specifications, the wall heat flux was measured. Form the wall heat flux and the indoor-outdoor temperature·
difference, the effective thermal resistance of the wall can he determined. Figure 6 shows the relationship between the measured rates of heat transfer and temperature difference for both the venniculite and polyurethane sections of the north wall. Each data point in this figure represents 48 hour averages. The inverse of the slope of Figure 6 is the effective overall thennal resistance of the wall section.

A comparison between ASHRAE (2} calculated overall thermal resistance and the measured values for the masonry walls- is shown in. Table 3. The ASHRAE predictions shown in this table were calculated using the thermal properties of unaged polyurethane foam, and the minimum value of thennal conductivity of vermiculite, ignoring the metal ties between the facing bricks and concrete blocks. There is reasonably good agreement between the measured and predicted resistances.

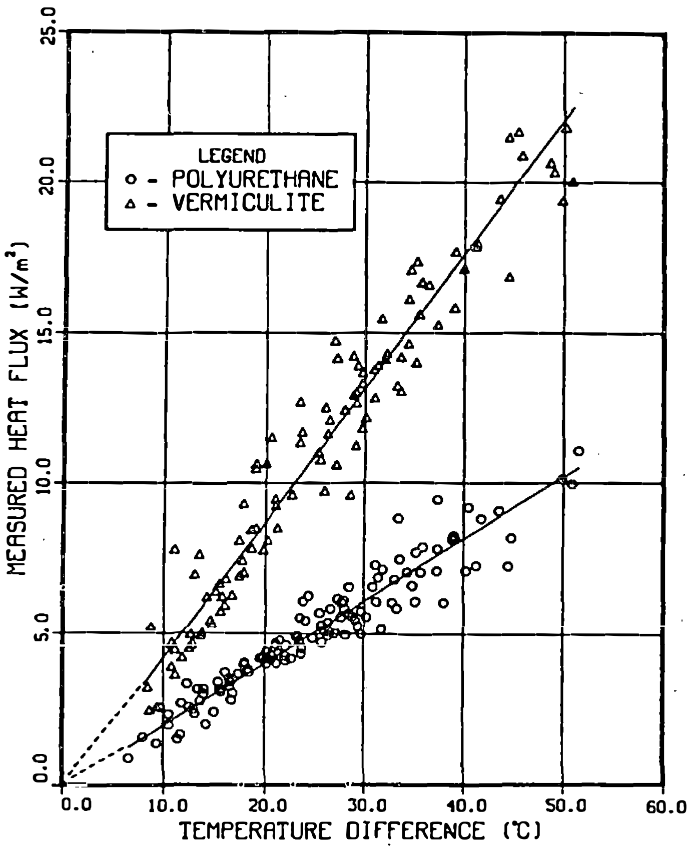

FIGURE 6 Overall Heat Transfer Through North Wall of Masonry Module

Table 3 Measured and Predicted Thermal Resistance for Walls of Masonry Module

Wall Section	Measured	Predicted
North - polyurethane	4.76	4.62[(a)]
South - polyurethane	4.81	4.62
vermiculite	2.10	2.06

(a) Based on unaged properties of polyurethane, ASHRAE Fundamentals, 1985

The age of polyurethane describes how much its thermal properties have deteriorated since it was first foamed, which is not related directly to the foam's chronological age (3,4). Initially, the thermal conductivity of a foam is low, and slowly its conductivity increases with time to a steady state fully aged value. To test the rate at which the polyurethane is aging inside the wall cavity, the wall's thermal resistance was calculated monthly over two heating seasons. A similar situation of aging is also associated with the settling of the vermiculite.

Figure 7 shows the montly measured resistance of the polyurethane and vermiculite wall sections. The measured average thermal resistance of the polyurethane decreased 31 from the first to the second heat season. The 31 change in resistance is not considered to be within the accuracy of the measuring system, and therefore cannot be attributed to the aging of the foam. The vermiculite does not appear to be aging either. Visual inspection of the vermiculite section shows that a 10% settlement has taken place over two years.

Effects of the Metal Ties

Metal ties between the inner and outer wythes of the masonry walls are used to transfer all or some of the wind load on the outer wythe to the inner wythe of the wall. The steel ties used in the masonry module are 3.2 mn in diameter, and extend approximately half way though both the concrete blocks and facing brick layers. The positioning of the ties are inside the mortar beds of the bricks and concrete blocks. The ties, spaced 406 mm apart, were laid down in strips on alternate levels of concrete blocks. The concern created is that highly conductive metal ties thermally bridge the main insulating layer of the walls. Calculating the ratio of the insulation area to the area of the metal ties in the masonry walls gives a value of approximately 20,000:1. One would normally assume to neglect the ties, except the ratio of the conductivity of steel to the conductivity of polyurethane is just under 3000:1.

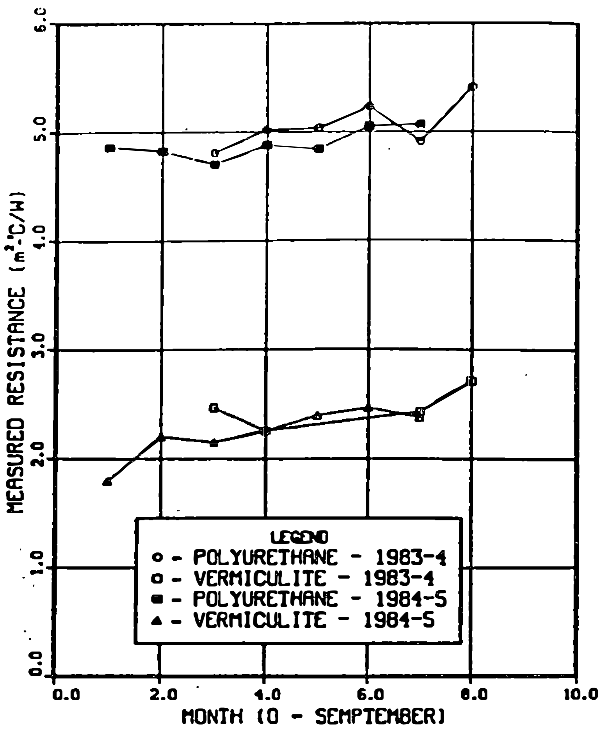

FIGURE 7 **Measured Thermal Resistance of Cavity Wall for Two Heating Seasons**

ASHRAE does have a method to deal with heat transfer though panels containing metal. The method is referred to as the "zone method". · The zone method predicts an increase in the heat transfer through the polyurethane wall section of 2.2% due to the steel ties.

There is no analytical solution available to calculate the multidimensional heat transfer around the metal ties. Even a numerical approximation to this problem would be very difficult to calculate for this wall because of the heat transfer across the air gap. A numerical solution could be done for a simplified wall section that did not include the air gap and wallboard layers. The results for this simplified wall section would not be directly applicable to the actual wall section, but would give the order of magnitude of the heat transfer to test the ASHRAE prediction.

The numerical technique used to analyze the temperature field around the metal ties was the finite element method. The finite element method was used so a fine mesh of elements could analyze the temperature field near the ties, and a course mesh could be used farther away from the tie. To model the wall section, the assumption was first made that the metal ties were sufficiently isolated for each other that it was only necessary to model the region around one of the ties. Figure 8 shows the mesh of elements used to model the area around the metal ties. Since the heat transfer is the same in all directions around the metal tie, only half of any section taken through the tie needs to be modelled.

The boundary conditions applied to the model of the masonry wall were:

1. Interior surface (concrete blocks) - specified temperature of 20°c.
2. Exterior surface (facing bricks) - specified temperature of 0°C.
3. Axis of symmetry at the metal tie - adiabatic or zero heat flux.
4. Infinite boundary - adiabatic or zero heat flux.

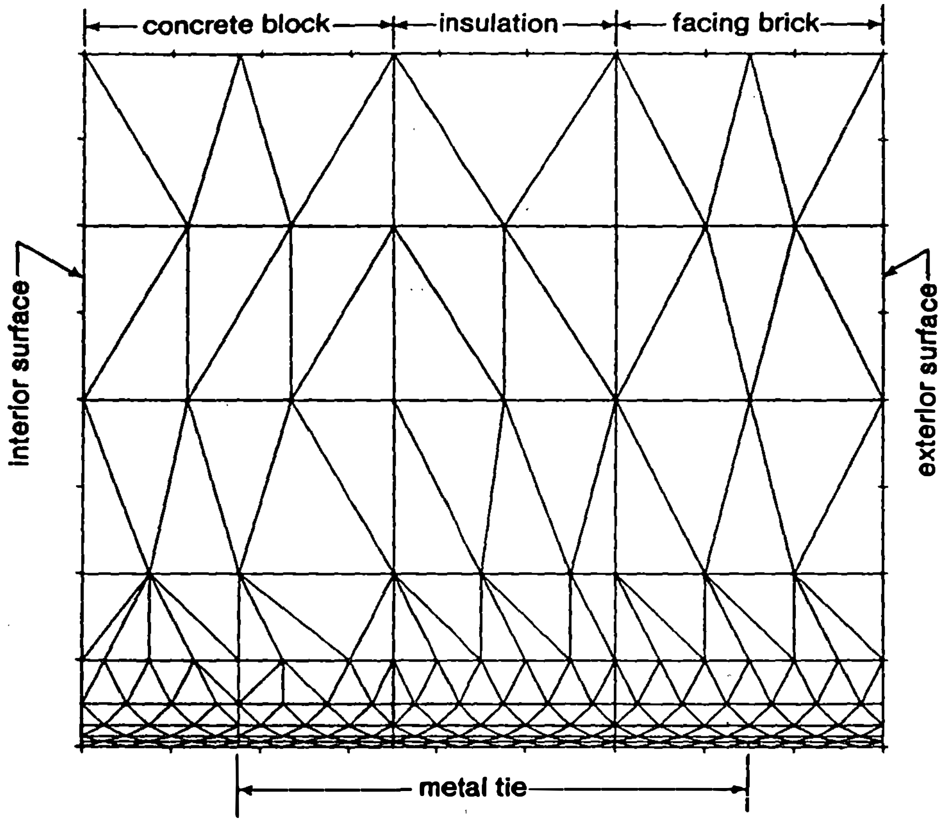

FIGURE 8 Finite Element Mesh for Simplified Wall Section

The solution of the finite element model approximates the value of the temperature at discrete points in the temperature field. To present these results in a useful manner, a plot of selected isotherms is shown in Figure 9. Figure 9 shows there is significant distortion of what would nonnally be parallel isotherms if the metal tie were not present. From this distorted temperature field the directio·n and magnitude of the heat flow can be approximated. The direction of the heat flow is always perpendicular to the isothenns, and the magnitude of the heat flow can be calculated from the temperature gradient. The effective resistance of the simplified wall

section with the metal tie is 3.90 $m^2 \cdot {}^\circ C/W$ a decrease of 9% from 4.3 $m^2 \cdot {}^\circ C/W$ when the tie is not present. Since this model does not include the air gap and wallboard, which further isolate the effect of metal ties, it cannot be applied directly to the wall section in the masonry module. It does suggest the ASHRAE zone method prediction of the masonry walls appears to be of the right magnitude, and can be considered a reasonable prediction of the effect of the metal ties.

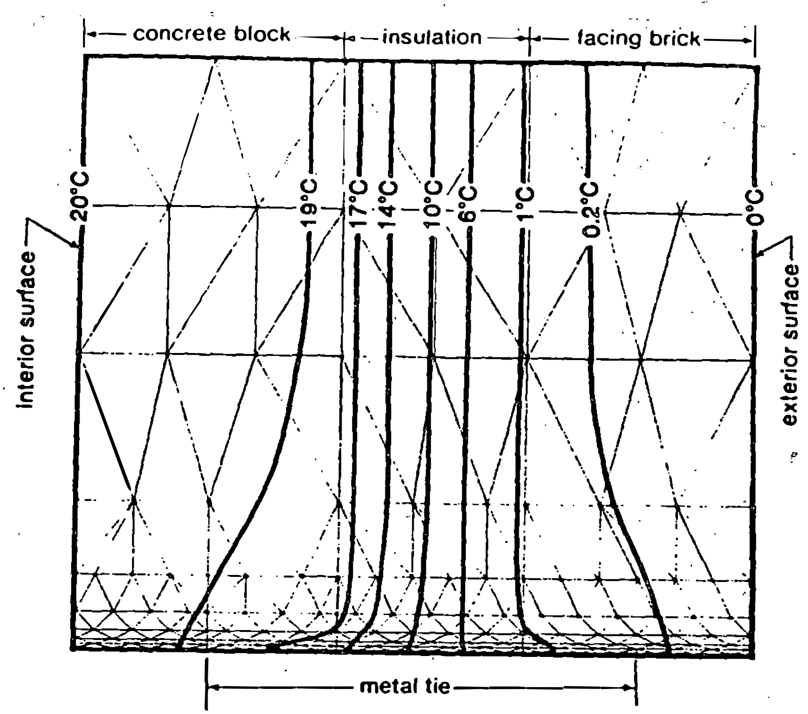

FIGURE 9 Selected Isotherms Around Metal Tie

CONCLUSIONS

Based on the results presented on a module with double wythe wall construction and foamed-in-place insulation, the following conclusions are drawn.

1. The heating energy requirements of the module was only 79% of that of a module with identical ceiling and basement but with wood framed above grade walls.
2. Reasons for the lower energy consumption was due to high insulation levels in the walls, and lower rates of natural air infiltration.
3. The natural air infiltration rate of the module averaged approximately 0.2 air changes per hour after a loose makeup air vent was sealed. This rate was about 60% of the rate found in the wood framed module.
4. The measured thermal resistance of the polyurethane of the.masonry walls were consistent with the properties of unaged polyurethane.

5. The polyurethane does not appear to have aged significantly over two years.
6. The vermiculite insulation has settled approximately 10%._
7. Based on a finite element approximation the metal ties can have a significant effect on the heat transfer through a simplified, insulated cavity wall. The effect on the wall section tested appears to be very small.

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