Thermal Modeling of a Basement with Insulated Walls and Uninsulated Floor

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ABSTRACT

The basement of an unoccupied house in Saskatoon, SK, was fully instrumented to measure heat rates and temperature distributions through and on the insulated walls and uninsulated floor over a period of one year. The measured data were compared to two well-established transient design methods of heat loss calculation and to a two-dimensional finite element model that incorporates internal radiation heat exchange. The results suggested some transient differences between the measured data and predictive models. Radiative heat exchange, not convective heat transfer, was found to be the dominant mode of internal heat exchange. Temperature data on each surface compared well with the numerical model, which included radiative heat transfer between the surfaces. Although condensation on cool inside surfaces was not a problem in the test house, slightly more humid climatic conditions or porous materials inside of the vapor retarder could lead to problems.

INTRODUCTION

Background

Canadians consume more energy on a per capita basis than almost any other country. In the period before the oil embargo of 1973 the Canadian homeowner's response to large home heat losses was to purchase a furnace with a high capacity. Since then, attitudes have shifted from consumption to conservation, with high levels of insulation becoming the standard in Canadian housing construction. Higher levels of insulation above grade have increased the importance of basement heat loss. It has been estimated that basement losses can contribute from 30% to 50% of the total housing heat loss in highly insulated homes (Besant et. al. 1982). It has become increasingly important to be able to accurately predict the magnitude of basement heat loss, but this has been difficult due to the complexity of the heat transfer process for below-grade structures. Basement heat loss is a three-dimensional process with large time delays in response due to the huge thermal mass of the surrounding soil. Steady-state and/or one-dimensional methods of heat loss calculations cannot be applied. While several transient models of basement heat transfer have been developed, they may contain unjustifiable simplifying assumptions. One such assumption is that radiant heat transfer between internal basement surfaces is negligible or can be dealt with by including a linearized radiation term in with the convective heat transfer coefficient. The first approach is unacceptable because, in a model for a basement with insulated walls and floor developed by Richmond and Besant (1985), it was determined that radiation represents a substantial portion of the heat transfer in typical full basements. The second approach to dealing with radiative heat transfer assumes that internal basement surface temperatures are the same as that of the air convecting heat to the surfaces. Direct measurements have shown that air temperature may vary by up to 2°C over the basement height, and temperature differences of several degrees between the basement surfaces also exist. Neglecting the radiative heat transfer also causes an incorrect prediction of surface temperatures in the basement, which is important because of human comfort and water vapor condensation considerations. Basement heat loss calculations, which are directly related to operating cost, are not sufficient if the ultimate aim is to provide comfortable conditions in a healthy environment with reasonable capital and operating costs.

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The general requirements that any acceptable model of basement heat transfer has to satisfy can be summarized as follows:

1. The model must accurately predict heat loss, as this represents the direct cost to the homeowner through increased heating energy consumption.
2. Accurate prediction of the temperatures is required because this is the factor that most affects the human comfort level. Both air temperature and surface temperatures affect this comfort level. Accurate calculation of the surface temperatures is also necessary if problems due to condensation and the resulting mold and mildew (a common problem in most climates) are to be predicted and avoided.
3. The model must be able to allow for variability in material properties, basement geometry, and boundary conditions.
4. Moisture transfer must be included in the heat transfer model if a considerable amount of condensation is occurring, as this would significantly contribute to the heat transfer.

Review of Existing Heat Loss Calculation Methods

Although many papers have been published on the calculation of basement heat losses in houses (Meixel et al. 1980; Swinton and Platts 1981; Kuehn 1982; Akridge and Poulos 1983), there are only a few general design methods. Furthermore, very few papers present measured data. A simplified steady-state design method is presented in ASHRAE (1985). Generally, this method, which can lead to large transient and steady-state errors, should only be used for heat loss estimations. Two more detailed transient methods, which are used later for comparison purposes here, are briefly summarized below. More recently, several researchers have adapted the main features of these models into building energy computer simulation programs (Huang et al. 1988, Shen et al. 1988).

Mitalas. A design method was developed by Mitalas (1983) based upon a two-dimensional finite element model verified with measurements of heat flux from many basements across Canada. These heat loss measurements were made using insulated mimic box calorimeters. This method calculates heat loss through five separate surface areas of the basement: the upper wall, above grade; the middle wall, from grade to 1.97 ft (0.6 m) below grade; the lower wall, from floor to 1.97 ft (0.6 m) below grade; a 3.28 ft (1 m) wide perimeter of the floor; and the remaining floor.

Shape factors are calculated from the thermal resistances of the floor and walls using values from tables for several different insulation strategies and soil conductivities. The shape factors, basement air temperature, outside air temperature, and deep ground temperature are used to calculate the heat losses. Allowances can be made for adjacent homes through corner effect factors.

One inadequacy of this model is its neglect of internal radiant heat transfer. Also, the design method is inflexible in dealing with insulation configurations and soil conductivities other than the 26 variations given. This design method does not predict internal surface temperatures.

Yard. The Yard method (Yard et al. 1984) calculates monthly heat losses through the basement wall and floor surfaces. It was developed using a two-dimensional finite element model and was verified against the Mitalas model. Dimensionless conductances for the walls and floor are obtained using basement dimensions, wall and floor resistances, and soil conductivity values. The effective temperatures of the surrounding soil for the wall and floor heat transfer are calculated using average outdoor air temperature, soil thermal diffusivity, and basement depth. The heat transfer through the surfaces is calculated using the difference between the internal basement temperature and the overall conductances for the walls and floor.

This method has several inadequacies. Radiation heat transfer inside the basement and outdoor solar irradiation are not included. The insulation over the wall or floor is assumed to be continuous and uniform over the entire surface. Variations of the heat flux over the surfaces cannot be obtained from this method. This method, like the Mitalas method, yields no information about surface temperatures within the basement.

Objective

The objective of this paper is to compare experimental data of heat loss rates and temperature distribution from the surfaces of a full basement with calculated values using well-established methods of predicting basement heat losses and temperature distributions.

THERMAL MODELING OF A BASEMENT

Description of the Computer Model

A two-dimensional, radiation-incorporating finite element method (RIFEM) model of the basement and surrounding soil consisting of 330 nodes and 300 elements was used to simulate the basement heat transfer process. Mitalas (1983) has indicated that this is an adequate number of elements for accurate calculations. Symmetry was assumed to exist about the center of the basement so that only half of the basement need be modeled. The RIFEM model includes the concrete basement, the interior wall insulation, and the surrounding soil mass. The finite element layout is shown in Figure 1. The following boundary conditions were specified on the exposed surfaces:

1. Radiant heat transfer between the interior surfaces of the basement was included in this model. Radiant heat is transferred between all the interior surfaces so it was necessary to include the whole interior surface of the basement in the model. The surfaces of the half-basement were reflected across the basement centerline and a ceiling surface was added in the two-dimensional model. The temperature distribution on the reflected surfaces was coupled to their counterparts, thereby maintaining the assumption of temperature symmetry across the basement centerline. The emissivity of all the interior surfaces was assumed to be 0.9.
2. Three meters below the basement floor a constant deep ground temperature of 50.7°F (10.4°C) was imposed. This value was extrapolated from soil temperature measurements taken around the basement.
3. Along the centerline of the basement, adiabatic boundary conditions were specified.
4. The basement heat loss is assumed to have no effect 32.8 ft (10 m) away from the basement wall. An adiabatic boundary condition was used to model this.
5. On the outside ground and exterior wall surfaces, convection to outside air is modeled. Incident solar irradiation is accounted for through use of the sol-air temperature. Snow cover is modeled by decreasing the convective coefficient.
6. On the interior surfaces of the basement, the convection heat transfer coefficient is taken to be constant. The air speeds in the basement were measured to be less than 0.82 ft/s (0.25 m/s). Convection coefficients of 0.44 and 0.26 $Btu/(h.ft^2.F)$ (2.5 and 1.5 $W/(m^2.K)$) were used for the wall and floor due to the extremely low air velocities present. The stratification of the basement air was included in the model by varying the air temperature over the wall. The variation of the air temperature over the basement height was obtained by experimental measurement.

The basement heat loss is a highly time-dependent process with large time lags between outdoor and indoor conditions caused by the large soil mass. For every simulated year, an initial solution for a "thermal charging" period was performed in order to provide "correct" initial conditions for the simulation for the test year. The shortest possible charging period was used to reduce the computation time. The most economical method involved doing an initial steady-state solution of the heat transfer followed by a transient solution of the model of the six months prior to the test year. With the six-month charging period the differences in the calculated fluxes between the beginning and end of the year were less than 2%. The boundary conditions were assumed to be cyclical, with a period of one year.

Experimental Measurements

Description of Test House. Measurements were taken from a single-level, 981 ft^2 (91.2 m^2) unoccupied bungalow located in a residential area of Saskatoon, SK, Canada. The basement was of full concrete construction with 8 in. (.203 m) thick walls and a 4 in. (.102 m) thick floor. The walls were 7.68 ft (2.34 m) high. The basement was thermally isolated from the main level of the house by a vapor retarder and insulating the basement ceiling with R12 (RSI 2.11) fiberglass batting. The entrance to the basement, the furnace, and the hot water heater were enclosed in a vapor retarder and insulated to R12 (RSI 2.11) with fiberglass batting. The basement was heated with an electric heater and its power consumption was measured with a power meter. The house was oriented in a north-south direction with houses located 15 ft (4.57 m) away to the east and 25 ft (7.62 m) away in the west direction. Houses to the north and south were more than 100 ft (30 m) away and therefore would not interact with the house thermally.

In late September 1987, the basement walls were insulated over their entire height to a level of R20 (RSI 3.52). The insulating material used varied from wall to wall. The north wall was insulated with semi-rigid, paper-backed fiberglass insulation. The west and south walls used expanded polystyrene boards, while the east wall was insulated using 2 in. by 4 in. (51 mm by 102 mm) wood stud framing with fiberglass insulation batting between the studs. The insulation was covered on each wall with a vapor retarder and 0.5 in. (13 mm) gypsum board. The basement floor remained uninsulated.

Types of Measurements Taken. The basement was assumed to be thermally symmetric about its north-south centerline in order to simplify the modeling, as this would mean that an accurate representation of the basement heat loss could be obtained by taking measurements from only half of the basement. The direction of the assumed axis of symmetry was chosen as north-south because it was felt that the differences between the east and west halves of the basement would be less than the north-south differences due to such factors as solar irradiation. The west side of the basement was chosen as the one to be instrumented for two reasons. The adjacent house to the east was much closer to the test house than the one on the west side. These adjacent houses may affect the heat loss process and it was felt that the west house was a more representative distance away than the abnormally close east house. The second reason was that the furnace/water heater room was located on the east side. This would complicate the modeling of the heat loss.

The basement heat loss process was monitored using 136 t-type thermocouples and 19 light gauge heat flux sensors. The types of measurements taken can be summarized as follows:

1. Temperature measurements were taken over the wall, floor, and ceiling surfaces.
2. The temperature of the concrete wall surface was measured and, along with the inside surface temperatures, was used to calculate the measured heat flux through the wall.
3. Air temperatures were monitored over the entire basement height.
4. Heat losses though the floor were measured directly with heat flux sensors.
5. Soil temperature distributions outside the west wall were measured.

All the indoor sensors were monitored using a microcomputer-based data acquisition system. Measurements were taken continuously and average values for each hour were written to computer diskette. The outdoor soil temperatures were measured manually every two weeks. Data were collected for one year, from January 1 to December 31, 1988.

The computer thermal model of the basement required that a number of boundary conditions be known. Whenever possible, actual measurements from the house were used in the model. These measured boundary conditions include the deep ground temperature, basement air temperatures and ceiling temperature.

Soil Properties Measurement. Soil samples were collected from the test house in September 1988. The samples were taken at three locations: 5 ft (1.5 m), 10 ft (3 m), and 20 ft (6 m) away from the house at depths down to 6.6 ft (2.0 m) using a hand auger. The samples were analyzed for water, air, and solid particle content as well as density. These values were used to calculate the soil thermal conductivity in the unfrozen and frozen states using the method developed by Johansen (1975). The calculated values were used in the computer model, with the frozen values assigned to the soil when the individual element's temperature was below $0^{\circ}C$ and the unfrozen values were used otherwise. The heat produced or, consumed during phase change was modeled by including the heat of fusion as a spike in the soils specific heat vs. temperature curve located around $0^{\circ}C$. Studies have shown that the actual soil conductivities may differ by up to 25% from predicted values (Farouki 1981). Additional uncertainty in the calculated soil conductivity arises due to possible errors in the measurement of the saturation ratio of the soil. The soil collection method may have caused an increase in the saturation ratio (the ratio of actual water content to the maximum possible content) due to soil compaction. Also, the samples were collected after a month of high rainfall and the measured water content and saturation may not be representative of average values for the year. The calculated conductivities and specific heat for the measured saturation ratio of 70% are presented in Table 1 along with the calculated soil properties for a more reasonable saturation ratio of 50% and an average of the two calculated values. Values obtained from Jumikis (1977) for the soil at a saturation of 65% are also given in the table. The Johansen average properties, presented in Table 1, were used in the computer model.

Results

Heat Loss Predictions. The heat loss was measured over the north, west, and south walls and over the west half of the basement floor. The floor heat loss measurements varied by up to 0.6 Btu/(h.ft^2) (2 W/m^2) over the entire surface, and a variation of up to 0.3 Btu/(h.ft^2) (1 W/m^2) in the measured wall heat flux was observed. Heat loss from the basement was calculated by the RIFEM model. The Mitalas and Yard models were also used to calculate the basement heat loss. These calculated results are compared with the average measurements of heat flux over each surface in Figures 2 and 3. In Figure 2a the predicted heat losses over the entire floor calculated by the RIFEM and Yard models show good agreement with the measurements. It can also be seen that the Mitalas calculation appears to be under-reactive to dynamic conditions within the basement and the large variations in the measured heat loss over the year are not predicted accurately with this method. The measured heat loss shows a sharp increase between August and September (Julian days 220 to 260) but this phenomenon is mirrored only in the RIFEM model. In Figures 2b and 2c the heat losses through the separate central and perimeter sections of the floor are examined. Once again, the RIFEM model shows reasonable agreement with the measurements. The Mitalas model overestimates the central losses while underestimating the maximum perimeter losses.

Figure 3a shows that all three models predict the wall heat losses over the wall reasonably well although the Yard and Mitalas models tend to slightly overestimate the loss. The RIFEM model predicts the winter loss better than the other models but it underestimates the losses in summer. A similar comparison between the RIFEM and Mitalas models can be seen in Figures 3b, c, and d.

A summary of the measured and calculated yearly average basement heat loss rate is presented in Table 2. It is noted that the Mitalas model leads to large errors compared to the RIFEM and Yard models.

A comparison of the yearly average measured and computed heat rates through the separate floor and wall sections is presented in Tables 3 and 4. Again, the Mitalas model has significant errors compared to the other two models.

Comparison of Convection and Radiation. The individual contributions of radiation and convection to the total heat loss through the floor and walls were calculated by the RIFEM model and are presented in Figures 4 and 5. Figure 4 shows that both convection and radiation are, on average, equally important in the heat transfer process through the wall area, with radiation predominant in the winter and and convection being the major mode of heat transfer in summer. Figure 5 shows that almost all of the heat being transferred to the floor is by radiation and negligible heat is transferred from the basement air to the floor through convection. The importance of radiation can also be observed in the test measurements. If the temperatures over the wall, ceiling, and central floor surfaces are assumed to be uniform, the heat transferred to the floor through radiation can be approximated as:

$$q_{rad} = \varepsilon\sigma[F_{c-f}(T_c^4 - T_f^4) + F_{w-f}(T_w^4 - T_f^4)] \qquad (1)$$

where q_{rad} is the heat per unit area radiated to the floor; ε is the surface emissivity; σ is the Stefan-Boltzman constant, $0.1714 * 10^{-8}$ Btu/(h*ft^2*R^4) ($5.67 * 10^{-8}$ W/(m^2*K^4)); F_{c-f} and F_{w-f} are the radiation view factors from the ceiling and wall surfaces to the floor; and T_f, T_c, and T_w are the average absolute temperatures of the floor, ceiling, and wall surfaces, respectively.

Values of 0.67 and 0.33 were used for F_{c-f} and F_{w-f} for the 42 by 26 by 6.9 ft (12.8 by 7.9 by 2.1 m) basement interior. The emissivities of all the surfaces were assumed to be 0.9. Figure 6 shows the approximation of the radiated heat calculated from Equation 1 and the total heat loss through the central area of the floor. Although the calculated radiation is only a rough approximation due to neglecting the temperature variations over the surfaces, it can be clearly seen that the radiation heat transfer is most significant.

Temperature Predictions. The temperatures predicted by the RIFEM model are compared with the measurements taken over the surfaces in Figures 7 and 8. There is good agreement between the two except for the first few months of the simulation. This can be attributed to the fact that the boundary conditions input to the model are assumed to be cyclical over the year, but the conditions preceding the test year were not exactly the same as the end of the year, which was taken to be the assumed initial condition in the RIFEM model.

DISCUSSION

Comparison of the RIFEM model with experimental measurements shows that the model apparently predicts the heat loss and temperature conditions in the basement. The Mitalas model appears to be unable to deal with large changes in basement conditions and was not as accurate as the other methods in predicting the heat loss from the basement. The Yard model was more responsive than the Mitalas model and provided accurate predictions of the heat loss. The only exception to this occurred between August and September, when a sharp increase in the measured heat loss was not indicated by the Yard model. Since the RIFEM model was the only model that also showed this increase it can be deduced that there is some important factor included in the RIFEM model that is neglected in the others. This factor may have been the inclusion of radiation into the RIFEM model. The importance of radiative heat transfer was confirmed when the individual contributions of convection and radiation to the total heat transfer in the RIFEM model were examined. The RIFEM model suggests that radiation can play a substantial role in the wall heat transfer process and that heat transfer to the floor surface may be almost entirely from radiation. This claim is given substance by the calculation of the apparent radiation heat transfer to the central floor area using the measured surface temperatures. The calculated radiation was virtually the same as the total measured heat loss through the floor. If radiation is a major factor in the basement, then, due to the lower temperatures on the floor compared to the wall, radiative transfer between the wall and floor surfaces will tend to decrease the wall temperature and conditions leading to water vapor condensation problems may be created. Thermal modeling done without considering radiation transfer will not be able to predict this problem. Radiation to the floor is from ceiling and wall surfaces, with the major source being from the ceiling surface because of its higher temperature and larger radiation view factor to the floor. The stratification of the basement air means that the ceiling typically will be warmer than the air near the floor. Through radiation, it is possible for the floor to be warmer than the adjacent air. The inclusion of radiation would affect predictions for human comfort levels due to the altered surface temperatures.

The measured temperature results also suggest that a potential problem with condensation may exist if humidities were higher or if porous insulating materials were placed on the surfaces. Surface temperatures between 59^{o} and 73^{o}F (15^{o} and 23^{o}C), were observed. These measured temperatures were often below the 5% design wet-bulb temperature of 67^{o}F (19^{o}C) for Saskatoon. In more humid climates the problem of surface temperatures below the dew point could be acute and the heat transfer due to condensation would have to be included in any model. Furthermore, the measured floor temperatures would not be comfortable for most people without well-insulated footwear. This is in spite of the fact that the measured ceiling temperatures would not likely lead to uncomfortable operative temperatures in the space.

In the RIFEM model, it was assumed that the convective coefficients for the floor and wall surfaces were small due to low air velocities (1.5 and 2.5 W/(m^{2}.^{o}C), respectively). While this may have unjustly exaggerated the importance of radiation in the total heat transfer, it can be seen from the close agreement of the temperature results that this assumption did not substantially affect the results. The RIFEM model used measured basement air temperatures in calculating the convective heat transfer to the floor and wall. The model predictions of temperature distributions on these surfaces were always within 1.8^{o}F (1^{o}C) of the measured temperatures, so the predicted temperature difference between the air and the surface also closely simulates actual conditions. Because this predicted temperature difference for the floor surface and air is so small the use of a larger convective coefficient would scarcely affect the relative importance of the two modes of heat transfer, and radiation would still be predominant over convection.

SUMMARY AND RECOMMENDATIONS

Temperature and heat flux data on and through the basement walls and floor of a house in Saskatoon, SK, were taken over one year (1988). The heat flux data were compared to the transient design methods of Mitalas and Yard and a two-dimensional finite element model. Discrepancies between the data and these models are discussed and results generally agree with the finite element method for both heat flux and surface temperature distribution. Radiation may be the major mode of internal heat transfer in the finite element model but not in the other two models. Heat transfer to the basement floor appears to be almost entirely through radiation. For this reason, models of basement heat loss should include radiative heat transfer and the importance of the ceiling temperature should be included in the design methods. Incorrectly modeled basement heat transfer processes will lead to errors in the calculation of heat rates and interior basement temperatures, which could result in problems with human comfort levels and water vapor condensation on cold surfaces. The finite element model was also used to predict the wall and floor temperatures in the instrumented basement. The measured and predicted temperature distributions appear to confirm radiation as the main mode of internal heat exchange. The measured temperatures suggest that condensation could occur on the wall and floor surfaces if the relative humidities were slightly higher than those in the test house or if porous insulating materials were placed on these surfaces. The vapor retarder should be the innermost surface in all cases.

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TABLE 1a
Soil Properties Predicted for the Test House, I-P Units

Method	k_{thaw} Btu/(h·ft·F)	k_{froz} Btu/(h·ft·F)	$c_{p,thaw}$ Btu/(lb·F)	$c_{p,froz}$ Btu/(lb·F)
Johansen 70% SR	0.81	1.20	0.36	0.26
Johansen 50% SR	0.62	0.73	0.31	0.24
Johansen ave.	0.72	0.96	0.33	0.25
Jumikis	0.71	0.99	0.39	0.26

TABLE 1b
Soil Properties Predicted for the Test House, SI Units

Method	k_{thaw} W/(m·K)	k_{froz} W/(m·K)	$c_{p,thaw}$ J/(kg·K)	$c_{p,froz}$ J/(kg·K)
Johansen 70% SR	1.40	2.07	1510	1100
Johansen 50% SR	1.07	1.27	1280	1020
Johansen ave.	1.24	1.67	1400	1060
Jumikis	1.23	1.72	1620	1100

TABLE 2
A Comparison of the Yearly Average Total Measured and Predicted Heat Loss Rate per Unit Area

Method	Floor Total Btu/(h·ft^2) [W/m^2]	Wall Total Btu/(h·ft^2) [W/m^2]	Basement Total Btu/(h·ft^2) [W/m^2]
Measured	1.64 [5.18]	0.75 [2.38]	2.38 [7.56]
RIFEM	1.59 [5.02]	0.79 [2.50]	2.38 [7.56]
Mitalas	2.38 [7.51]	1.02 [3.20]	3.40 [10.71]
Yard	1.64 [5.16]	0.93 [2.93]	2.57 [8.08]

TABLE 3
A Comparison of the Yearly Average Measured and Predicted Unit Heat Loss Rate Through Basement Floor Sections

Method	Total Area Btu/(h·ft^2) [W/m^2]	Central Area Btu/(h·ft^2) [W/m^2]	Perimeter Area Btu/(h·ft^2) [W/m^2]
Measured	1.64 [5.18]	1.28 [4.03]	2.38 [7.39]
RIFEM	1.59 [5.02]	1.42 [4.48]	2.23 [7.03]
Mitalas	2.38 [7.51]	1.52 [4.77]	3.78 [11.91]
Yard	1.64 [5.16]		

TABLE 4
A Comparison of the Yearly Average Measured and Predicted Unit Heat Loss Rate Through Basement Wall Sections

Method	Total Area Btu/(h·ft^2) [W/m^2]	Lower Area Btu/(h·ft^2) [W/m^2]	Middle Area Btu/(h·ft^2) [W/m^2]	Upper Area Btu/(h·ft^2) [W/m^2]
Measured	0.75 [2.38]	0.63 [1.98]	0.87 [2.73]	0.94 [2.97]
RIFEM	0.79 [2.50]	0.60 [1.88]	0.84 [2.66]	1.24 [3.90]
Mitalas	1.02 [3.20]	0.85 [2.68]	1.09 [3.43]	1.33 [4.19]
Yard	0.93 [2.93]			

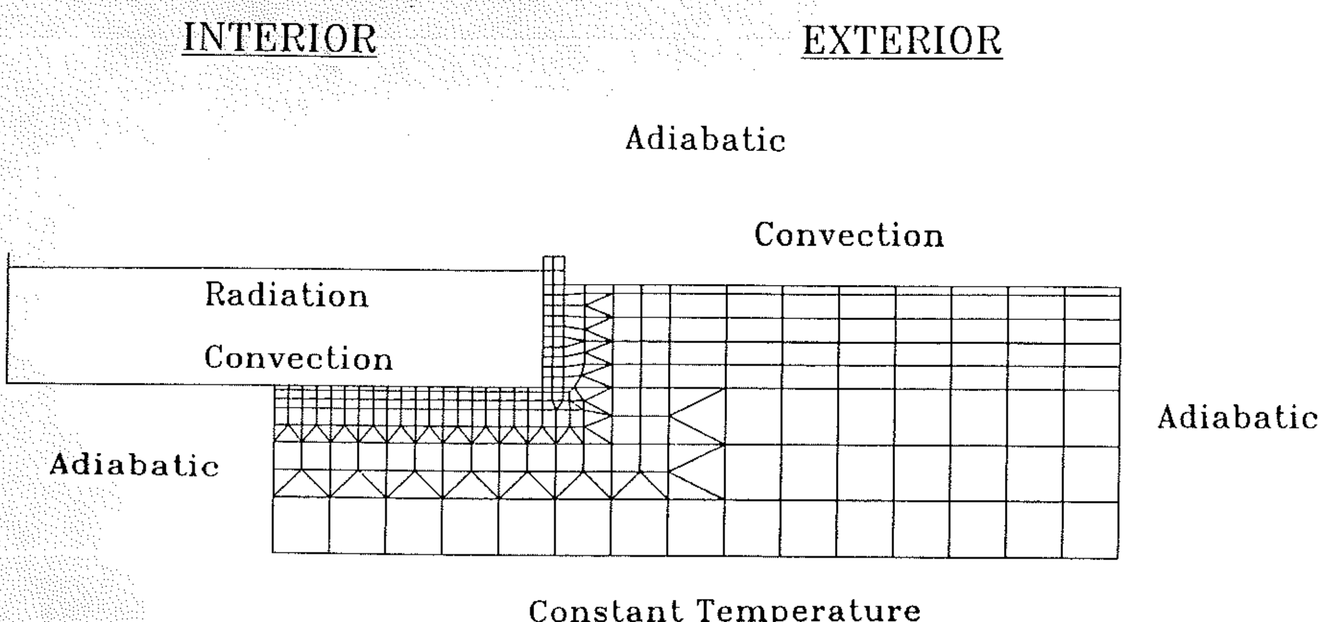

Figure 1. Schematic representation of the element layout and boundary conditions used in the radiation incorporating finite element model (RIFEM)

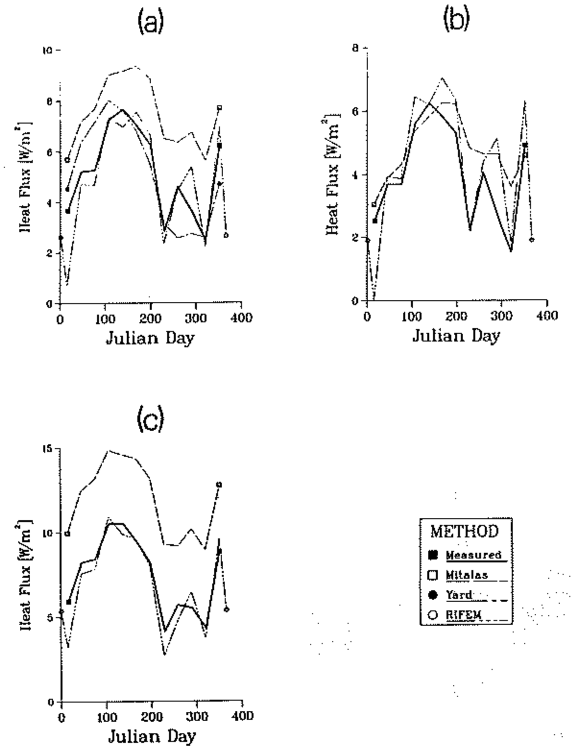

Figure 2. *A comparison of measured and modelled heat loss through the basement floor: (a) total floor average; (b) through the central floor area; and (c) through the 3.28 ft. (1 m) wide perimeter area*

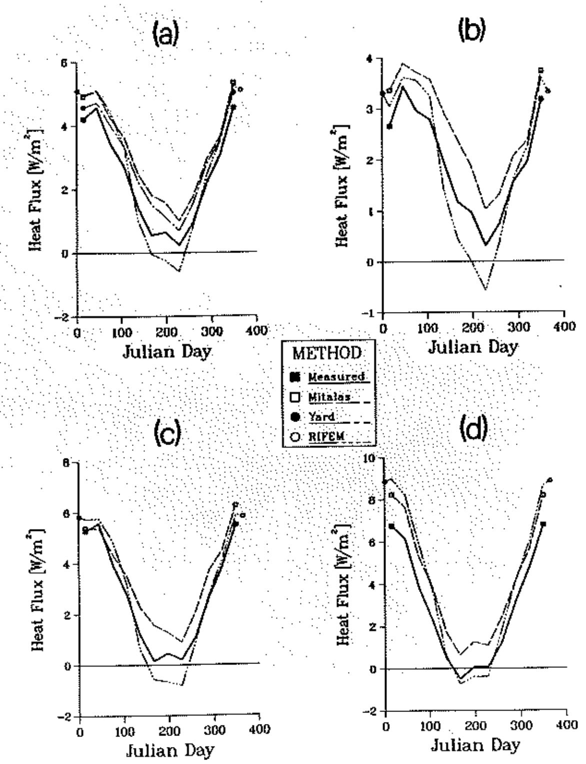

Figure 3. *A comparison of measured and modelled heat loss through the basement wall: (a) total wall average; (b) through the lower wall area, from the floor to 1.97 ft. (0.6 m) below grade; (c) through the middle wall area, from grade to 1.97 ft. (0.6 m) below grade; and (d) through the above grade section of the wall*

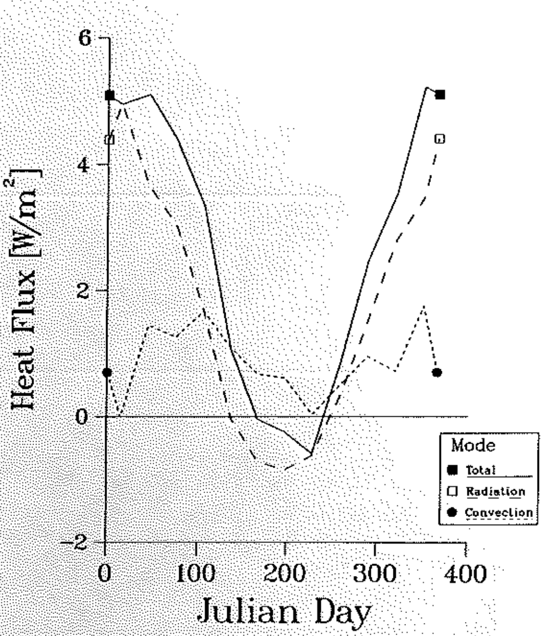

Figure 4. *Calculated total, convective and radiative heat rate exchange at the surface of the wall*

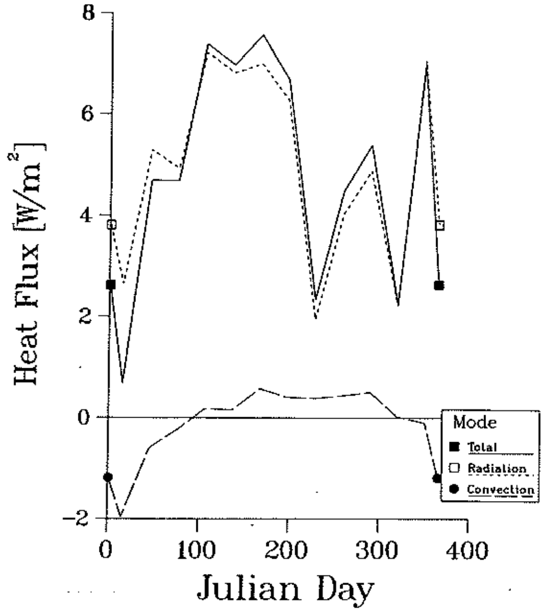

Figure 5. *Calculated total, convective and radiative heat rate exchange at the surface of the floor*

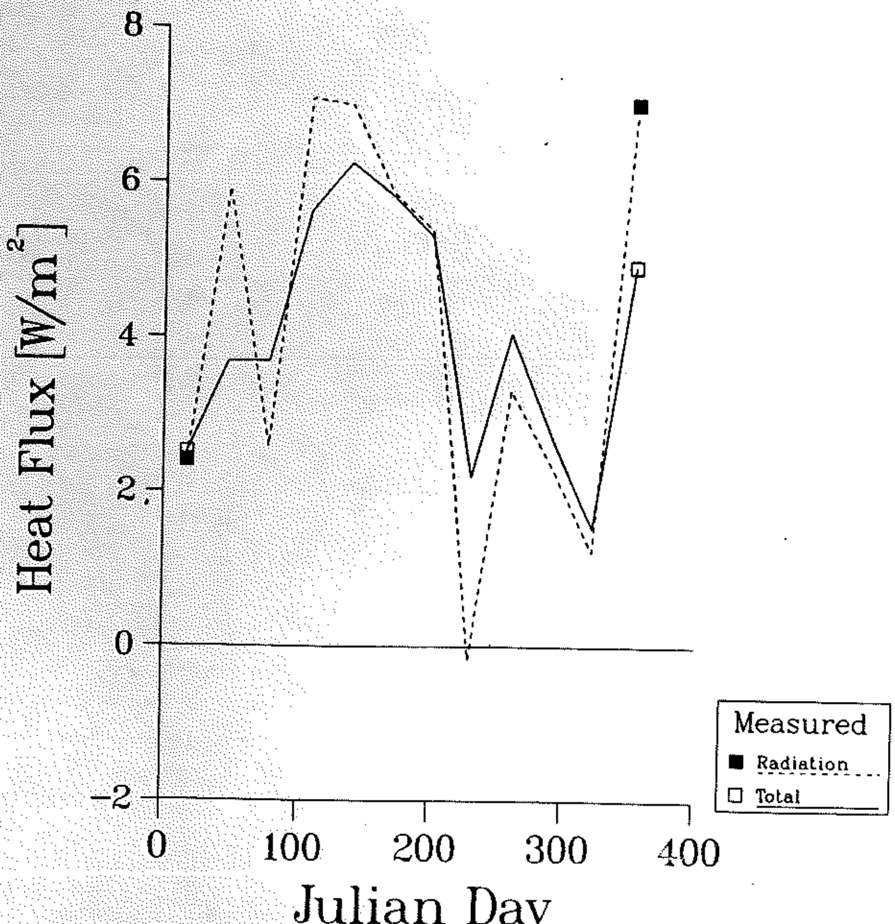

Figure 6. *A comparison of measured total heat rate to the basement floor and the calculated radiative heat rate using only the measured average surface temperatures of the ceiling and walls*

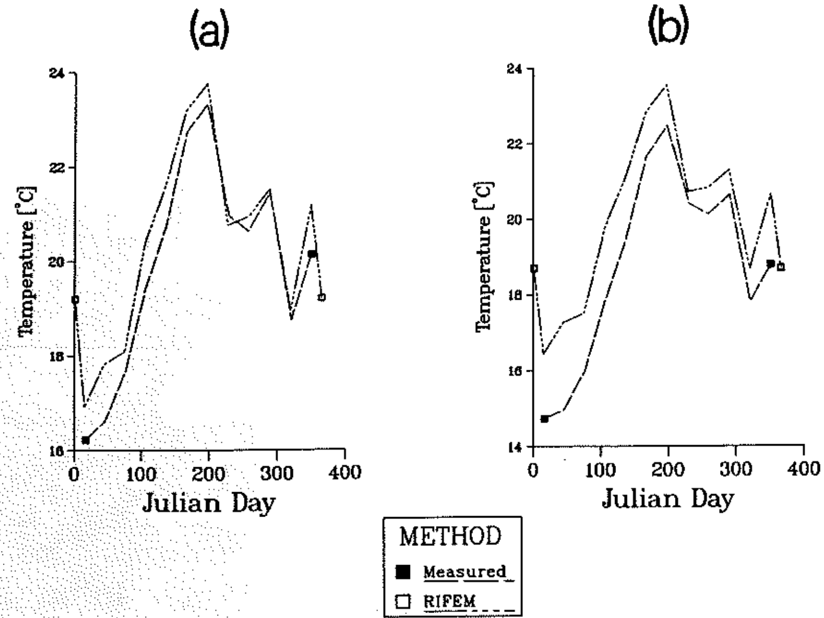

Figure 7. A comparison of the measured and computed temperatures on the basement floor; (a) for the central floor area; and (b) for the floor perimeter area 3.28 ft. (1 m) wide

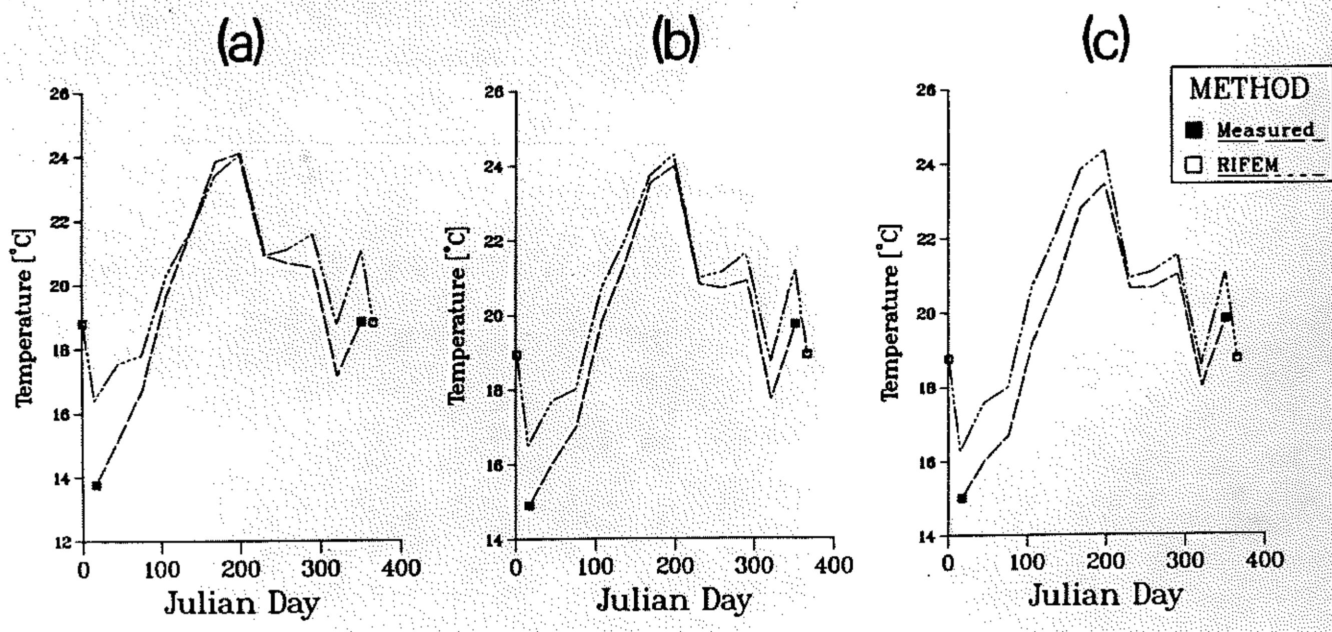

Figure 8. A comparison of the measured and computed temperatures on the interior basement wall: (a) for the lower wall section, from the floor to 1.97 ft. (0.6 m) below grade; (b) on the middle wall section, from grade to 1.97 ft. (0.6 m) below grade; and (c) on the upper wall section above grade