The Impact of Insulation Placement on the Seasonal Heat Loss Through Basement and Earth-Sheltered Walls

George D. Meixel Paul H. Shipp Thomas P. Bligh

ABSTRACT

A transient, finite difference computer program has been developed and utilized to investigate the dynamic thermal performance of basement and earth-sheltered walls to determine the spatial and temporal characteristics of the heat flux through these walls. Comparisons between underground walls and between underground and aboveground walls serve to:

1) delineate limitations of the current American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) recommended procedure for assessing the heat loss through basement walls,

2) present evidence for the possibility of freeze/thaw or frost-heave damage to inappropriately insulated basement walls, and

3) demonstrate the significant benefits to the annual energy balance that can be achieved through appropriate insulation to take maximum advantage of both the thermal buffering characteristic of the soil mass and its potential as a heat sink.

These initial studies of several different insulation configurations highlight critical aspects of effective insulation strategies for earth sheltered walls.

INTRODUCTION

Several authors [1,2,3] have discussed the features of earth-sheltered construction that have the potential for reducing the energy demands of a building. These features are the moderation of the building's external thermal environment by the soil mass and vegetation, reduced infiltration and windchill, compatibility with passive solar heating and the use of the ground as a thermal sink. The purposes of this paper are to investigate the dynamic interaction between the building walls and the ground throughout the annual temperature cycle and to provide the details of the soil temperature profile and the consequent conduction heat transfer that determines the effectiveness of a particular wall insulation configuration. Initial results of this investigation of spatial and temporal details of thermal behavior of the exterior walls of basements and earth-sheltered buildings highlight aspects of the heat transfer process that should be optimized to insure an energy-conservative interface between living spaces and the ground.

Appropriate insulation enables earth-protected and underground structures to conserve energy by reducing unwanted heat gains and losses through their exterior envelopes [1,4,5]. Similarly, the performance of basement walls and floors (which for houses are responsible for 10-20% of the heating load [6,7]) can be improved by suitable placement of insulation [5]. In addition to substantiating the magnitude of the reductions in winter heat loss obtainable

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through insulation of the basement wall, this paper demonstrates that inappropriate placement of insulation to reduce winter heat losses can reduce the energy savings when the complete annual cycle of heating and cooling is analyzed. At least one experimental study on a test house has shown that additional insulation installed to reduce winter heat loss to the ground resulted in an increase in the summer cooling load apparently due to a reduction in the ability of the ground to act as a summertime heat sink [8]. Since cooling can be more expensive and require more energy than heating, it is important to evaluate the overall annual effect of insulation placement on wall thermal performance to develop an optimum approach to insulating. This paper introduces a method for making these evaluations. In addition, the existence of sub-freezing temperatures within below grade walls that are insulated on the inside surface is predicted for cold northern climates. The possibility of frost-heave damage to these walls is a serious problem that should be examined in more detail, both analytically and experimentally [5,9].

To a provide perspective for the following detailed examination of underground walls, a comparison between above grade walls and available experimental data for an underground wall is shown in Fig. 1. The monthly average heat fluxes for the above grade R-11 and R-19 walls were calculated using the hourly load determination section of the computer program BLAST [10]. (The thermal resistance R is in conventional units of hr-ft^2-°F/BTU.) Weather data used for this simulation was obtained from the TRY weather tape for Minneapolis (1970). The inside air temperature was allowed to float between 20.0°C and 25.6°C; walls were composed of 15 cm thick concrete plus the necessary thicknesses of fiberglass insulation to bring them to R-11 and R-19 respectively. Individual data points represent monthly averages of experimental data gathered by Shipp [11], during the calendar year 1978, from heat flux gauges placed on the inside surface of the exterior walls of Williamson Hall, an underground building on the campus of the University of Minnesota, Minneapolis. The data points on Fig. 1b are from the heat flux guages placed 0.71 m and 2.54 m below the roof of the building at several locations around the building perimeter. As discussed by Shipp [11], the scatter in the experimental data is due largely to different ground surface conditions, e.g., the presence of concrete pavers, grass, varying amounts of snow or shrubbery. Note that during the heating months, the magnitude of the measured wall heat flux from the underground building, which has only 3.8 cm of rigid wall insulation to a depth of 1.2 m, is roughly the same as well-insulated R-11 or R-19 above grade walls. However, during the cooling months of June, July and August the underground building walls continue to lose heat to the soil mass at nearly all gauge locations, while the R-11 and R-19 above grade walls show heat gains. The principal objective of this paper is to focus attention on this aspect of earth-sheltered walls by utilizing an experimentally validated computer model to assess the seasonal performance of several insulation configurations.

The soil, due to its relatively large thermal mass, provides a steady thermal sink during the summer cooling season even though ambient outdoor air temperatures often exceed the indoor air temperature. Proper placement of insulation is necessary if optimum utilization of this thermal sink is to be achieved. In addition, as shown in Fig. 1b, the thermal mass of the soil provides an effective buffer to reduce the impact of the cold winter temperatures on winter heat loss. The results of computer simulations discussed in this paper show the reduction in winter heat loss that accompanies increased wall insulation.

COMPUTER MODEL

The finite difference computer program utilized in the analytical studies presented in this paper is an extension of the program developed and documented by Shipp in reference [11]. The program solves the transient, two-dimensional heat conduction equation in a Cartesian coordinate system. To obtain the requisite detail for an accurate determination of the heat flux magnitudes and directions, and the temperature profiles that are necessary for the purposes of this investigation, the spatial resolution of the finite difference grid was increased from the 2025 nodes spaced at 30 to 120 cm intervals employed by Shipp to 6400 nodes, which enabled the dependent variables to be calculated at 10 cm intervals over a spatial domain of depth 17m and horizontal extent 12 m. By dividing the two-dimensional building down its vertical axis of symmetry, only one half of the simulated building required analysis and an adiabatic boundary condition could be imposed at this axis as shown in Fig. 2. At the bottom of the calculation region, the temperature is set to a constant deep ground temperature, which was 13°C for the Minneapolis simulations presented in this paper. The boundary conditions at the interior wall, floor and ceiling surfaces are determined by calculating the convective heat flux between the specified building air temperature and the computed inside surface temperatures. The horizontal extent of the calculation is sufficiently large so that it has negligible influence on the wall heat flux calculations. At the ground surface, the finite difference equations for the boundary conditions provide for convective interchange between the soil and the air as well as radiative heating due to solar insolation.

The surface convection heat transfer coefficient at the ground-air interface, h_{ga}, is a function of the local wind speed and the surface material in terms of both the permanent presence of pavement or plant cover and seasonal considerations such as snow cover. Initial estimates for h_{ga} were based on weather data for the Minneapolis area [12] and standard design estimates for surface heat transfer coefficients [13]. Due to the uncertainty in choosing from possible values, refinement of monthly estimates for h_{ga} were made by means of direct comparisons with previously recorded soil and weather conditions. Algren's study of the effect of weather conditions on ground temperatures in an open field in Edina, Minnesota, was selected for a data base [14]. Since the soil heat transfer in an undisturbed open field is one-dimensional, a simplified computer program was developed to calculate the ground temperature profile for Algren's conditions. Figure 3 illustrates the fit to Algren's data obtained from the simplified computer model with monthly values of h_{ga} suitably chosen. A second check was performed using the measured soil temperatures for the Washington, D.C., region as reported by Kusuda [15]. Through this procedure characteristic ground surface heat transfer coefficients were determined for each month. Values for this coefficient varied from 1.0 W/m^2 -K during the winter to 16.0 W/m^2 -K from May to October. The solar heat gains used in the surface heat balance were determined by multiplying the average solar insolation as specified in the ASHRAE 1977 Handbook of Fundamentals [16] by the solar absorptivity of the ground surface cover. A time step of one day was used for the finite difference calculations. Longer time steps of one week or one month generated results that departed significantly from Algren's data.

COMPARISON WITH THE ASHRAE PROCEDURE

The 1977 ASHRAE Handbook of Fundamentals recommends the use of an approximate graphical procedure [17] developed by Boileau and Latta [18] to determine the winter heat loss from basement walls. In this procedure the heat flow from the basement wall is assumed to travel along circular paths, perpendicular to radial isotherms, to the surface of the ground as shown in Fig. 4. Boileau and Latta suggest that this is a reasonable approximation only for situations which are close to a time independent steady state. Heating design load conditions for an uninsulated basement wall as shown in Fig. 5a satisfy these criteria. Figure 5b shows a plot of the results of an ASHRAE/Boileau and Latta calculation of the basement wall heat flux profile for a building at 20.0°C and an ouside air temperature of -9.3°C, which is typical of Minneapolis, during February. The thermal properties and surface heat transfer coefficients which were used for the Boileau and Latta calculation and for the computer simulation were: soil conductivity=2.00 W/m-K, soil density=1820 Kg/m^3, soil specific heat=1150 J/Kg-K, concrete conductivity=1.40 W/m-K, concrete density=2310 Kg/m^3, concrete specific heat=880 J/Kg-K, wall surface convection coefficient=4.00 W/m^2-K and a February ground surface coefficient=2.00 W/m^2-K. The results of the transient, finite difference computer analysis of this case are plotted as isotherms in Fig. 5a and as inside wall heat flux values on Fig. 5b. Outside air temperatures used with the computer analysis were thirty year average data for the period 1940 to 1970 for Minneapolis. Average air temperature for February during this period is -9.3°C; The same value as used for the Boileau and Latta calculation. The good agreement between the two methods of analysis justifies the steady state assumption of Boileau and Latta's graphical procedure for this case. Note how the initial lengths of the isotherms emanating from the ground surface/basement wall intersection are nearly radial as Boileau and Latta assume. The graphical method does, however, predict a slightly smaller wall heat loss than does the computer model. This is because the graphical procedure does not take into account the small vertical gradient in the building wall temperature and the consequent heat flux. This limitation will lead to larger errors for the ASHRAE procedure in the next example in which inside wall insulation is introduced.

Figure 6 presents winter heat flux data calculated by the two methods with 10 cm thick insulation (conductivity=0.027 W/m-K, density=32.04Kg/m^3, specific heat=1130 J/Kg-K) on the inside surface of the basement wall, all other conditions being the same as the preceding example. The shapes of the computed isotherms plotted in Fig. 6a do not fulfill the requirement of the Boileau and Latta technique--that the isotherms radiate from the ground surface/basement wall intersection (see Fig. 4). Comparison of the computer analysis of the wall heat flux with the Boileau and Latta method , Fig. 6b, shows that the presence of the inside wall insulation has reduced the heat flux from the building wall into the soil beyond the ASHRAE predictions. Again, this is due to the presence of a significant vertical temperature gradient in the building wall, which the graphical method does not consider. This vertical temperature gradient is a property of the surrounding soil mass created by the seasonal variations in outside air temperature, insolation, precipitation and ground cover. The heat lost from an uninsulated basement wall reduces the natural gradient, Fig. 5. The presence of inside wall insulation, Fig. 6, isolates the inside of the building from the soil, thereby reducing heat flow to the ground. As a consequence, the effect of the vertical temperature gradient on the calculated heat fluxes is more pronounced in this case (i.e., because the vertical component of the total temperature gradient at the wall is relatively larger when the inside of the wall is insulated).

A very important aspect of the thermal response to this insulation configuration, illustrated in Fig. 6a, is that the 0°C isotherm enters the building wall; thus the potential exists for foundation deterioration due to freeze/thaw cycling and frost heaves.

SEASONAL RESPONSE OF BASEMENTS AND EARTH SHELTERED WALLS

This section presents the results of the computer analysis for several basement and earth-sheltered walls to:

1) illustrate the effect of the soil mass on the monthly average heat flux through basement and earth-sheltered walls,

2) point out why currently available methods do not give correct predictions of seasonal heat flux, and

3) compare monthly average wall heat fluxes for different insulation configurations.

A correct evaluation of the contributions of each facet of the exterior envelope to the annual energy consumption of a building requires knowledge of the temporal dependence of the heat flux to each surface from the interior of the building throughout the entire year. For this reason, the computer program discussed in this paper has been developed to accurately predict the heat flux through earth-sheltered walls for each day of the year and for as many years as needed for a particular investigation. Monthly average wall heat fluxes were obtained from this computer program by averaging the daily heat fluxes for the complete month.

The major contribution of this paper is the quantitative prediction of monthly average earth-sheltered wall heat fluxes, which continuously draw energy out of the building interior during the summer months of June, July, and August. This distinctive feature of the computer predicted basement wall heat fluxes, shown on Fig. 7, demonstrates that when traditional above grade walls are adding to the cooling load, earth-sheltered walls are providing a natural means of cooling.

Figure 7 shows the computed results of the monthly average heat fluxes for three basement walls with the computed results for aboveground R-11 and R-19 walls. During the initial months of building operation, energy is absorbed by the soil mass at a larger rate than in subsequent years when the surrounding soil mass will be in a slightly warmed equilibrium condition. Because the computer program has been designed to simulate the underground heat transfer from a building which is created instantaneously on the first day of the analysis (which for this study is January 1, and the surrounding soil mass is relatively colder than for subsequent years), the monthly average basement wall heat flux for January of the second year is considerably less than for January of the first year. Implications of this point will be discussed later.

For reasonably well-insulated basement walls--e.g. basement wall number 2 in Fig. 7, which has 10 cm of insulation (R-25) on the outside surface of the top half of the wall--the summertime cooling advantage is matched by an equally favorable winter performance. Basement wall 2 has a winter heat loss approximately the same as the R-11 aboveground wall during the first January through April period of the building operation and performs considerably better than the R-11 wall for subsequent years. If the maximum available summertime cooling from the basement walls is not needed, additional insulation can be placed on the wall to reduce the winter heat loss. Basement wall 3, the results for which are shown on Fig. 7, has 10 cm of insulation (R-25) down the entire inside wall surface and performs as well as an R-40 aboveground wall during the winter heating season. To avoid frost damage to the foundation in very cold climates, such as the Minnesota conditions used in this paper, inside basement wall insulation must be used with caution. Benefits equivalent to those obtained with basement wall 3 can be achieved by placing the insulation outside the basement wall surface or by extending it horizontally as detailed in reference [5] to eliminate the risk of frost-heave damage to the foundation.

Figure 8c illustrates the computed monthly average wall heat fluxes for earth-sheltered walls with two different insulation configurations (Figs. 8a and 8b) for the first 28 months of the building operation. Again, the aboveground R-11 and R-19 walls are included for comparison. Note that after the first year the computed heat fluxes reach a reasonably close annual periodicity. However, during the initial transient warming of the soil mass by the building when more energy is absorbed than in subsequent years, the wall heat loss to the ground is correspondingly larger. Evaluations of the performance of earth-sheltered walls should focus on the behavior of such walls after the initial soil warm-up transient period to avoid misleading conclusions. Methods that do not account for changes in the ground temperature distribution due to the influx of energy from the building (such as the methods suggested by Kusuda [19] or by Robertz et al [20]), cannot yield the detailed results of thermal performance required for optimizing insulation strategies and using the soil mass for energy conservation.

For the summer cooling period, Fig. 8c shows that both of the earth-sheltered designs experience beneficial wall heat losses. Since the outside air temperature is also greater than the soil temperature (in fact, as the heat fluxes for the aboveground walls show, the monthly average air temperature is greater than the building interior temperature) the assumptions required by the Boileau and Latta approach are not satisfied and this method cannot be used for estimates of below grade wall heat fluxes during this period, as both ASHRAE and Boileau and Latta imply.

Applying the Boileau and Latta graphical technique where it should have resonable accuracy--to estimate the February wall heat loss from insulation placements A and B as sketched in Fig. 8a and Fig. 8b respectively--these configurations are determined to have equal wall heat fluxes. The Boileau and Latta procedure does not distinguish insulation placement A from insulation placement B. For February the Boileau and Latta calculated average heat loss is $4.0 W/m^2$, approximately the same as for insulation placement B. Insulation placement A has an average February heat flux twice as large as placement B, and insulation configurations A and B obviously do not behave as equivalent thermal systems. Insulation placement B demonstrates a heating season advantage over placement A because the thermal buffering of the extreme cold temperatures by the thermal mass of the soil reduces the February temperature drop outside the vertical insulation, which then acts effectively to reduce winter heat loss. However, configuration A allows the soil mass to be more strongly coupled to the building interior than configuration B, thereby enhancing the capacity of the soil around wall A to act as a summertime heat sink by 140% over the B configuration.

DISCUSSION

The results of this investigation of the seasonal performance of basement and earth-sheltered walls provide quantitative information on several factors which should be considered when placing insulation to minimize the annual energy budget for heating and cooling buildings. Without any insulation, underground walls are roughly equivalent to well insulated above ground walls (R-11 or better) during the heating season once the initial transient warm-up of the soil mass is complete. Because of the free cooling due to the wall heat loss from the building to the ground the uninsulated underground wall is a valuable component of the summer cooling system. For example, a typical house in Minnesota would loose heat through the basement walls and floor during June, July and August equivalent to the continuous operation of a 3,000 to 5,000 BTUH air-conditioner.

Conventional placement of insulation to reduce the wall heat flux to the soil during the winter will also reduce the beneficial heat loss during the summer cooling season. Configuring the insulation to maximize summer cooling (insulation placement A, Fig. 8a) increases the winter heat loss slightly. Adjusting the insulation configuration to optimize the seasonal heat loss through the walls requires a thorough understanding of the dynamics of the heat transfer process to the ground and the consequent trade-offs between reductions in winter heat loss and increases in beneficial summer heat loss through the walls. This optimization will vary for different climatic conditions.

The information obtained in this initial study is the result of an effort to develop a research tool that can accurately analyze the building/ground interaction. The present two-dimensional computer program models the wall in sufficient detail (10cm grid spacing, time step=1 day) to obtain acceptable accuracy for daily and monthly average wall heat flux calculations. Coarser finite difference grids of 30cm spacing have generated heat flux preditions at least 20% to 30% lower than those obtained with the 10cm grid and are not satisfactory. Increasing the resolution of the spatial grid finer than the 10 cm spacing used for these calculations with a one day time step generates temperature profiles and heat flux data in agreement with the 10 cm grid results. For passive solar and thermostat setback studies wall thermal performance on a time scale of hours is required and finer grid spacing and smaller time steps are necessary.

Winter heat loss from the underground walls is dominated by the interaction with the outside air temperature buffered by the soil mass and consequently the two-dimensional Cartesian coordinate system functions quite well for the determination of wall heat loss during this season. However, from the predictions of the two-dimensional computations, during the spring, summer and fall much of the heat transfer from the walls and essentially all of the heat lost from the floor appears to be transmitted to and stored in the soil mass. To properly assess the magnitude of these three-dimensional effects the problem must be re-formulated in two-dimensional cylindrical coordinates (see Davies [4]) or with a three-dimensional Cartesian coordinate system as used by Kusuda and Achenbach [21]. The economic impact on the annual energy budget of the unique cooling advantage available with basement and earth-sheltered walls cannot be accurately evaluated until the heat sink capability of the soil mass is correctly modeled. The two-dimensional simulation of the underground walls presented in this paper provides a lower limit for the summer cooling heat loss from the walls; inclusion of the third dimension will provide another direction in which heat can be conducted away from the building.

The economic importance of employing the heat sink capability of the soil mass to full advantage or of using the thermal buffering of the ground to reduce heating loads is dependent on the size of the heating and cooling loads. These loads are generated by the particular function for which the building is being utilized and by the climate in which the building is located. Houses with their relatively small heating and cooling loads can certainly benefit from the summertime heat loss and from the reduced winter heating load. For larger buildings with high internal loads it is necessary to carry out simulations analogous to those presented in this paper for a variety of climatological regions to evaluate the benefits of earth-sheltered walls. Because the energy expenditure for cooling a large building is often much larger than for heating (many large buildings have a cooling load all year), evaluation of the potential for using the soil mass as an aid in reducing the cooling energy requirements is important. Investigations must include the effects of building geometry and insulation placement, factors which obviously effect the building/ground interaction, to determine both heating and cooling benefits. In addition it may be useful to experiment with the design of ventilation systems to increase the surface convection heat exchange at underground walls and floor surfaces to increase heat fluxes.

CONCLUSIONS

Through the use of an experimentally validated transient, finite difference computer program, the seasonal heat loss through basement and earth-sheltered walls has been predicted for several insulation configurations. For weather conditions typical of Minneapolis, Minnesota, computer calculated monthly average heat fluxes demonstrate that insulated underground walls have less winter heat loss than comparably insulated aboveground walls. A basement wall with 10cm additional inside insulation (R-25) performs better than an aboveground R-40 wall. However, insulating the inside of basement walls results in (computer predicted) sub-freezing temperatures inside the basement wall and the surrounding soil which have the potential for frost-heave damage to the walls. This paper demonstrates that placing the insulation horizontally outside the basement wall results in good winter performance, reduces the possibility of foundation damage, and allows the underground wall to lose heat to the soil during the summer cooling period.

This investigation has determined that basement and earth-sheltered walls typically provide an average of 5-8 W/m^2 of continuous heat loss during the summer months for Minneapolis weather conditions. This estimate represents a lower bound for the summer heat loss. To correctly simulate the heat sink capability of the soil mass, the full three-dimensional building/soil interaction must be modeled.

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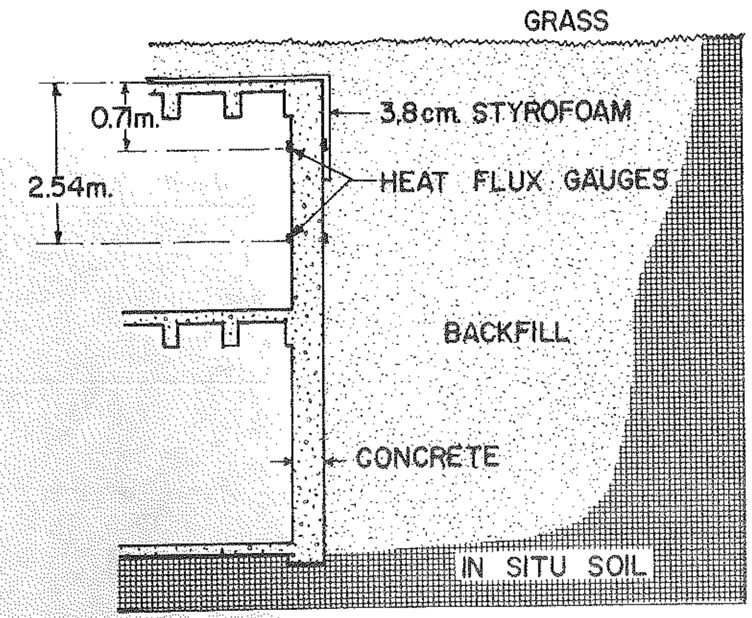
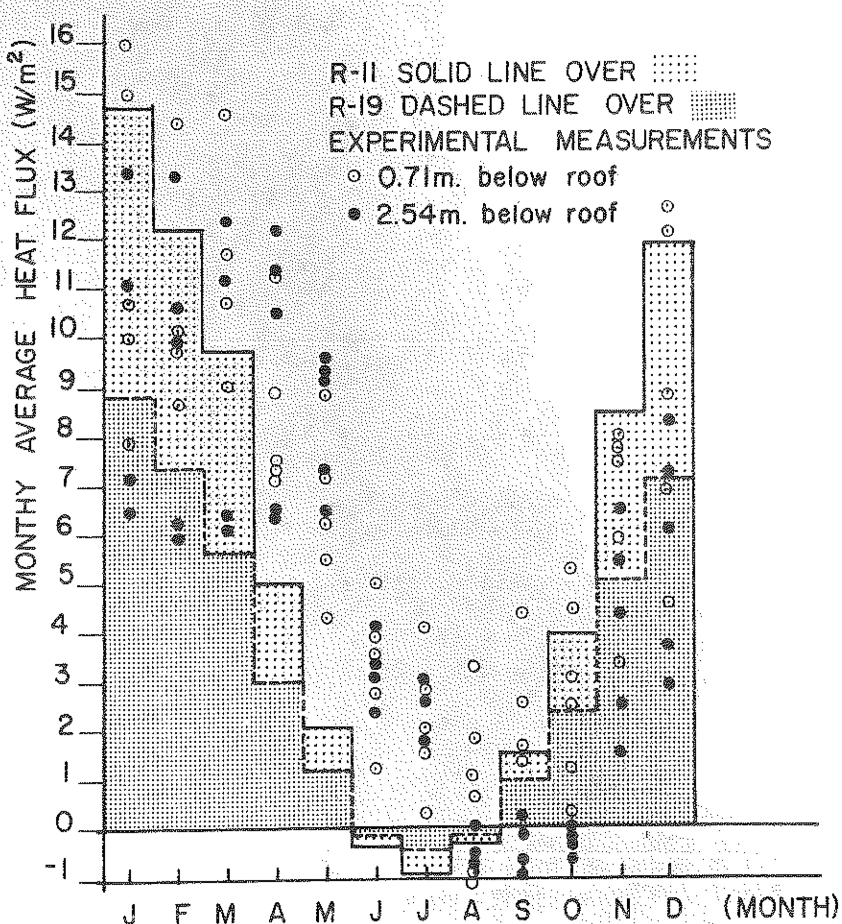


Figure 1a. A typical schematic cross-section of Williamson Hall, which shows the location of the heat flux gauges.



1b. Monthly average heat fluxes for R-11 (solid line) and R-19 (dashed line) aboveground walls compared to experimental data for an underground wall at locations 0.71 m (open circle) and 2.54 m (solid circle) beneath the top of the roof slab.

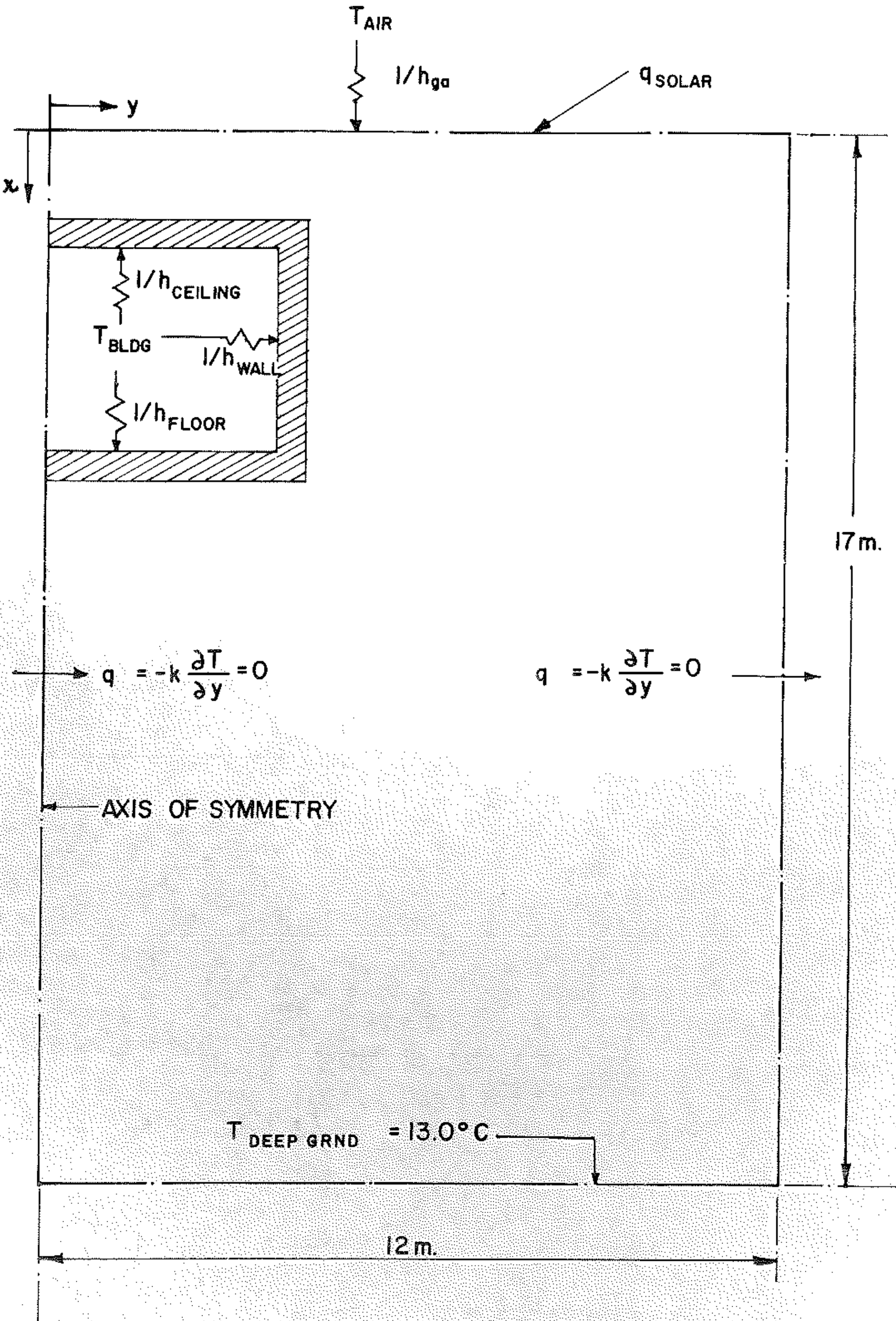


Figure 2. The spatial extent of the two-dimensional Cartesian calculation domain indicating boundary conditions.

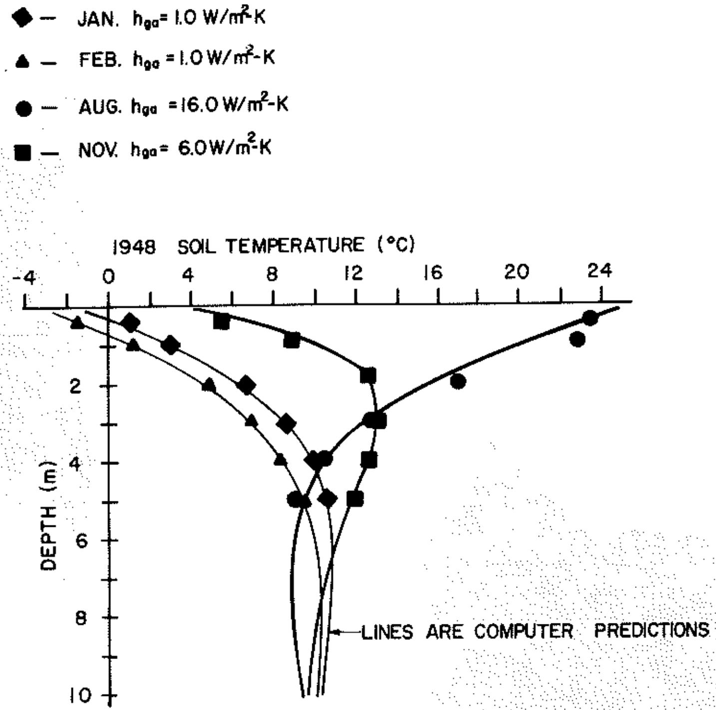


Figure 3. A comparison of numerically predicted soil temperatures (solid lines) with measured values (symbols) taken by Algren [4] in 1948 in Edina, Minnesota.

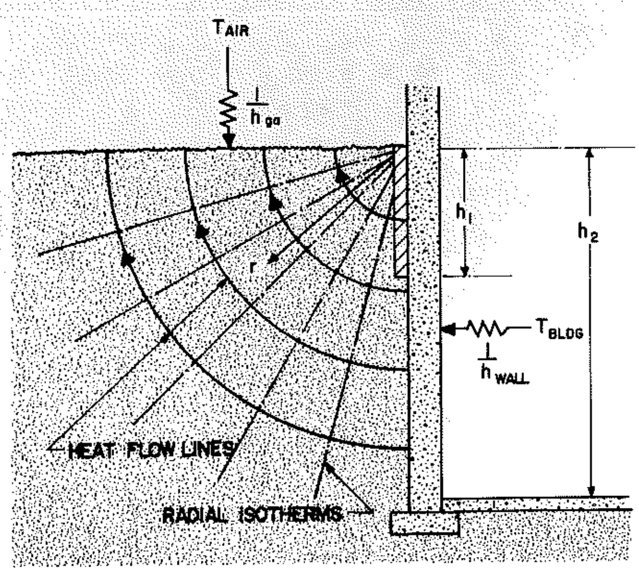


Figure 4. Radial isotherms and circular heat flow lines assumed by the ASHRAE recommended Boileau and Latta graphical procedure [18].

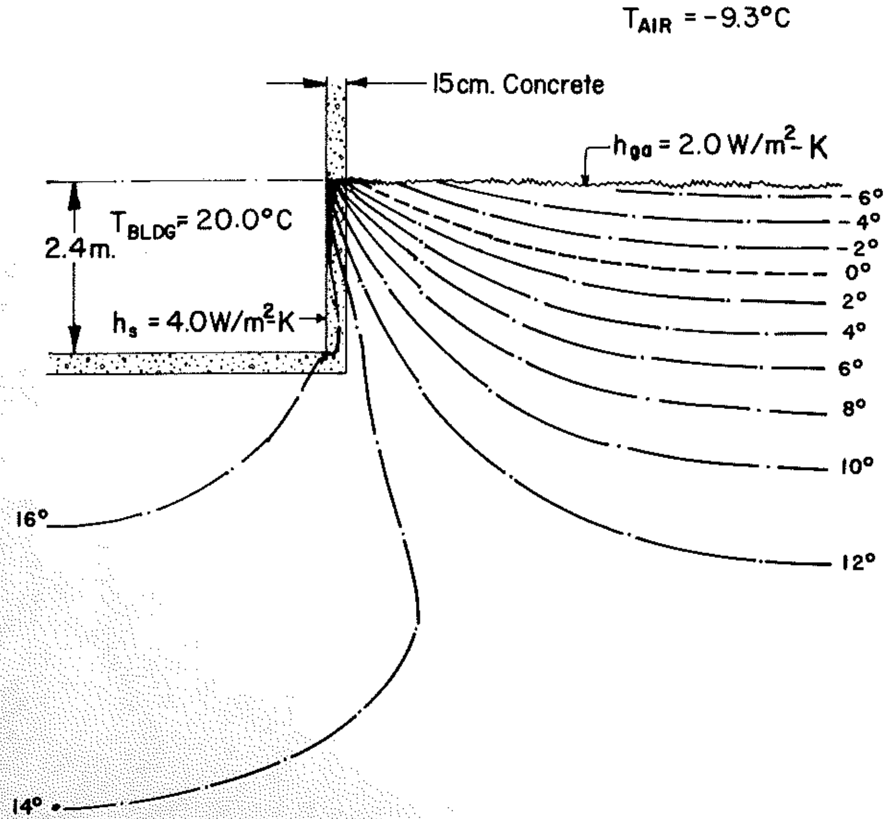
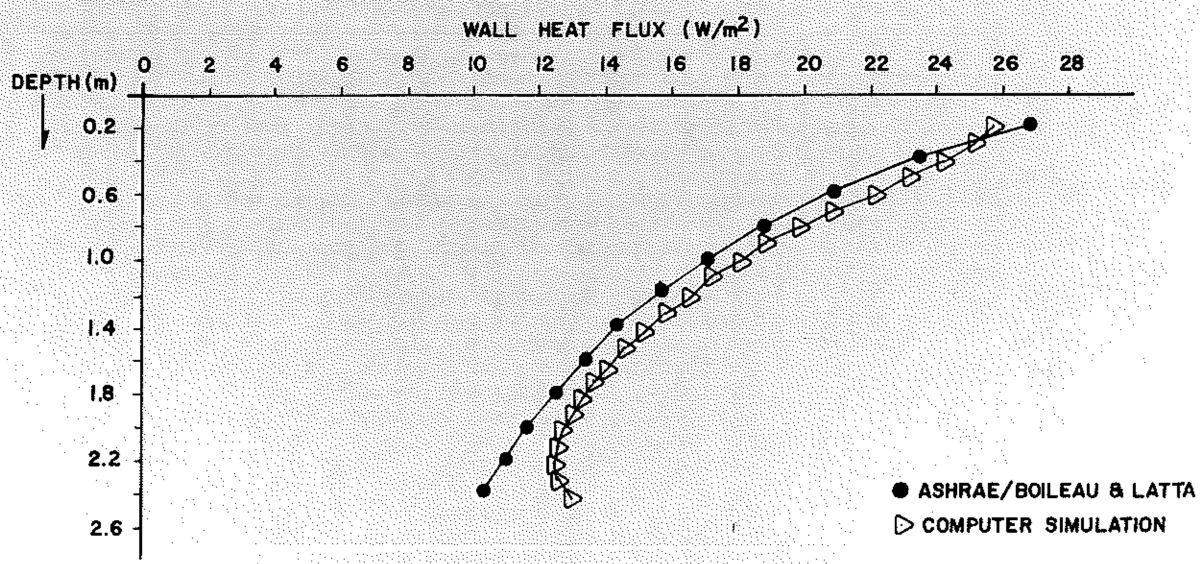


Figure 5a. Computed temperature profiles around an uninsulated basement for typical February conditions in Minneapolis, Minnesota.



5b. The ASHRAE recommended procedure compared to computer predictions for the heat flux profile from an uninsulated basement wall.

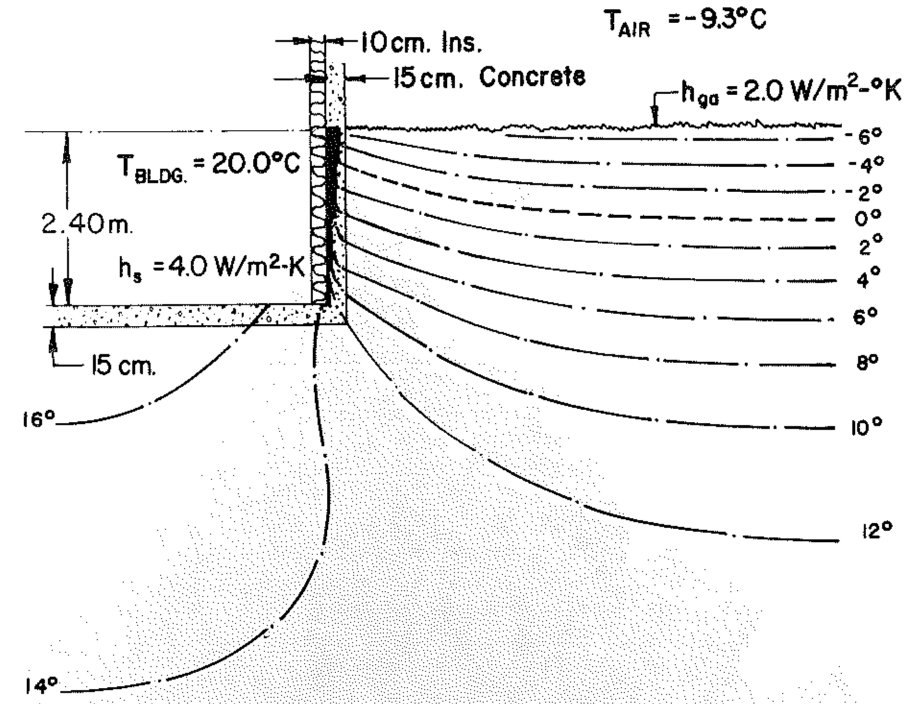
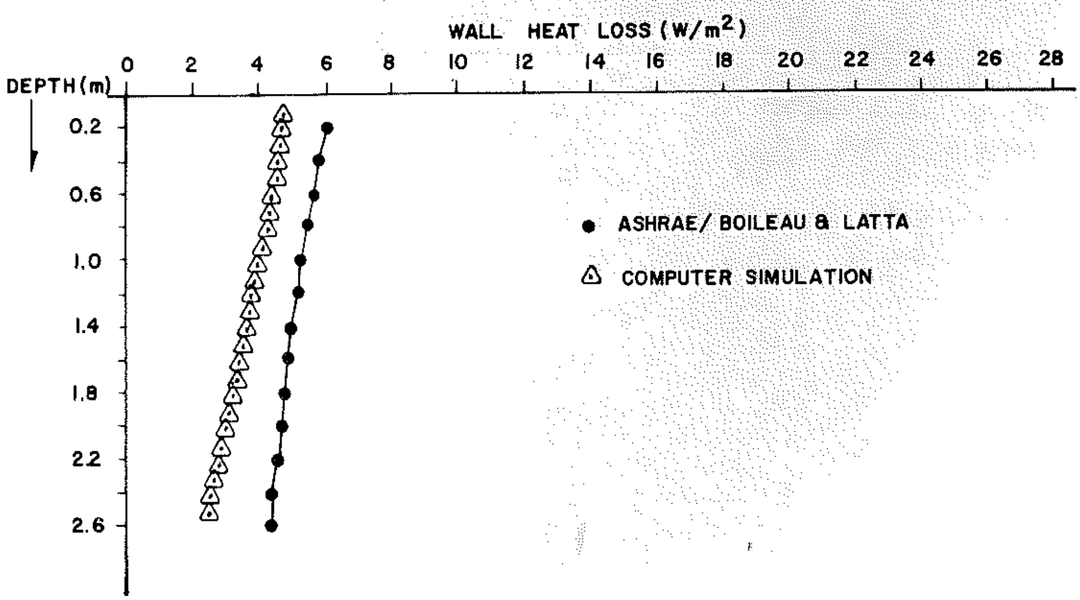


Figure 6a. Computer predicted temperature profiles around a basement wall insulated with 10 cm of rigid insulation (R_{INS}=25), showing the penetration of sub-freezing temperatures into the concrete wall.



6b. The ASHRAE procedure compared to computer-predicted wall heat fluxes.

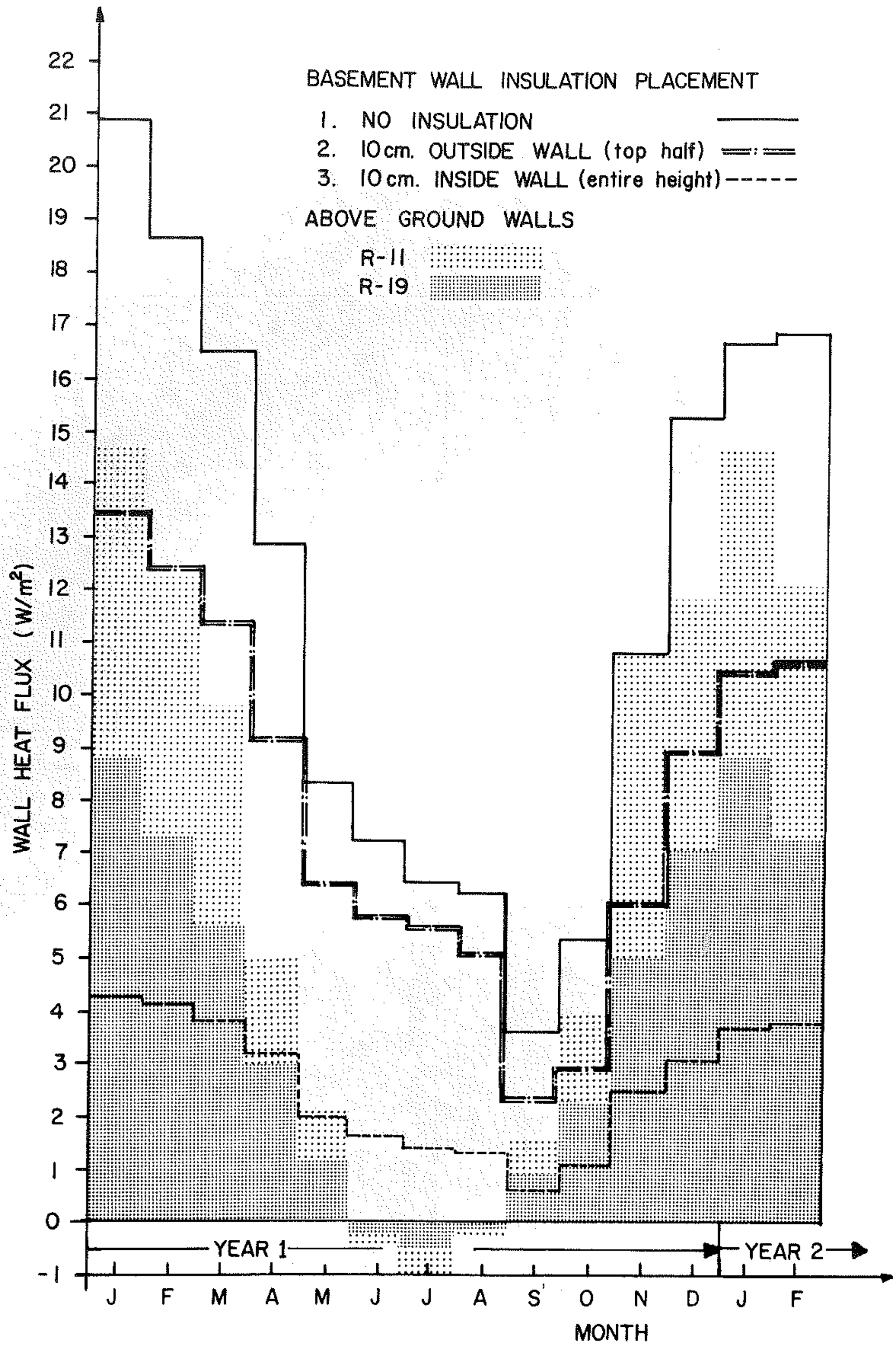


Figure 7. A comparison of computed monthly average wall heat fluxes for aboveground and underground walls during the first year of building operation.

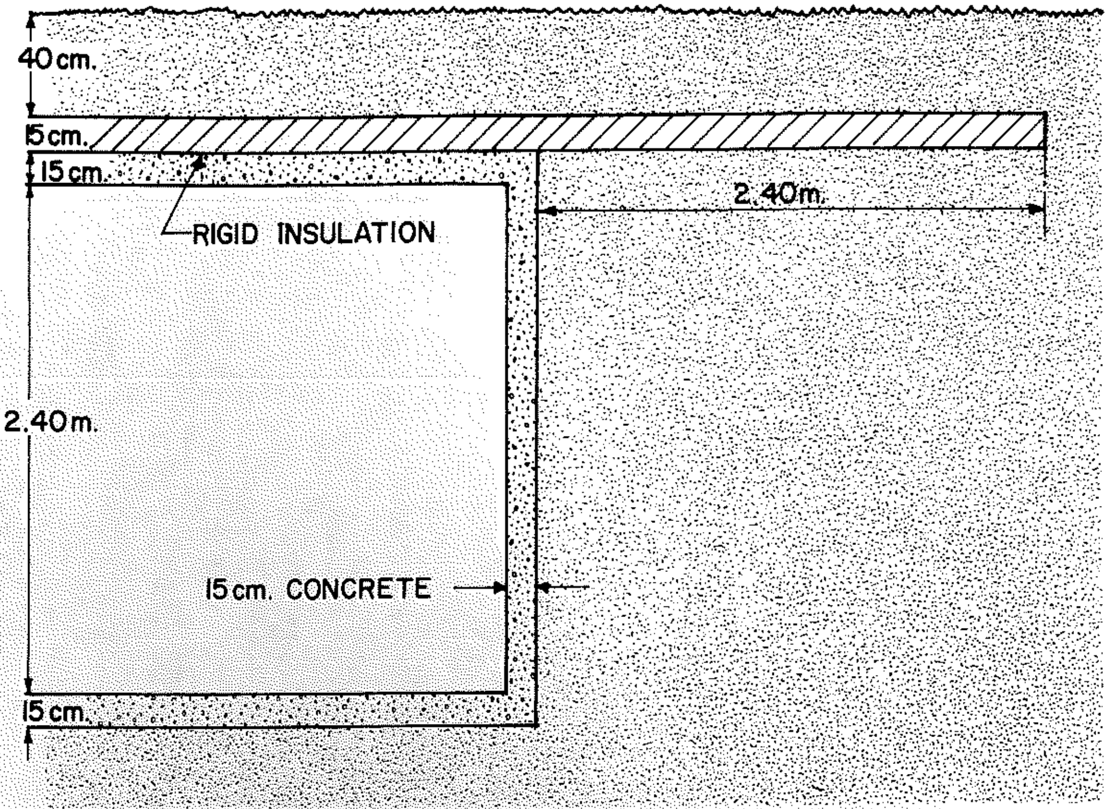
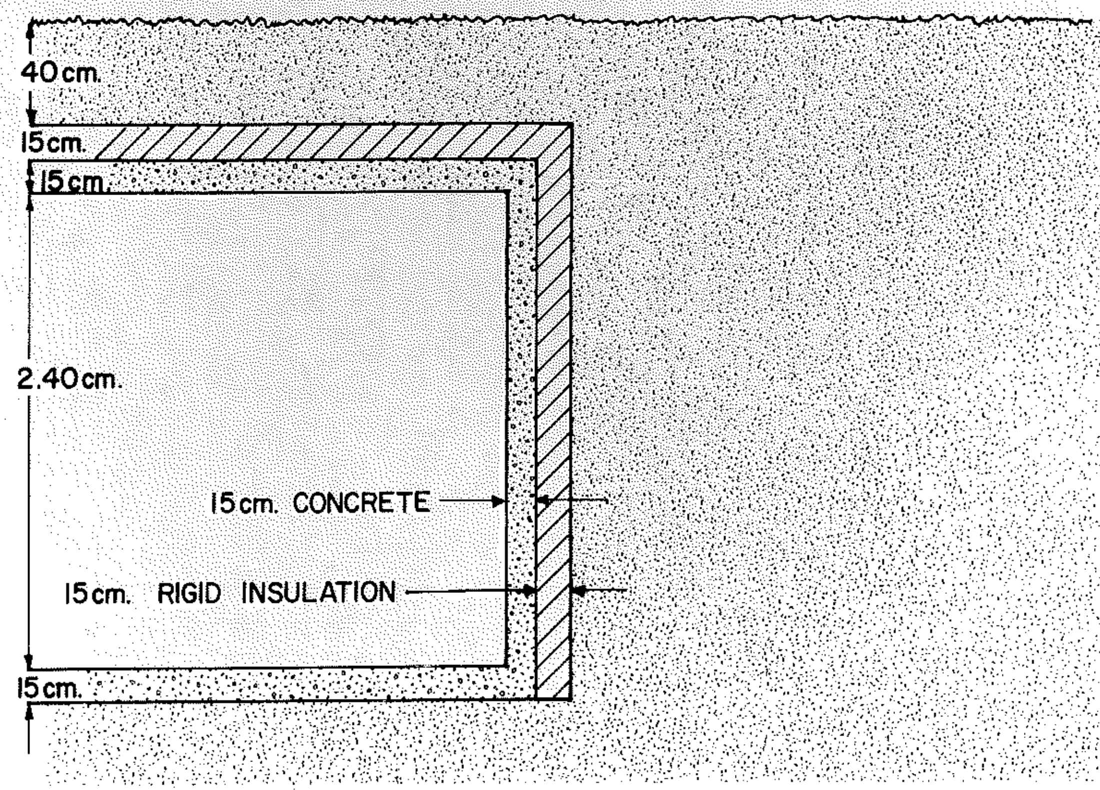
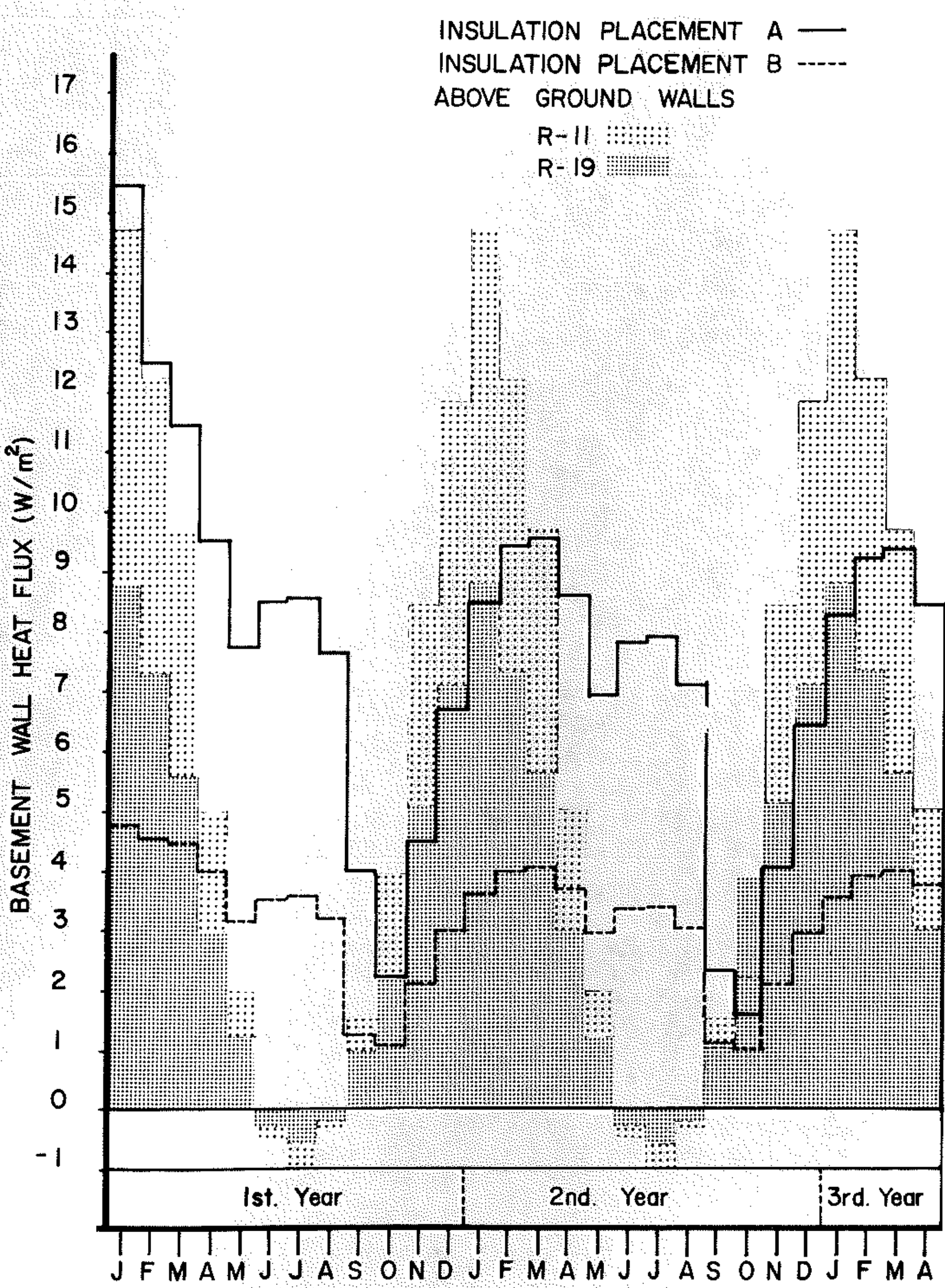


Figure 8a. Schematic elevation showing insulation A placed horizontally out from the roof level of the underground building.



8b. Schematic elevation showing insulation B placed vertically down the outside wall of the underground building.



8c. Computed monthly average wall heat fluxes for insulation placements A and B compared to aboveground R-11 and R-19 walls, for the first 28 months of the building operation.

SESSION X QUESTION AND/OR COMMENT

Rossiter, Weidt, Saxler

a. Paul Lewis, Florida Power Corporation

Q: Any experience with retrofit insulation process of filling core of block with foam product or other type insulation material? If so, resulting R value of this process?

A: None of the houses included in the study had sidewalls consisting of concrete masonry blocks with foam filled cores. Most of the houses were of typical wood-frame construction. One concrete masonry house contained urea-formaldehyde foam which was applied in cavities created by the attachment of gypsum wallboard to the concrete blocks with the use of furring strips.

b. Edwin M. Perrin, RAPCO FOAM, LORCON

Q1: How many of the UF insulated homes were opened for shrinkage measurements?

A1: All twenty-five houses containing urea-formaldehyde based foam insulations were opened with the intent of measuring the shrinkage. However, shrinkage was only measured in seventeen houses. In four houses, gaps and voids were too numerous to allow a shrinkage measurement. In the remaining four houses, the presence of batt insulation precluded a determination of the shrinkage.

Q2: How many of the UF insulated homes had existing batts?

A2: As mentioned in the previous answer, four houses retrofitted with urea-formaldehyde based foam contained batt insulation.

c. Charles A. Campbell, AEROLITE Space Corporation

Q1: What do you attribute the shrinkage range of 4% to 9% to, if the density has no effect on shrinkage?

A1: The field study was not designed to determine the causes of shrinkage of urea-formaldehyde based foam insulations, so we have no answer to your question. In our opinion, factors affecting the shrinkage of these foam insulations are not well understood and need further investigation.

Q2: What was the shrinkage rates of foams that had been applied up against batts already in the wall?

A2: The percent shrinkage of the foam insulations was not measured in those cases where batt insulation was present in the side-walls. The presence of the batt precluded the measurement.

Q3: How much, generally, were the batts compressed where UF foam was applied against batts or how thick was the foam in these cavities?

A3: The question is difficult to answer quantatively, since we did not have available the original thickness of the batt insulation. Qualitatively, the existing batt insulation was compressed slightly in some cases, and considerably in others. The reason for the variation was that the foam insulation both compressed the batt and intermingled with it. The thickness of the foam varied according to the amount applied and the extent of compression of the batt. In some cases, the foam had a thickness of about 3 inches (75mm). Regardless of the extent of batt compression, the cavities were filled with insulation in all cases were batts were present.

Q4: Did you find any evidence of foam adhesion to building cavity components, i.e., studs, plaster board, sheathing board, etc. And, if so, what effect did this have on shrinkage?

A4: We found no evidence of any significant adhesion of foam insulation to these wall components.

Q5: Did you test for flame retardency or fire resistance ability of any of the insulations inspected, and if so, what were the results?

A5: The scope of the field study did not include a determination of the flammability of the insulations.

Klems & Selkowitz

a. H.L. Redfoot, Rohm & Haas

Q1: Can you and/or do you plan to measure daylighting characteristics as well as thermal transfers?

A2: We do not plan to measure daylighting characteristics in the MoWitt. Although it is designed to adequately simulate the thermal environment of a window or skylight in a building, we consider it unlikely that it will be a very realistic simulation of the lighting environment, due to the wall colors, the presence of equipment and the room cavity ratio. We feel that daylighting can better be studies in scale models using an artificial sky facility which we are also constructing.

Q2: What size are the skylight units you plan to test? What % of the roof area do these comprise?

A2: Each chamber can accomodate a skylight up to 4 ft. x 6 ft. (nominal dim). This is 37% of the interior area of the test chamber and about 27% of its roof area. Up to four such skylights can be tested simultaneously.

Sherman

a. Charles A. Campbell, AEROLITE Space Corporation

Q: What is the effect of causing aging due to installation of the board, e.g., holes cut in the board for electrical boxes or smaller cavities, etc. Is the R-factor reduced when the foil-facing cut or punctured during installation? Are the edges sealed to prevent rapid aging, and, if not, what effect does that have on the R-factor?

A: Complete encapsulation with metal over all surfaces, e.g., both major surfaces and four board edges, offers the greatest potential for retaining as-manufactured R-value levels with time. However, conventional construction systems predominantly involve field cut and trim modifications to fit around electrical boxes, duct outlets, doors, windows, roof stacks, drains, hatches and other such penetrations in the wall or roof surface, and make complete encapsulation protection impractical and uneconomical for consideration. The foil-faced boardstock reported in this paper had foil protection <u>only</u> on the two major surfaces; board edges were not foil covered against gas permeation circumstances, yet only 15% reduction in R-value from manufacture to time-aged plateau was experienced. On an affected area basis, incidental cuts and punctures should have very little adverse effect on whole board R-value; large area facer delamination can result in aged R-values equivalent to unfaced slabstock foam.

Tye, Desjarlais, Bourne, Spinney

a. Charles A. Campbell, AEROLITE Space Corporation

Q1: Are you basing the % reduction of Foam R-factor using a mock-up panel that establishes a maximum R-factor for the complete wall assembly or are you using calculations as a baseline? A huge % reduction would be realized from the calculations baseline because the calculations do not agree with the experimentally derived R-factors of wall assemblys.

A1: No response

Q2: Do you think there would be a significant difference in your tests on carefully machined and perfectly cut (dimension-wise) polystyrene from that of In Situ shrunken foam that was not regular but, in fact, will have several cracks and undulated fissures throughout the cavity?

A2: No response

Q3: Is the suspended polystrene foam sample that simulates an air space continum completely surrounding the sample a realistic, real-world approximation? In other words, would a UF foam In Situ installed specimen actually shrink and remain suspended in the center of the cavity?

A3: No response