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by G.P. Mitalas

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ABSTRACT

A simplified calculation method has been developed for predicting:

1) maximum rate of heat loss from a basement

2) the basement total heat loss over the heating season

This method differs from previous ones mainly because it recognizes the annual variation of basement heat loss as a significant component of the total basement heat loss. The development of the method is based on both experimental and analytical studies of basement heat loss. The essential data needed to calculate the basement heat loss are the steady-state and periodic shape factors, the amplitude attenuation factor and the time-lag factor and ground surface temperatures. The basement heat loss factors for several insulation systems as well as the ground temperature data for several locations in Canada are listed in the paper. A comparison of the calculated and measured basement heat loss values indicate that the method is capable of reasonably accurate prediction of basement heat loss.

LES ÉTUDES DE LA DRB/CNRC SUR LES PERTES DE CHALEUR PAR LES SOUS-SOLS par G.P. Mitalas

RÉSUMÉ

Une méthode de calcul simplifiée a été mise au point en vue de prévoir:

1) le taux maximal de déperdition de chaleur par le sous-sol;

2) le total des pertes de chaleur par le sous-sol durant la période de chauffage.

Cette méthode est le résultat d'études expérimentales et analytiques. Elle diffère des autres en ce qu'elle considère les variations annuelles de pertes de chaleur comme un élément significatif des pertes totales de chaleur. Les données nécessaires aux calculs des pertes de chaleur par les sous-sols sont le facteur de régime permanent et le facteur périodique de forme, les facteurs d'atténuation d'amplitude et de temps mort, et les températures superficielles du sol. Les facteurs de pertes de chaleur de plusieurs méthodes d'isolation, ainsi que les données relatives à la température du sol de plusieurs endroits au Canada sont présentés dans le document. Une comparaison entre les pertes de chaleur calculées et mesurées indique que cette méthode permet de prévoir avec une précision raisonnable les pertes de chaleur par les sous-sols.

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(All dimensions used in this paper are in SI units except if noted otherwise.)

NOMENCLATURE

A_n	area of segment n
a_n, b_n, c_n, and d_n	constants that are specific to the basement thermal insulation system
C_n	corner allowance factors
D	height of basement wall above grade
E(t)	experimental energy consumption
G	basement perimeter
H	total height of basement wall
k lower and k upper	soil thermal conductivity
L	basement length
M	height of insulation coverage over wall
m	month number (1 to 12)
N	number of segments constituting interior surface area of below-grade portion of the basement
P(t)	instantaneous heat supplied to the basement or calorimeter (power)
Q_T	annual basement heat loss
Q(t)	heat loss from the below-grade portion of the basement
Q_W	below-grade basement heat loss for winter period
$q_{a,n}$	annual mean value of $q_n(t)$
$q_n(t)$	average heat flux through the segment area, A_n, at time t

$q_{v,n}$	amplitude of the first harmonic of the heat flux variation
$q_{v,n}(t)$	variable component of the average heat flux through the segment, A_n, at time t
R	thermal resistance of basement insulation
R_T	over-all thermal resistance of basement wall above grade level
S_n	shape factor the steady-state heat loss component
$S_n(R)$	steady-state shape factors for a basement insulated to a thermal resistance, R
t	time
U	over-all thermal conductance of basement wall above grade level, $1/R_T$
V_n	shape factor for the periodic heat loss component
$V_n(R)$	steady-state and periodic shape factors for a basement insulated to a thermal resistance, R
W	basement width
X_n	corner allowance
Y and Y_o	coefficients determined by a straight line fit to the measured energy data over winter period
Z_0, Z_1, Z_2 and Z_3	coefficients determined by "least squares" fit of Eq. (8) to measured data

Subscripts

a	denotes steady-state component
n	denotes the segment of the interior surface of below-grade portion of basement
v	denotes variable component
m	month number (1 to 12)

Greek Symbols

α	time lag of power wave
δt	time interval between kWh meter readings

Δt_n	time lag of the heat flux harmonic relative to surface temperature variation
θ_B	basement space air temperature
θ_G	ground surface temperature averaged over both time and area, which equals mean ground temperature
$\theta_{o,m}$	monthly value of outdoor air temperature
$\theta_o(t)$	outdoor air temperature as function of time
θ_v	amplitude of the first harmonic of the ground surface temperature
σ_n	amplitude attenuation factor
ω	angular velocity of the first harmonic of the annual cycle

BASEMENT HEAT LOSS STUDIES AT DBR/NRC

by

G.P. Mitalas

INTRODUCTION

One area of uncertainty in the methods for calculating energy needs for heating is the prediction of basement heat loss. The methods used to calculate this loss are not sufficiently sensitive to be able to distinguish between different insulation methods or types, e.g., area of basement covered with insulation and thickness of insulation. This deficiency is especially important today when houses are constructed with more insulation, better fitting windows and a greater degree of airtightness. As the basement has become a major component of the total house heating requirement, there is need of an accurate method to predict basement heat loss so that designers and regulatory officials can make well-informed decisions regarding basement insulation.

To satisfy this need, a house basement study was initiated at the NRC Division of Building Research consisting of both an experimental and an analytical component. The objective of the study was to develop a simple calculation procedure for predicting basement heat loss in order to determine, for any given situation,

(1) the maximum rate of heat loss from a basement, and

(2) the total heat loss from a basement over the heating season.

The basement heat loss problem has been studied by many investigators. Of more than 30 papers on this subject, the most relevant are listed as References (1) to (11). Numerous calculation methods have been developed and used. Many of these treat basement heat loss as a two-dimensional steady-state heat conduction problem and have solved it by paper analogue, finite-difference and finite-element calculation methods.

The paper by F.C. Houghten et al (1) was cited for many years as the source of the basement heat loss factors given in the ASHRAE Handbook of Fundamentals (2). It describes a detailed experimental study of basement heat loss and temperature conducted on one basement. A question has always existed as to the applicability of the experimental results from one basement to other situations.

The paper by G.G. Boileau and J.K. Latta (3) describes a novel approach for deriving house basement heat loss factors. The heat flow paths around the basement are assumed to be circular and the length of these paths used to estimate the basement heat loss factors. Unfortunately, heat flow paths are not necessarily circular for all insulation arrangements.

Any review of basement heat loss must acknowledge pertinent Swedish studies (4). They recognized the significance of below-grade heat loss in the total house heat balance and carried out studies to assess the effect of insulating below ground level. Although the Swedish analytical studies are based on steady-state heat conduction models, their reports contain a great deal of useful information on basement insulation.

The paper by M.C. Swinton and R.E. Platts (5) follows an approach based on correlating experimentally determined basement heat loss with "degree days" for different levels of insulation. This is a questionable approach since the correlation of ground temperature and number of "degree days" has not been established.

The method in this paper differs from the previous ones in two major respects: it recognizes the variation of basement heat loss during the year as a significant factor in the house heat balance and utilizes analytical as well as experimental data to develop a proposed calculation method and to establish the significant factors involved in the calculation of basement heat loss.

This paper on the DBR basement heat loss studies consists of six parts:

(1) Description of the basement physical model and the derivation of the calculation method,

(2) Detailed description of the proposed calculation method,

(3) Description of the basement heat loss experiments,

(4) Analysis of test data,

(5) Comparison of the experimental and calculated basement heat loss results, and final recommendations for basement heat loss calculations factors,

(6) Comments and discussion.

1. DERIVATION OF CALCULATION PROCEDURE FOR BASEMENT HEAT LOSS

1.1 Basement Model

Figure 1 shows a physical model of the elements involved in the heat loss from a basement:

(a) the basement wall above grade,

(b) the basement wall and floor below grade,

(c) the ground surface adjacent to the basement,

(d) a lower thermal boundary at a constant temperature equal to the mean ground temperature,

(e) the conducting solid mass between the basement, the ground surface and the lower thermal boundary.

The model assumes that sufficient groundwater flow occurs to maintain a constant temperature at some depth below the basement floor.

1.2 Above-Grade Heat Loss

The instantaneous heat flux through the above-grade portion of the basement wall can be represented by

$$q_1(t) = U \cdot (\Theta_B - \Theta_o(t)) \tag{1}$$

where

$q_1(t)$ = heat flux through the above-grade wall,

U = over-all thermal conductance of the basement wall above grade level, $1/R_T$,

R_T = over-all thermal resistance of the basement wall above grade level,

Θ_B = basement space air temperature,

$\Theta_o(t)$ = outdoor air temperature as a function of time,

t = time.

1.3 Below-Grade Heat Loss

The instantaneous heat loss from the below-grade portion of the basement can be expressed as

$$Q(t) = \sum_{n=2}^{N} A_n \cdot q_n(t) \tag{2}$$

where

N = number of segments constituting the interior surface area of the below grade portion of the basement,

A_n = area of segment n,

$q_n(t)$ = average heat flux through the segment area, A_n, at time t.

The amplitude values for the first and second harmonics of the ground surface temperature for several locations in Canada (12), obtained by a Fourier series analysis, are shown in Table I.

Since the second harmonic is relatively small, the annual ground surface temperature variation can be approximated using only the first harmonic of the annual cycle.

The instantaneous heat fluxes, $q_n(t)$, can thus be expressed as

$$q_n(t) = q_{a,n} + q_{v,n} \cdot \sin (\omega t) \qquad (3)$$

where

$q_{a,n}$ = annual mean value of $q_n(t)$,

$q_{v,n}$ = amplitude of the first harmonic of the heat flux variation,

ω = angular velocity of the first harmonic.

Heat conduction through a linear thermal system is in direct proportion to the temperature difference across the system and the over-all conductance. The two components of $q_n(t)$ given by Eq. (3) can, therefore, be expressed as

$$q_{a,n} = S_n \cdot (\Theta_B - \Theta_G) \qquad (4)$$

and

$$q_{v,n}(t) = V_n \cdot \sigma_n \cdot \Theta_v \cdot \sin \omega (t+\Delta t_n) \qquad (5)$$

where

S_n = shape factor for the steady-state heat loss component. It is assumed that steady-state and mean annual heat loss are equal.

Θ_B = basement air temperature,

Θ_G = ground surface temperature averaged over both time and area, which equals mean ground temperature,

V_n = shape factor for the periodic heat loss,

σ_n = amplitude attenuation factor,

Θ_v = amplitude of the first harmonic of the ground surface temperature,

Δt_n = time lag of the heat flux harmonic relative to surface temperature variation.

The shape factor, S_n, represents the over-all conductance between the basement interior surface segment n (including the surface heat transfer coefficient) and the two boundaries; and between the ground surface adjacent to the basement and the hypothetical lower boundary plane at mean ground temperature, as indicated in Figure 1. The shape factor, V_n, represents the over-all conductance between only the basement interior surface segment n and the ground surface.

Thus the shape factors for the steady-state and periodic heat loss components are not the same. Steady-state heat loss consists of two components: one between the interior surface segment and the ground surface, and the other between the interior surface segment and the plane at a constant temperature below the basement floor. Periodic heat loss, on the other hand, is only between the interior surface segment and the ground surface, since the ground temperature deep down is assumed to be constant.

1.4 Determining Basement Heat Loss Factors

Below-grade basement heat loss can be calculated using Eqs. (2) to (5) if values can be assigned to: the shape factors, S_n and V_n; the amplitude attenuation factor, σ_n; and the time lag, Δt_n. The cross-sectional model of a basement and the surrounding ground (Figure 1) was used to determine these factors. This simple model assumes that two-dimensional heat conduction prevails around the basement. (The three-dimensional heat conduction effect of an exterior corner in a rectangular basement will be discussed later.) Factors that are not taken into account by this model are:

- time variations of temperature and level of the ground water,
- the flow of rain or melt water into the soil surrounding the basement,
- spatial variation of ground temperature around a basement due to solar effects, adjacent buildings and variations in the snow cover,
- the difference in thermal properties of backfill and undisturbed soil, and of the soil above and below the freezing plane.

The model can allow for some variation in soil thermal properties by assigning a different conductivity value to the soil above and below the basement floor level.

A set of shape factors, S_n and V_n, for a given basement insulation system was obtained by calculating the heat flux, q_n, through A_n using one constant unit for ground surface and basement space temperatures.

Finite-element numerical methods were used to determine the heat flux through the basement interior surface and short descriptions of the programs used is given in Appendix A.

An analysis of the calculated shape factors indicates that, in most cases, the basement insulation thermal resistance, R, and the shape factors can be related by

$$S_n(R) = 1/(a_n+b_n \cdot R) \tag{6}$$

and

$$V_n(R) = 1/(c_n+d_n \cdot R) \tag{7}$$

for the range $1 \leqslant R \leqslant 5$

where

$S_n(R)$ and $V_n(R)$ = steady-state and periodic shape factors for a basement insulated to a thermal resistance value, R,

a_n, b_n, c_n = constants that are specific to the basement thermal insulation system.

The expressions of S_n and V_n for several basement insulation systems and for two sets of soil conductivity values are listed in Tables II and III.

The attenuation factor, σ_n, and the time lag factor, Δt_n, have been determined by calculating the periodic heat flux using a sine wave variation of the ground surface temperature. Calculated attenuation and time-lag factors are plotted in Figure 2. Based on these curves, a set of attenuation and time-lag factors were derived and are included in Table III.

Experimental studies have indicated that the variation in basement heat loss can be adequately described using monthly mean values of the basement heat loss. Thus, a time increment, m, of one month was used, with January identified by m = 1 and angular velocity of 30 degrees per month.

1.5 Corner Heat Loss

Using Figure 1 as the basic cross-section of a three-dimensional model, three-dimensional heat conduction calculations were performed for a basement exterior corner with two levels of insulation: the wall insulated to half-way down below grade, and insulation over the full height of the wall. The calculated surface heat flux values for the two cases are shown in Figures 3a and 3b. Note that the increase in surface heat flux towards the corner is only of significance for the lower section of an uninsulated wall and for the floor.

Based on the surface heat flux values calculated for the two levels of basement insulation, a set of corner allowance factors, C_n, was derived for all the basement insulation systems listed in Table III.

2. CALCULATION OF BASEMENT HEAT LOSS

The inside surface of the basement, as shown in Figure 1, is made up of the following five segments:

A1 = inside surface area of wall above grade,

A2 = upper inside surface area of wall below grade,

A3 = lower inside surface area of wall below grade,

A4 = inside surface area of floor strip 1 m wide adjacent to wall, and

A5 = inside surface area of the remainder of the floor.

The basement floor was divided into two regions because heat flux calculations have shown that the floor heat flux adjacent to the wall differs substantially from the heat flux through the remainder of the floor.

The essential data needed to calculate the basement heat loss are the steady-state and periodic shape factors, S_n and V_n, the amplitude attenuation factor, σ_n, and the time-lag factor, Δt_n. Table II lists calculated heat loss factors for several insulation systems found in the test basements. (These values are used in the following sections to compare calculated and measured basement heat loss results.) Based on this comparison, the steady-state floor shape factors were modified to improve agreement between measured and calculated results. These adjusted factors (where the adjustments are based on experimental results) for a large number of basement insulation systems are listed in Table III.

It should be noted that the factors for the cases of the partially insulated walls were calculated assuming a vertical dimension (M-D) of 0.6 m for A2. The dimension, 0.6 m, was selected because that is the amount specified in some Canadian building standards. The factors for these cases can, however, be used to calculate the losses from other partially insulated walls where $D \leq M \leq H$.

The following summarizes the steps to be taken to calculate the heat loss. For a specific basement:

Step 1 - Specify the required input data for:

(a) Inside basement dimensions

- length, L,
- width, W,
- total height of wall, H,
- height of wall above grade, D.

(b) Basement insulation

- over-all thermal resistance of wall above grade, R_T,
- resistance value of insulation, R,
- height of insulation coverage over wall, M,
- extent of insulation coverage over floor (e.g., none, 1 m strip adjacent to wall, full coverage).

(c) Temperature

- basement space temperature, Θ_B,
- mean ground temperature, Θ_G (see Table 1 of Ref. 12),
- amplitude of the first harmonic of the ground surface temperature variation, Θ_V, and the time lag of the first harmonic, Δt_n, in months (see Table I),
- monthly average outdoor air temperature, $\Theta_{o,m}$, where m identifies the month (see Ref. 13).

Step 2 - Calculate the areas of the segments constituting the basement floor and walls.

(a) For a rectangular basement of a detached house:

G = perimeter = $2 \cdot (L+W)$

$A1 = G \cdot D$,

$A4 = G - 4$,

$A5 = (L-2) \cdot (W-2)$, and

(i) with insulation partially covering the wall,

$A2 = G \cdot (M-D)$,

$A3 = G \cdot (H-M)$;

(ii) with insulation covering the entire wall, use the following:

$A2 = G \cdot (0.6)$,

$A3 = G \cdot (H-D-0.6)$.

(Even though both A2 and A3 are covered by insulation, they are treated separately because of the manner in which the factors were derived (Table III).

(b) For a basement of a home that is located in the middle of a row of housing units, note the following changes:

$G = 2 \cdot L$

$A4 = G$, and

$A5 = L \cdot (W-2)$

Step 3 - Select an appropriate value of soil thermal conductivity; for the particular R-value of basement insulation, extract and calculate the factors S_n, V_n, C_n, σ_n and Δt_n from Table III. (The high value of soil thermal conductivity would probably be appropriate for rocks and wet sand; the lower value could be used for well-drained clay.)

Step 4 - Using the selected corner allowance factors, C_n, calculate the actual corner allowances, X_n, for the basement.

(a) For the two upper wall segments, the increased heat loss due to corners can be neglected, i.e., $X_1 = X_2 = 0$.

(b) For the bottom segment of the wall,

$$X_3 = i \cdot C_3$$

(c) For the one metre strip of floor,

$$X_4 = i \cdot C_4, \text{ and}$$

(d) For the central area of floor,

$$X_5 = C_5 \cdot V_5$$

For a detached house, i = 4. For a semi-detached or end unit of a row of houses, i = 2. There are no corners to be considered in a middle unit of a row of houses, all X factors are zero.

Step 5 - Calculate the monthly average heat loss rate (power) through the five basement segments:

$$q_{1,m} = A_1 \cdot U \cdot (\Theta_B - \Theta_{o,m})$$

$$q_{2,m} = A_2 \left[S_2(\Theta_B - \Theta_G) - V_2 \cdot \sigma_2 \cdot \Theta_V \cdot \sin(30(m+\Delta t_2))\right]$$

$$q_{3,m} = (A_3 + X_3) \left[S_3(\Theta_B - \Theta_G) - V_3 \cdot \sigma_3 \cdot \Theta_V \cdot \sin(30(m+\Delta t_3))\right]$$

$$q_{4,m} = (A_4 S_4 + X_3 \cdot V_4) \cdot (\Theta_B - \Theta_G) - (A_4 + X_4) \cdot V_4 \cdot \sigma_4 \cdot \Theta_4 \cdot \sin(30(m+\Delta t_4))$$

$$q_{5,m} = A_5 \left[(S_5 + X_5)(\Theta_B + \Theta_G) - (V_5 + X_5) \cdot \sigma_5 \cdot \Theta_5 \cdot \sin(30(m+\Delta t_5))\right]$$

where

"30" is in degrees per month which equals $2\pi/12$ radians per month

Δt_n and t = time in months (m plus a number from 1 to 12 identifies the month)

(Note that the corner allowance, X_n, is not used in the same fashion for all the segment heat loss calculations.)

Step 6 - Calculate the annual heat loss (energy) from the full basement:

$$Q_T = \sum_{m=1}^{12} (730)(3600) \sum_{n=1}^{5} q_{n,m}$$

where

(730)(3600) = average number of seconds per month,

Q_T = annual basement heat loss.

<u>Step 7</u> - Calculate below-grade basement heat loss for the winter period, Q_W

$$Q_W = \sum_{m_1}^{12+m_2} (730)(3600) \sum_{n=2}^{5} q_{n,m}$$

where

m_1 = start of winter season

m_2 = end of winter season.

This equation can be rearranged as follows:

$$Q_W = (\Theta_B - \Theta_G) \sum_{n=1}^{5} A_n \cdot S_n \cdot (730)(3600)(m_2 - m_1)$$
$$+ \Theta_v \cdot \sum_{n=2}^{5} A_n \cdot V_n \cdot \sigma_n \cdot \sum_{m_1}^{12+m_2} \sin \omega(m+8+\Delta t_n).$$

A sample calculation of basement heat loss is presented in Appendix B.

3. EXPERIMENTAL MEASUREMENTS OF BASEMENT HEAT LOSS

During a three-year period (Sept. 1978 to Sept. 1981), heat loss experiments were conducted on several basements by the Division and by a private consultant under contract to DBR/NRC. These experiments were conducted on:

1) three experimental basements (A, B and C) constructed on the NRC campus in Ottawa,

2) basement of an experimental house (basement D) located near the Ottawa International Airport,

3) basements in two experimental houses (HUDAC Mark XI Houses H1 and H4) in Orleans, Ontario,

4) three basements of houses in Gatineau, P.Q., and

5) several basements in Saskatoon, Charlottetown, and Ottawa.

The majority of heat loss measurements were made with large calorimeters with a test area of 2 m^2 (14). Total basement heat loss measurements were only attempted in a few cases. A description of the tests conducted by the contractor on basements in Gatineau, Ottawa, Saskatoon and Charlottetown, are given in References 15 to 17. The construction details of the HUDAC houses are given in Reference 18. Test basements A, B, C and D are described in Appendix C.

4. ANALYSIS OF TEST DATA

It was found that the energy consumption values measured in these experiments could be represented quite accurately by the following equation:

$$E(t) = Z_o + Z_1 \cdot t + Z_2 \cdot \sin(\omega t) + Z_3 \cdot \cos(\omega t) \qquad (8)$$

where

$E(t)$ = experimental energy consumption,

Z_o, Z_1, Z_2, and Z_3 = coefficients determined by a "least squares" fit of Eq. (8) to measured data;

ω = 30 degrees per month.

The differentiation of Eq. (8) gives the power,

$$\frac{dE(t)}{dt} = P(t) = Z_1 + \sqrt{Z_2^2 + Z_3^2} \cdot \omega \cdot \sin(\omega t + \alpha) \qquad (9)$$

where

$P(t)$ = instantaneous heat supplied to the basement or calorimeter,
Z_1 = steady state or the average power,
$\omega \cdot \sqrt{Z_2^2 + Z_3^2}$ = time lag of the power wave where the reference point is the starting date of the test.

The power was also calculated by numerical differentiation, i.e.,

$$P(t + \frac{\delta t}{2}) = [E(t + \delta t) - E(t)]/\delta t \qquad (10)$$

where

δt = time interval between the kWh meter readings $E(t)$ and $E(t + \delta t)$

The foregoing analysis was performed on all the measured heat loss data for the DBR/NRC test basements and the HUDAC Mark XI basements.

Figure 5 demonstrates the steps used to arrive at the heat loss rate (or power). The energy consumption data points and the curve fit represented by Eq. (8) are indicated as curve 1. Curve 2 represents the non-cyclic component of the heat loss, i.e., $Z_o + Z_1 \cdot t$. Curve 3 represents Eq. (9), the differentiation of the energy consumption curve. Finally, curve 4 represents the numerical differentiation of the actual data points of curve 1 (Eq. (10).

The comparison of measured and predicted heat loss values for the HUDAC houses are given in Figure 4 and Table IV. The comparison of measured and predicted loss rates for the DBR/NRC test basements are shown in Figures 5 to 15.

Test data were collected only during the winter period for the test basements in Ottawa, Gatineau, Saskatoon, and Charlottetown. Values of the average heating (power) over the winter period were obtained by performing a straight line fit to the data, i.e.,

$$E(t) = Y_o + Y_1 \cdot t \tag{11}$$

where

Y_1 = average power over the time period under consideration.

The experimentally-determined heating input power and the calculated heat loss rate for these basements are compared in Tables V and VI.

5. COMPARISON OF CALCULATED AND EXPERIMENTAL RESULTS

5.1 Influencing Factors

Before comparing the calculated and measured heat loss values, it might be helpful to discuss those factors that have a significant effect on this comparison. These factors are:

(a) the seasonal temperature of basement space air,

(b) the soil thermal conductivity,

(c) the mean ground temperature,

(d) the water flow in ground adjacent to basement (e.g., flow at footing drain),

(e) the level and flow of groundwater.

(a) The basement air temperature is one of the main factors controlling basement heat loss. In most basements, a change of 1 K in basement temperature can change basement heat loss by 5 to 10 per cent (19, 20). Knowledge of the basement temperature is essential.

(b) The computation of basement heat loss requires a reasonably precise estimate of soil thermal conductivity, especially when a significant portion of the total thermal resistance is provided by the soil. This condition prevails with both the partially insulated basement wall and the external insulation that goes down the wall and then outwards. In the latter case, a soil with a low thermal resistance located beneath the insulation could negate much of the heat resistance of the insulation.

(c) A change of 1K in the mean ground temperature can change the steady-state component of the basement heat loss by 5 to 10 per cent.

Snow-cleared driveways, attached garages, carports, walkways, and solar shading are all factors that can reduce the mean ground temperature and, hence, increase basement heat loss. Conversely, the proximity of a neighbouring basement could increase the mean ground temperature and reduce basement heat losses. Unfortunately, these effects are difficult to quantify.

(d) Basement heat losses increase with an increase in water flow at the footing. This was indicated by the water flows and heat loss rates measured in the DBR test basements in 1978/79.

(e) The level and flow of groundwater affect the ground temperature field beneath the basement and, therefore, affect the floor heat loss and, to a lesser extent, the wall heat loss. Unfortunately the influence of water on basement loss cannot be quantified.

5.2 Example Comparisons

5.2.1 Saskatoon, Ottawa and Charlottetown (Table V)

For these 6 houses, heat loss rates from the basements were measured with calorimeters during the heating season only. Basement air temperatures were not controlled during the 1978/79 test year, but they were closely controlled in subsequent years. The measured heat loss rates listed in Table V are values averaged over the heating season.

(a) Basement A (Saskatoon) - The basement was uninsulated except for a section of the north wall which was covered with insulation (R = 1.6) 3.6 m wide and extended from the top of the wall down to 0.6 m below grade. In all cases, the measured heat loss rates were greater than the calculated ones, but the difference between the two was somewhat less for the insulated wall. This would indicate that the actual ground thermal conductivity was greater than the values assumed in the calculations (i.e, 0.8 and 0.9 W/m•K).

As already noted, the basement air temperature was allowed to vary in 1978/79. It went from 14.5°C in November to 10°C in January to 13.5°C in April. The effect of this variation in space temperature was not allowed for in the calculated values.

(b) Basement B (Saskatoon) - There was reasonable agreement between the calculated and measured heat loss values.

(c) Basement C (Saskatoon) - a section of the north wall was covered with insulation (R = 1.32) on the external face (above grade only). Another section of the north wall was covered with insulation on the external face above grade; the insulation projected horizontally 1.2 m away from the wall on the grade. The width of wall covered with insulation was 3.05 m which is only 2 m wider than the calorimeter. This probably resulted in heat bypassing the horizontal insulation and explains the relatively large difference between measured and calculated heat loss rates.

The floor calorimeter was located near the northeast corner of the basement and probably experienced three-dimensional conduction which was not accounted for in the calculated value. This could explain the difference between measured and calculated floor heat loss.

(d) Basement E (Ottawa) - The measured and calculated values agree quite well.

(e) Basement A (Charlottetown) - This was a well insulated basement (R = 3.52 in 1979/80) with the earth bermed up against the basement wall. The calculated values assumed grade level was the highest point of the earth berm against the wall. In actual fact, the thermal resistance of the ground would be less than that assumed in the calculation due to a reduction in earth cover away from the wall. This could be the reason for the higher measured heat loss rates.

(f) Basement D (Ottawa) - This basement was characterized by a relatively high water table which would tend to increase heat loss. This was probably the reason why the measured loss from the uninsulated floor was higher than that calculated. The loss from the insulated walls showed better agreement between measured and calculated values.

5.2.2 Houses in Gatineau (P.Q.) (Table VI)

In these three homes an attempt was made to isolate the basement thermally from the remainder of the house. The power input to the electric heater that maintained the basement at a constant air temperature was recorded from December 1977 to April 1978.

Isolation of the basement from the house was only partially successful as the air infiltration into the house through the basement could not be completely eliminated. An allowance for heating infiltrating air was made, therefore to arrive at the "measured" values listed in Table VII. These values also incorporate a small correction for extraneous heat loss from the basement through the heavily insulated house above. Considering all these factors, Table VI shows reasonably good agreement between estimated measured heat loss rates and calculated loss rates.

5.2.3 HUDAC Mark XI Houses (Table IV, Figure 4)

The basement of house H1 was insulated on the inside (R = 1.23) from the top of the wall to 0.9 m below grade. The insulation value was increased to R = 3.52 and coverage was increased to full height in November 1980. The basement of house H4 was insulated on the exterior face (R = 1.23) over the full height of the wall. Calorimeters were mounted on the north wall of H1, and on the north and west walls and the floor of H4.

The basement air temperature was held as constant as possible using a residential thermostat that controlled the furnace. The energy inputs to the five electric calorimeter heaters were recorded from January 1979 to December 1981 (see Figure 4). Only the data recorded up to November 1980 (when the insulation system in H1 was upgraded) were used in the comparison shown in Table IV.

Values of soil thermal conductivity, measured along a conductivity probe, were 0.72 W/(m•K) adjacent to the basement wall, and 1.1 W/(m•K) 15 m from the house. The water flow at the foundation footing, which was also monitored, was intermittent with a maximum flow rate of 30 L/h.

Expressions describing the heat loss rate were derived from the experimental data (1979 and 1980) and are presented in Table IV. Loss rate expressions calculated with soil conductivity values of 0.8 and 0.9 W/m•K are also presented. The H1 values are for the original, partial insulation system.

The large difference in measured loss through the north and west walls of H4 is important. The reasons for this difference could be that: the west wall faces another house which is only 4 m away; the north wall calorimeter was placed on a relatively short section of wall and therefore the measured loss might be influenced by the three-dimensional effect of two corners.

The calculated values for the west wall of house H4 agree with the measured loss value, but there is a considerable underestimation of the heat loss through the north wall, even when the corners of the north wall are considered. One reason for the higher measured loss through the north wall could be that, because of solar shading, the actual ground temperature on the north side was lower than the value of 8.9°C used in the calculation.

As noted earlier, the basement air temperature was indirectly controlled by the space heating thermostat located on the main floor of the house. It is possible, therefore, that the basement air temperature was higher than the 20.7°C thermostat temperature which was used to calculate the losses. This could explain why the measured loss values were always higher than the calculated ones. the measured floor heat loss was significantly higher than that predicted, possibly due to some groundwater flow beneath the basement. This indicates that a higher value of steady-state, floor shape factor should have been used in the heat loss prediction.

5.2.4 DBR/NRC Test Basements (Figures 5 to 15)

Test basements A, B and C, located on the NRC grounds in Ottawa, are described in Appendix C. Both calorimeter and total basement heat loss measurements were recorded for the three-year period (September 1978 to September 1981). Data from the first year are not included in the following discussion because the thermal balance of the ground surrounding the basements was in a transient state during that time and because the groundwater flow was abnormally high during this period, as shown in Figure 16. A drainage ditch was dug around the test site in the summer of 1979 to lower the water table uniformly and to reduce the water flow at the footings to a more "normal" rate.

The measured test data were analyzed as described in section 4, and are presented in Figures 5 to 15. The heat loss values calculated by the method presented earlier are shown on the same figures. The total heat loss values for basements A, B and C are given in Figures 5, 9 and 13, respectively. The heat loss values for specific sections of the basements are shown in the other figures in that group.

The following are some observations and comments that apply to all three test basements.

(a) The groundwater table after construction of the drainage ditch was about 0.5 m below the basement floor surface. The water level difference across basement C (which had experienced the greatest water flow at the footing drains) was reduced to practically zero, indicating very little groundwater flow past the basement.

(b) The basements were constructed in an area of Leda clay. The measured soil thermal conductivity values are given in Appendix C. (For more information on soil thermal conductivity see Ref. 21.)

(c) Each test basement was divided into a north, a centre and a south room, and each room had its own electric heater. For all three basements, it was found that the north room required more heating energy input than the south room:

- 8% more in basement B (partial insulation),
- 7% more in basement A (full-height insulation),
- 5% more in basement C (down-and-out insulation on exterior).

This difference was probably due to a lower temperature of the ground adjacent to the north basement room caused, in part, by solar shading of the ground by the huts (see Fig. C1), and by augmented ground heat loss from a pathway leading to the huts which was kept free of snow all winter.

Following are comments on each of these three basements.

<u>Basement A</u> (full-height wall insulation on inside, floor uninsulated)

Figures 5 to 8 show that there is reasonable agreement between the measured and calculated heat loss values (both total and sectional) except for the floor, where the measured values are considerably higher than those calculated. This large difference could be due to groundwater effects that were not accounted for in the calculations, i.e., the values used in the calculations were too low to approximate the conductance to the lower boundary.

<u>Basement B</u> (partial-wall insulation on inside, floor uninsulated)

Figures 9 to 12 show reasonable agreement between measured and calculated heat loss values. Again, a higher floor heat loss was measured than was predicted probably because of unaccounted groundwater effects.

Special calorimeters were used to measure the surface heat flux through the upper (insulated) section of the east wall and through the lower (uninsulated) section. For the insulated portion of the wall, the measured heat loss was slightly higher than that predicted; for the uninsulated portion, the measured heat loss was significantly higher than that predicted. The reason for the difference between measured and predicted loss for the lower section could be the same as that for the floor, i.e., effects of groundwater.

Basement C (exterior insulation to 0.35 m below grade, then outwards 1.4 m; floor uninsulated)

There was poor agreement between measured and calculated heat loss values when the calculations assumed clay soil surrounding the basement (i.e., k = 0.8 and 0.9 W/m•K for upper and lower soil (Fig. 1), respectively). Agreement was much better when losses were calculated assuming sandy soil (i.e, k = 1.2 and 1.35 W/m•K for upper and lower soil, respectively). These latter values are compared with measured values in Figures 13 to 15.

Calculations using the high conductivities may be appropriate when it is recalled that sand was used as backfill underneath the insulating layer projecting outward from the basement wall (see Appendix C). Moreover, this sand would have a relatively high moisture content (and high conductivity) since the water table at the test site is quite high.

The test results emphasize one potential weakness of the "down-and-out" exterior insulation method. Because it relies heavily on the thermal resistance of the soil to reduce wall heat loss, its use with a high conductivity soil or in a soil with moving groundwater may not be advisable.

This example also indicates that the simple prediction method outlined in this paper has difficulty in handling those insulation systems that rely primarily on the thermal resistance of the soil. This is especially true when there is some uncertainty regarding the soil conductivity.

5.2.5 Recommendations: Calculation Procedure and Factors for Basement Heat Loss Calculations

In general, comparison of the experimental and calculated basement heat losses indicates that the proposed calculation procedure for basement heat loss is capable of accounting reasonably well for all the significant weather parameters and basement shapes. The questionable part of the procedure is the factors used to predict floor-surface heat loss since, in nearly all cases, the predicted losses were less than the measured values. The underprediction of loss suggests that the actual conductance between the basement and the lower thermal boundary is greater than that calculated on the basis of the basement model shown in Figure 1 (i.e., the numerical values of the floor-surface steady-state shape factors given in Table II are too low).

The values of the floor shape factor were increased by assuming that the conductance between the basement and the lower boundary is 1.5 times the values calculated for the basement model (Figure 1). The floor shape factors listed in Table III include this increase in thermal conductance.

The change in the floor-surface steady-state shape factors improves the match between calculated and measured values (Figure 17). In this Figure the measured steady-state heat loss values for DBR/NRC test basements are plotted versus the calculated values based on the floor-surface steady-state shape factors given in Tables II and III. The improvement in agreement between the measured and calculated values using the modified factor is apparent.

It should be noted that the amplitude attenuation factors for floor surface were also changed (i.e., numerically increased) to increase the calculated annual variation of the floor surface heat flux. This improves the match between the calculated and measured annual heat loss variations.

Table III lists factors for a large number of basement insulation systems. The floor factors have been modified to provide a better match between the measured and predicted losses. It is recommended, therefore, that these factors be used in predicting basement heat loss.

6. COMMENTS AND DISCUSSION

From this comparison between measured and predicted basement heat loss values, it can be concluded that:

(a) The two-dimensional steady-state heat conduction model for house basements is adequate for calculating the shape factors required for the simplified basement heat loss calculation method.

(b) The annual variation of ground surface temperature can be accommodated by using a periodic heat flow calculation approach, i.e., by using amplitude decrement and time-delay factors. Because the predicted basement heat loss is not a strong function of these factors, only an approximation of amplitude reduction and time lag is sufficient and the factors do not have to be calculated for every case.

(c) Basements with simple rectangular shapes can be treated reasonably well by using shape factors determined for straight wall sections and corner allowance factors to accommodate three-dimensional heat flow at outside corners. The three-dimensional heat flow of basements with irregular shapes (such as those with inside corners) cannot be accommodated by this simple method. It is suggested that corners of irregularly-shaped basements can be treated as follows. Because the three-dimensional heat flow effect at an inside corner should be the opposite of the effect at an outside corner, their effects should cancel out each other. It should be possible therefore to ignore every pair of inside and outside corners in calculating basement heat loss. Thus a detached basement would always be considered as having four corners.

(d) The simplified method can be used to predict both the total basement heat loss and the heat loss through sections of the basement within ±10 per cent of actual values, except for those cases in which the soil provides a substantial portion of the total thermal resistance between basement and surroundings. For these cases, an accurate estimate or determination of soil thermal conductivity is required to establish appropriate shape factors.

(e) In the majority of comparisons between measured and predicted heat losses, the measured values were greater than the predicted values. Much of the difference could be due to groundwater effects that influence the effective depth of the lower ground thermal boundary. If it is known that the groundwater level is high, i.e., just below the basement floor, and that a potential exists for groundwater flow across the breadth of the basement, the tabulated shape factors for the floor could be arbitrarily increased by assuming a decreased ground thermal resistance beneath the floor. A decrease of 30 to 70 per cent in ground thermal resistance can be assumed, depending on the perceived severity of the groundwater effect.

(f) The simple basement heat loss calculation method does not account very well for the factors that influence the variation in mean ground temperature around the basement. The effects of solar gain and solar shading, and of snow-free surfaces near the basement, such as attached garages, driveways and entrance-ways, require further study.

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Reference 15 was never published but is substantially identical to Ref 5 p.25

By per ML Swinton 83/11/12

BASEMENT HEAT LOSS STUDIES AT DBR/NRC

by

G. P. Mitalas

LIST OF TABLES

Table I. Ground Surface Temperatures

Location	Annual Mean Ground Temp. Θ_G, °C	Amplitude of 1st Harmonic Θ_v, °C	Amplitude of 2nd Harmonic $\Theta_{v,2}$ °C
Goose Bay, Nfld.	4.9	10.3	2.9
St. John's West, Nfld.	6.7	8.5	1.5
Truro, N.S.	7.9	9.9	1.5
Kentville, N.S.	8.4	11.4	1.6
Charlottetown, P.E.I.	7.5	10.1	1.6
Fredericton, N.B.	7.7	11.9	1.5
La Pocatière, P.Q.	7.7	10.4	1.7
Normandin, P.Q.	5.7	8.9	2.7
Ste-Anne de Bellevue, P.Q.	6.9	12.1	2.3
St. Augustin, P.Q.	7.4	10.5	2.3
Val D'Or, P.Q.	6.5	10.6	2.5
Toronto, Ont.	11.1	12.1	1.3
Kapuskasing, Ont.	5.9	10.6	2.4
Vineland, Ont.	10.6	11.0	0.9
Ottawa, Ont.	8.9	11.4	1.8
Atikokan, Ont.	7.1	11.0	2.4
Winnipeg, Man.	6.1	12.4	1.2
Saskatoon, Sask.	5.9	14.6	1.2
Regina, Sask.	4.9	14.0	0.9
Swift Current, Sask.	5.7	11.4	1.2
Lacombe, Alta.	6.3	12.2	2.2
Edson, Alta.	5.2	8.9	1.7
Peace River, Alta.	5.3	12.0	1.5
Calgary, Alta.	6.3	12.2	0.9
Vegreville, Alta.	4.6	12.1	1.4
Summerland, B.C.	12.3	11.9	0.9
Vancouver, B.C.	11.3	8.5	0.9

In all cases, the minimum ground surface temperature occurs in January. If January is designated as m = 1, then the first harmonic can be expressed as $\Theta_v \cdot \sin(30 \cdot (m+8))$ where m is in months and sine angle is in degrees.

TABLE II. Calculated Shape, Amplitude Attenuation, Time Lag and Corner Allowance Factors for Basement Section Shown in Figure 1.

<u>In all cases for the range $1 < R < 5$:</u>

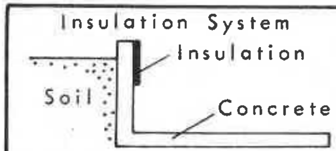
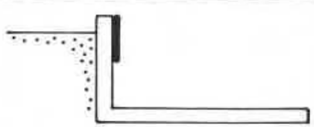
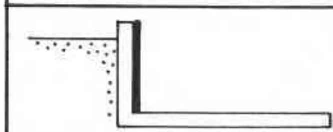
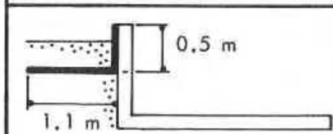
$\sigma_2 = 0.9$	$\Delta t_2 = 0$
$\sigma_3 = 0.7$	$\Delta t_3 = -1$
$\sigma_4 = 0.4$	$\Delta t_4 = -2$
$\sigma_5 = 0.3$	$\Delta t_5 = -4$

<u>Units:</u>

S, $W/(m^2 \cdot K)$	R, $m^2 .K/W$
V, $W/(m^2 \cdot K)$	σ, dimensionless
C, m^2 or dimensionless	Δt, month

(Δt is the time delay of heat flux sine wave relative to the ground surface temperature sine wave.)

SECTION A: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade, n = 2	Wall Segments: Bottom strip, n = 3	Floor Segments: 1 m strip adjacent to wall, n = 4	Floor Segments: Centre, n = 5
					
	S=	$(0.53 + 1.42R)^{-1}$	$(1.06 - 0.013R)^{-1}$	0.36	0.14
	V=	$(0.53 + 1.43R)^{-1}$	$(1.15 - 0.016R)^{-1}$	0.25	0.05
	C=	0	1.0	2.6	0.5
	S=	$(0.58 + 1.10R)^{-1}$	$(1.23 + 1.45R)^{-1}$	$(2.05 - 0.066R)^{-1}$	0.15
	V=	$(0.58 + 1.12R)^{-1}$	$(1.34 + 1.55R)^{-1}$	$(2.77 - 0.11R)^{-1}$	0.07
	C=	0	0.6	2.4	0.5
	S=	$(1.24 + 0.60R)^{-1}$	$(1.78 + 0.084R)^{-1}$	0.33	0.13
	V=	$(1.22 + 0.65R)^{-1}$	$(2.07 + 0.12R)^{-1}$	0.22	0.05
	C=	0	1.0	2.6	0.5

SECTION B: SOIL THERMAL CONDUCTIVITY: k upper = 1.2 W/(m.K); k lower = 1.35 W/(m.K)

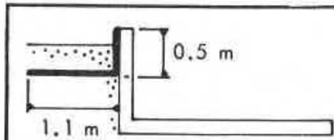
	S=	$(1.19 + 0.47R)^{-1}$	$(1.43 + 0.58R)^{-1}$	0.36	0.13
	V=	$(1.18 + 0.51R)^{-1}$	$(1.60 + 0.077R)^{-1}$	0.26	0.05
	C=	0	1.0	2.6	0.5

TABLE III. Shape, Amplitude Attenuation, Time Lag and Corner Allowance Factors for Basement Heat Loss Calculations.

In all cases for the range $1 < R < 5$:

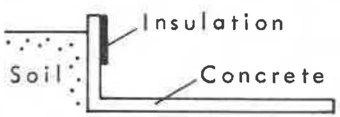
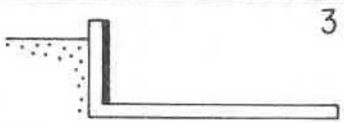
$\sigma_2 = 0.9$ $\Delta t_2 = 0$
$\sigma_3 = 0.7$ $\Delta t_3 = -1$
$\sigma_4 = 0.4$ $\Delta t_4 = -2$
$\sigma_5 = 0.3$ $\Delta t_5 = -4$

Units:

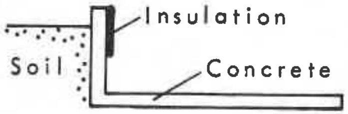
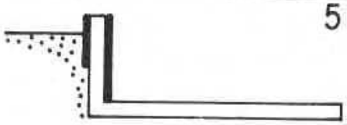
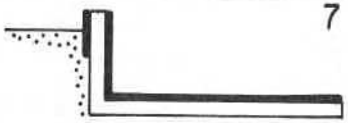
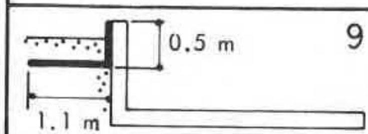
S, $W/(m^2 \cdot K)$ — R, $m^2.K/W$
V, $W/(m^2 \cdot K)$ — σ, dimensionless
C, m^2 or dimensionless — Δt, month

(Δt is the time delay of heat flux sine wave relative to the ground surface temperature sine wave.)

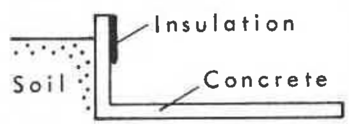
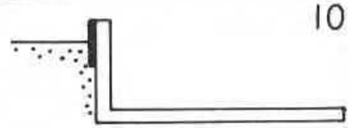
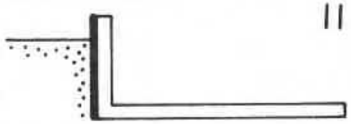
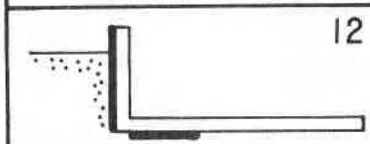
SECTION A: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade, n = 2	Wall Segments: Bottom strip, n = 3	Floor Segments: 1 m strip adjacent to wall, n = 4	Floor Segments: Centre n = 5
					
1 	S= V= C=	1.9 1.9 0	0.74 0.65 1.0	0.42 0.24 2.6	0.17 0.05 0.5
2 	S= V= C=	$(0.53 + 1.42 \cdot R)^{-1}$ $(0.53 + 1.43 \cdot R)^{-1}$ 0	$(1.06 - 0.013 \cdot R)^{-1}$ $(1.15 - 0.016 \cdot R)^{-1}$ 1.0	0.41 0.25 2.6	0.18 0.05 0.5
3 	S= V= C=	$(0.58 + 1.10 \cdot R)^{-1}$ $(0.58 + 1.12 \cdot R)^{-1}$ 0	$(1.23 + 1.45 \cdot R)^{-1}$ $(1.34 + 1.55 \cdot R)^{-1}$ 0.6	$(1.81 - 0.054 \cdot R)^{-1}$ $(2.77 - 0.11 \cdot R)^{-1}$ 2.4	0.19 0.07 0.5

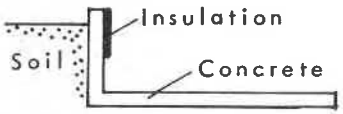
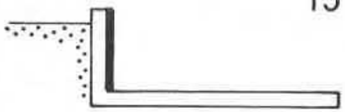
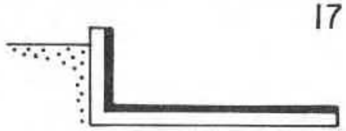
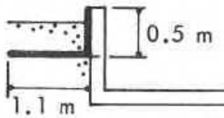
SECTION A: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade, n = 2	Wall Segments: Bottom strip, n = 3	Floor Segments: 1 m strip adjacent to wall, n = 4	Floor Segments: Centre n = 5
					
 4	S=	$(0.60 + 1.07 \cdot R)^{-1}$	$(1.22 + 1.22 \cdot R)^{-1}$	$(3.45 + 0.64 \cdot R)^{-1}$	$(4.42 - 0.14 \cdot R)^{-1}$
	V=	$(0.60 + 1.09 \cdot R)^{-1}$	$(1.33 + 1.34 \cdot R)^{-1}$	$(5.38 + 0.98 \cdot R)^{-1}$	$(11.08 - 0.58 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
 5	S=	$(0.67 + 1.12 \cdot R)^{-1}$	$(1.30 + 1.47 \cdot R)^{-1}$	$(1.82 - 0.055 \cdot R)^{-1}$	0.19
	V=	$(0.67 + 1.14 \cdot R)^{-1}$	$(1.42 + 1.58 \cdot R)^{-1}$	$(2.79 - 0.11 \cdot R)^{-1}$	0.07
	C=	0	0.6	2.4	0.5
 6	S=	$(0.69 + 1.08 \cdot R)^{-1}$	$(1.28 + 1.23 \cdot R)^{-1}$	$(3.48 + 0.64 \cdot R)^{-1}$	$(4.44 - 0.13 \cdot R)^{-1}$
	V=	$(0.69 + 1.11 \cdot R)^{-1}$	$(1.41 + 1.36 \cdot R)^{-1}$	$(5.43 + 0.98 \cdot R)^{-1}$	$(11.13 - 0.58 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
 7	S=	$(0.73 + 1.04 \cdot R)^{-1}$	$(1.42 + 1.03 \cdot R)^{-1}$	$(2.60 + 0.92 \cdot R)^{-1}$	$(4.93 + 0.71 \cdot R)^{-1}$
	V=	$(0.72 + 1.08 \cdot R)^{-1}$	$(1.53 + 1.21 \cdot R)^{-1}$	$(4.21 + 1.58 \cdot R)^{-1}$	$(12.91 + 1.25 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
 8	S=	$(0.63 + 1.03 \cdot R)^{-1}$	$(1.35 + 1.03 \cdot R)^{-1}$	$(2.59 + 0.92 \cdot R)^{-1}$	$(4.93 + 0.71 \cdot R)^{-1}$
	V=	$(0.62 + 1.07 \cdot R)^{-1}$	$(1.44 + 1.20 \cdot R)^{-1}$	$(4.17 + 1.57 \cdot R)^{-1}$	$(12.84 + 1.24 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
 9	S=	$(1.24 + 0.60 \cdot R)^{-1}$	$(1.78 + 0.084 \cdot R)^{-1}$	0.39	0.17
	V=	$(1.22 + 0.65 \cdot R)^{-1}$	$(2.07 + 0.12 \cdot R)^{-1}$	0.22	0.05
	C=	0	1.0	2.6	0.5

SECTION A: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

Insulation System	S_n, V_n, and C_n Factors	Wall Segments		Floor Segments	
		Top strip just below grade, n = 2	Bottom strip, n = 3	1 m strip adjacent to wall, n = 4	Centre n = 5
10 	S= V= C=	$(1.41 + 0.41 \cdot R)^{-1}$ $(1.42 + 0.42 \cdot R)^{-1}$ 0	$(1.52 + 0.0047 \cdot R)^{-1}$ $(1.72 + 0.006 \cdot R)^{-1}$ 1.0	0.42 0.25 2.6	0.17 0.05 0.5
11 	S= V= C=	$(0.73 + 1.08 \cdot R)^{-1}$ $(0.72 + 1.11 \cdot R)^{-1}$ 0	$(1.92 + 0.30 \cdot R)^{-1}$ $(2.16 + 0.40 \cdot R)^{-1}$ 0.6	0.43 0.25 2.4	0.18 0.06 0.5
12 	S= V= C=	$(0.74 + 1.07 \cdot R)^{-1}$ $(0.74 + 1.1 \cdot R)^{-1}$ 0	$(1.88 + 0.26 \cdot R)^{-1}$ $(2.14 + 0.36 \cdot R)^{-1}$ 0.6	$(2.99 + 0.11 \cdot R)^{-1}$ $(4.91 + 0.14 \cdot R)^{-1}$ 2.4	0.19 0.07 0.5
13 	S= V= C=	$(0.76 + 1.05 \cdot R)^{-1}$ $(0.75 + 1.09 \cdot R)^{-1}$ 0	$(1.91 + 0.17 \cdot R)^{-1}$ $(2.18 + 0.28 \cdot R)^{-1}$ 0.6	$(2.80 + 0.064 \cdot R)^{-1}$ $(4.74 + 0.12 \cdot R)^{-1}$ 2.4	$(5.47 + 1.05 \cdot R)^{-1}$ $(17.07 + 2.9 \cdot R)^{-1}$ 0.5

SECTION B: SOIL THERMAL CONDUCTIVITY: k upper = 1.2 W/(m.K); k lower = 1.35 W/(m.K)

Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade, n = 2	Wall Segments: Bottom strip, n = 3	Floor Segments: 1 m strip adjacent to wall, n = 4	Floor Segments: Centre n = 5
					
14 	S=	$(0.48 + 1.37 \cdot R)^{-1}$	$(0.85 - 0.008 \cdot R)^{-1}$	0.59	0.27
	V=	$(0.48 + 1.38 \cdot R)^{-1}$	$(0.93 - 0.0094 \cdot R)^{-1}$	0.35	0.09
	C=	0	1.0	2.6	0.5
15 	S=	$(0.51 + 1.09 \cdot R)^{-1}$	$(0.97 + 1.38 \cdot R)^{-1}$	$(1.36 - 0.03 \cdot R)^{-1}$	0.29
	V=	$(0.52 + 1.11 \cdot R)^{-1}$	$(1.06 + 1.49 \cdot R)^{-1}$	$(2.11 - 0.062 \cdot R)^{-1}$	0.11
	C=	0	0.6	2.4	0.5
16 	S=	$(0.52 + 1.06 \cdot R)^{-1}$	$(0.96 + 1.2 \cdot R)^{-1}$	$(2.76 + 0.54 \cdot R)^{-1}$	$(2.93 - 0.07 \cdot R)^{-1}$
	V=	$(0.53 + 1.08 \cdot R)^{-1}$	$(1.06 + 1.33 \cdot R)^{-1}$	$(4.39 + 0.88 \cdot R)^{-1}$	$(7.25 - 0.30 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
17 	S=	$(0.56 + 1.02 \cdot R)^{-1}$	$(1.08 + 1.01 \cdot R)^{-1}$	$(1.90 + 0.89 \cdot R)^{-1}$	$(3.27 + 0.76 \cdot R)^{-1}$
	V=	$(0.55 + 1.06 \cdot R)^{-1}$	$(1.15 + 1.18 \cdot R)^{-1}$	$(3.14 + 1.58 \cdot R)^{-1}$	$(8.46 + 1.55 \cdot R)^{-1}$
	C=	0	0.6	2.4	0.5
18 	S=	$(1.19 + 0.47 \cdot R)^{-1}$	$(1.43 + 0.058 \cdot R)^{-1}$	0.41	0.17
	V=	$(1.18 + 0.51 \cdot R)^{-1}$	$(1.60 + 0.077 \cdot R)^{-1}$	0.26	0.05
	C=	0	1.0	2.6	0.5
19 	S=	$(1.29 + 0.29 \cdot R)^{-1}$	$(1.12 + 0.0027 \cdot R)^{-1}$	0.59	0.26
	V=	$(1.31 + 0.30 \cdot R)^{-1}$	$(1.27 + 0.0033 \cdot R)^{-1}$	0.35	0.08
	C=	0	1.0	2.6	0.5
20 	S=	$(0.62 + 1.06 \cdot R)^{-1}$	$(1.58 + 0.26 \cdot R)^{-1}$	0.60	0.27
	V=	$(0.61 + 1.09 \cdot R)^{-1}$	$(1.79 + 0.35 \cdot R)^{-1}$	0.36	0.09
	C=	0	0.6	2.4	0.5

SECTION C: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

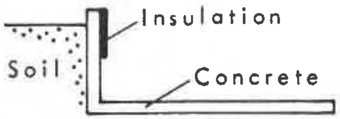
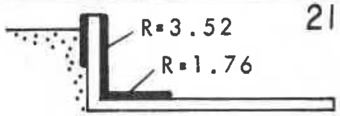
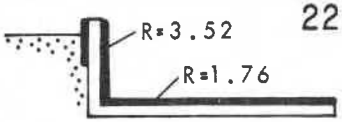
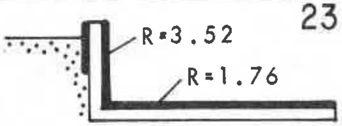
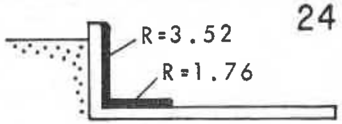
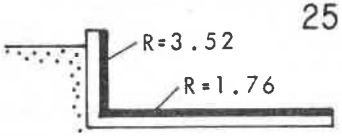
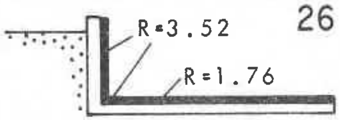
Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade n = 2	Wall Segments: Bottom strip n = 3	Floor Segments: 1 m strip adjacent to wall n = 4	Floor Segments: Centre n = 5
					
21 	S=	0.22	0.18	0.23	0.25
	V=	0.22	0.16	0.15	0.10
	C=	0	0.6	2.4	0.5
22 	S=	0.22	0.19	0.26	0.16
	V=	0.22	0.17	0.15	0.07
	C=	0	0.6	2.4	0.5
23 	S=	0.23	0.19	0.16	0.18
	V=	0.22	0.17	0.10	0.07
	C=	0	0.6	2.4	0.5
24 	S=	0.23	0.18	0.24	0.26
	V=	0.22	0.16	0.13	0.09
	C=	0	0.6	2.4	0.5
25 	S=	0.23	0.19	0.27	0.17
	V=	0.23	0.16	0.13	0.06
	C=	0	0.6	2.4	0.5
26 	S=	0.23	0.20	0.17	0.18
	V=	0.23	0.16	0.09	0.06
	C=	0	0.6	2.4	0.5

Table IV. Measured and Calculated Basement Heat Loss of Mark XI Houses (1979 - 1980)

HOUSE	Heat Loss, W/m^2	
	Measured*	Calculated*
House 4 West Wall	5.7 + 4.8 sin 30 (m + 7)	5.7 + 4.4 sin 30 (m + 7)
House 4 North Wall	8.4 + 6.7 sin 30 (m + 7)	6.1 + 4.6 sin 30 (m + 7)
House 1** North Wall	11.0 + 8.5 sin 30 (m + 7)	10.1 + 6.6 sin 30 (m + 7)
House 4 Floor	5.2 + 0.3 sin 30 (m + ?)***	2.7 + 0.5 sin 30 (m + 4)

*January is denoted by m = 1, February by m = 2, etc.

**H1 with partial insulation on basement wall

***Time lag could not be determined from measured data.

Table V. Measured and Calculated Heat Loss Through Segment of Basement Interior Surface*
(Measured values from Refs. 16 and 17)

Location	Test Year	Test Area Location	Insulation and R value $m^2 \cdot K/W$	Basement Space Temp., °C	Winter Season Heat Loss, W/m^2	Steady-State Component	Variable Component	Total	Difference between measured and calculated values, W/m^2
Saskatoon, Basement A	78/79	N. Wall	R=1.6;0.6 m below gr.	13	14	6.2	6.7	13	1
		N. Wall	None	13	33	17	13	30	3
	79/80	N-W Corner	None	20	48	31	17	48	0
		N. Wall	None	20	44	26	13	39	5
		N. Wall	R=1.6;0.6 m below gr.	20	22	11	7	18	4
		Floor	None	20	3.4	3	1.3	4.8	-1.4
Saskatoon, Basement B	78/79	N. Wall	None	17.3	30	24	12	37	-7
		N. Wall	R=1.87;Full height	17.3	10	5.1	3.1	8.1	1.9
Saskatoon, Basement C	78/79	Floor	None	20	5	3	0.6	3.6	1.4
	79/80	N. Wall	R=1.32 above gr.	20	23	17	11	28	-5
		N. Wall	R=1.32 above gr. and 1.2 m on gr.	20	18	9	4.7	14	4
Ottawa, Basement E	79/80	N. Wall	None	20	20	13	10	23	-3
		Floor	None	20	3	2.9	0.6	3.5	-0.5
Charlottetown, Basement A	78/79	N. Wall	R=1.41 Full Hgt.	17	14	7	4	11	3
	79/80	N. Wall	R=3.52 Full Hgt.	20	6	2.5	1.3	2.8	3.2
		Floor	None	20	6	1.8	0.2	2	4
Ottawa, Basement D	80/81	N. Wall	R=1.76 Full Hgt.	23	8	4	3	7	1
		E. Wall	R=1.76 Full Hgt.	23	8	4	3	7	1
		Floor	None	23	5	3	4	3.4	1.6

*See References 16 and 17 for details of measurements

Table VI. Measured and Calculated Heat Loss of Gatineau Basements*
(December 1977 to April 1978)

Basement	
G-1	Uninsulated
Measured**	2.3 to 2.7 kW
Calculated	Jan. 2.5 kW Feb. 2.6 kW March 2.4 kW
G-2	Insulation: 0.9 m strip on top section of wall. R = 1.32 m^2K/W
Measured**	1.6 to 1.8 kW
Calculated	Jan. 1.6 kW Feb. 1.6 kW March 1.5 kW
G-3	Insulation: Wall full height R = 1.58 m^2K/W
Measured**	1.2 to 1.5 kW
Calculated	Jan. 1.1 kW Feb. 1.1 kW March 1.0 kW

*See Reference 15 for details of experiment.

**The measured total basement heat loss was reduced by the estimated allowance for air infiltration loss. Depending on the assumed air infiltration rate, lower and higher loss values were obtained.

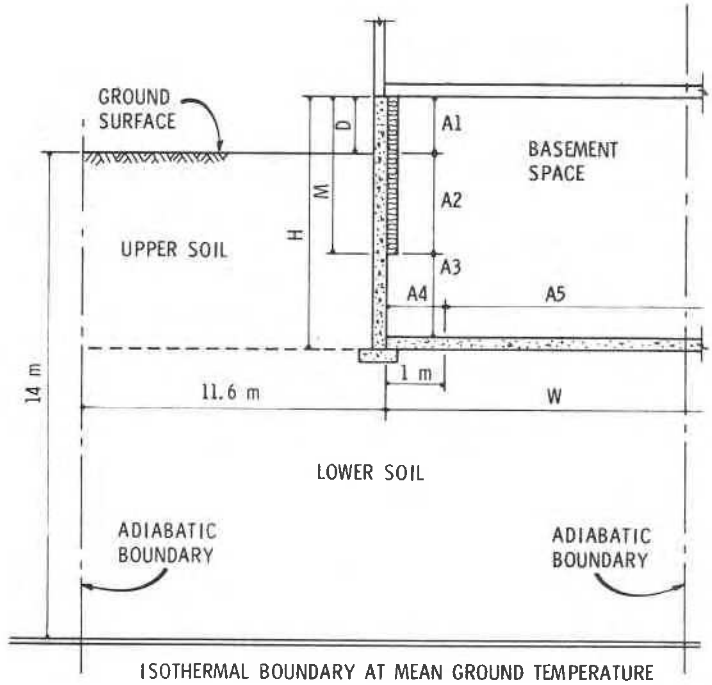


FIGURE 1
BASEMENT MODEL

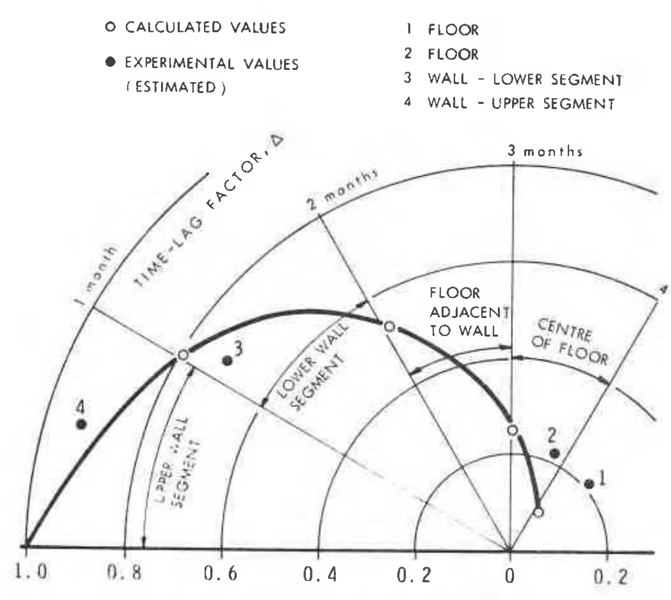


FIGURE 2
AMPLITUDE ATTENUATION AND TIME-LAG FACTORS

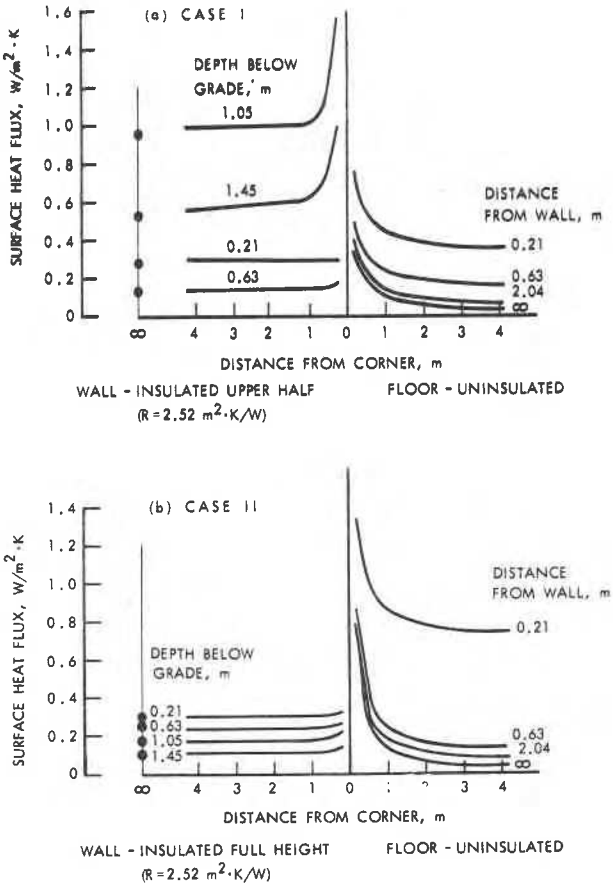


FIGURE 3

SURFACE HEAT FLUX PER UNIT TEMPERATURE DIFFERENCE NEAR CORNER

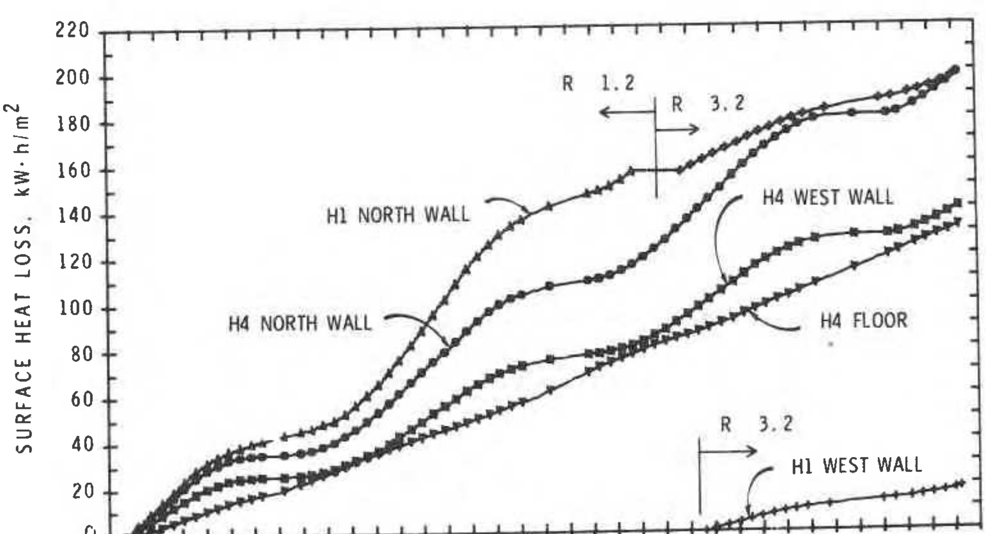


FIGURE 4

MEASURED BASEMENT INTERIOR SURFACE HEAT LOSS HUDAC MARK XI HOUSES, H1 AND H4

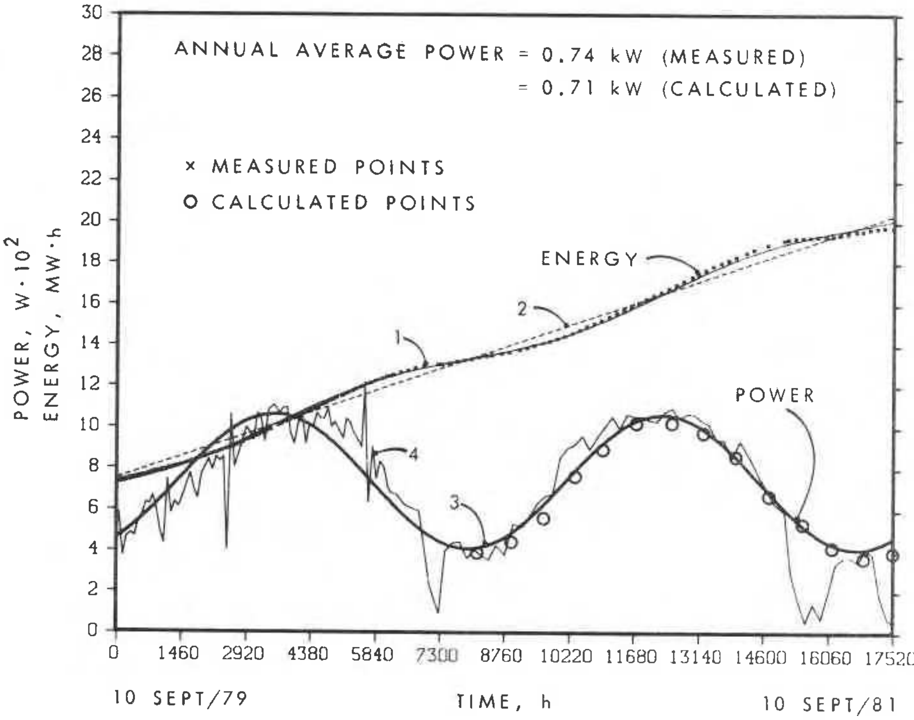


FIGURE 5

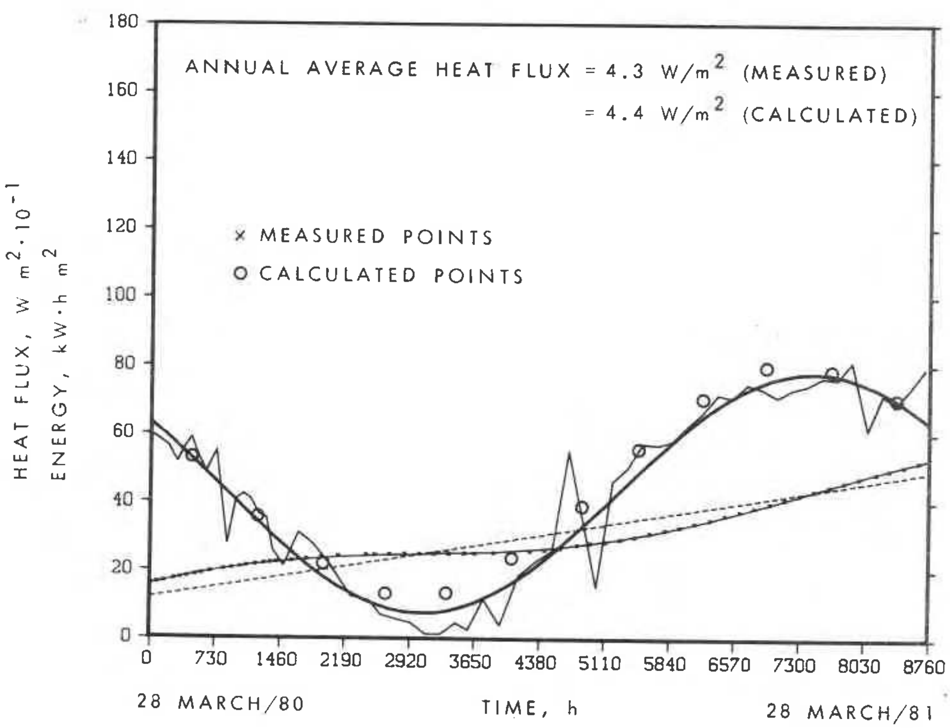


FIGURE 6

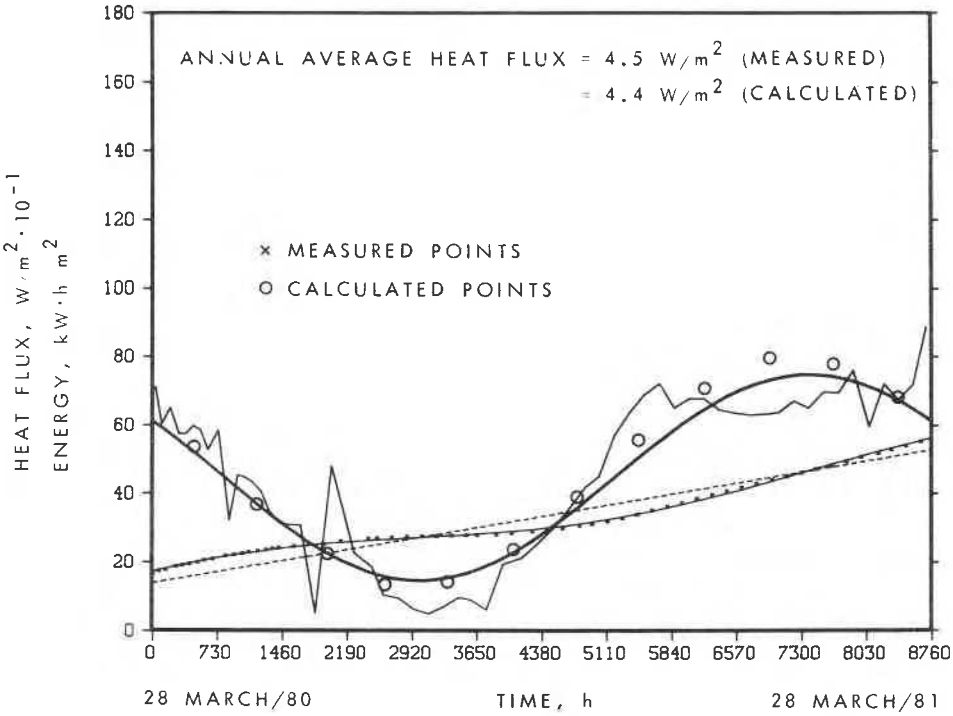


FIGURE 7

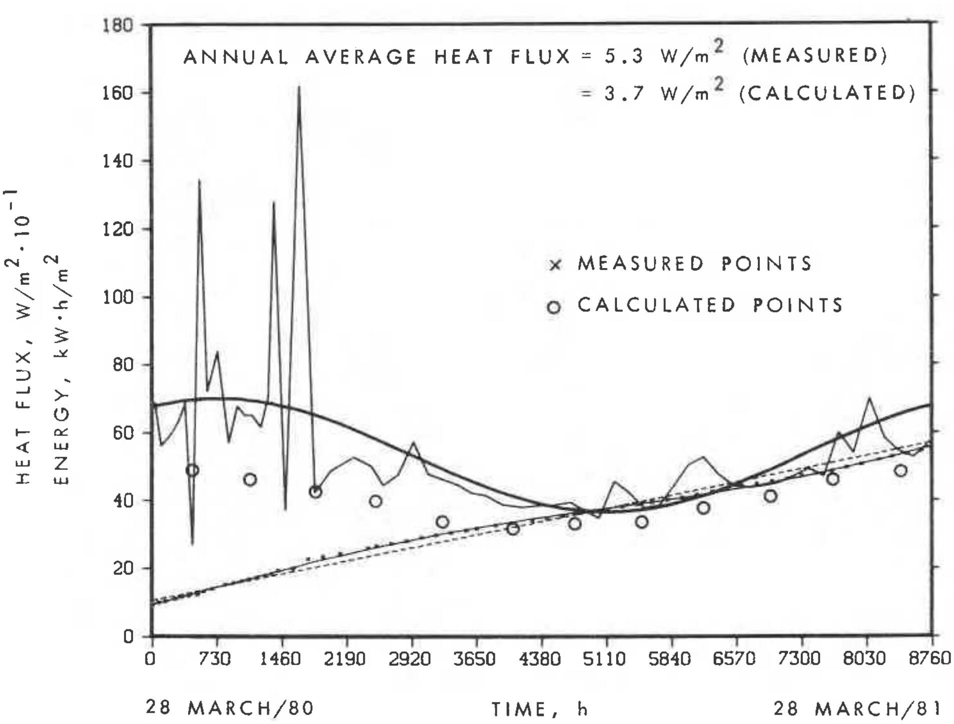


FIGURE 8

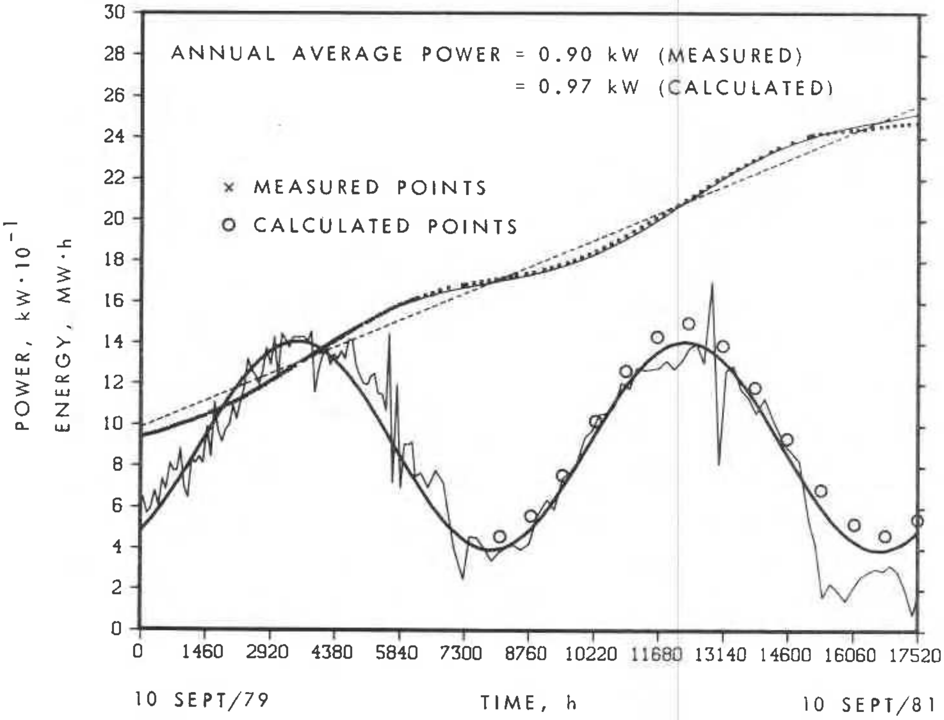


FIGURE 9

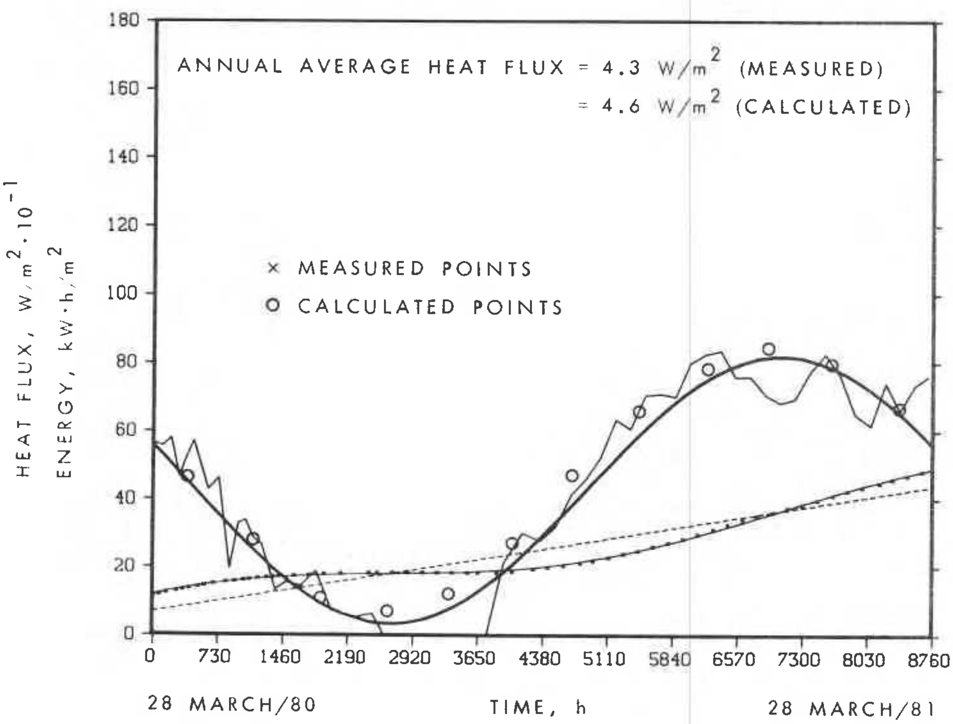


FIGURE 10

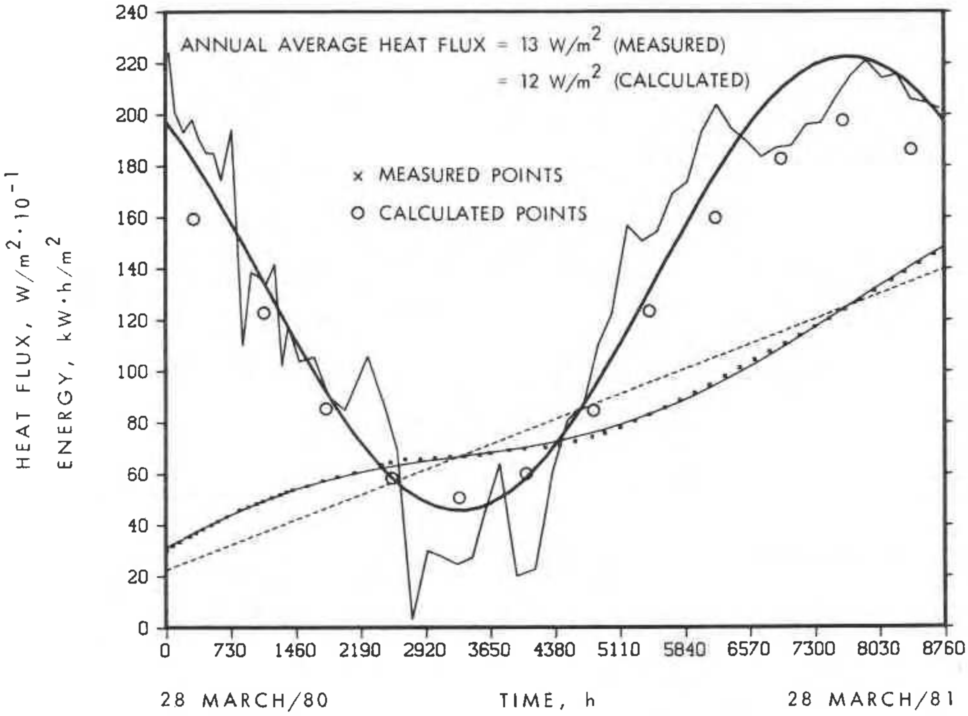


FIGURE 11

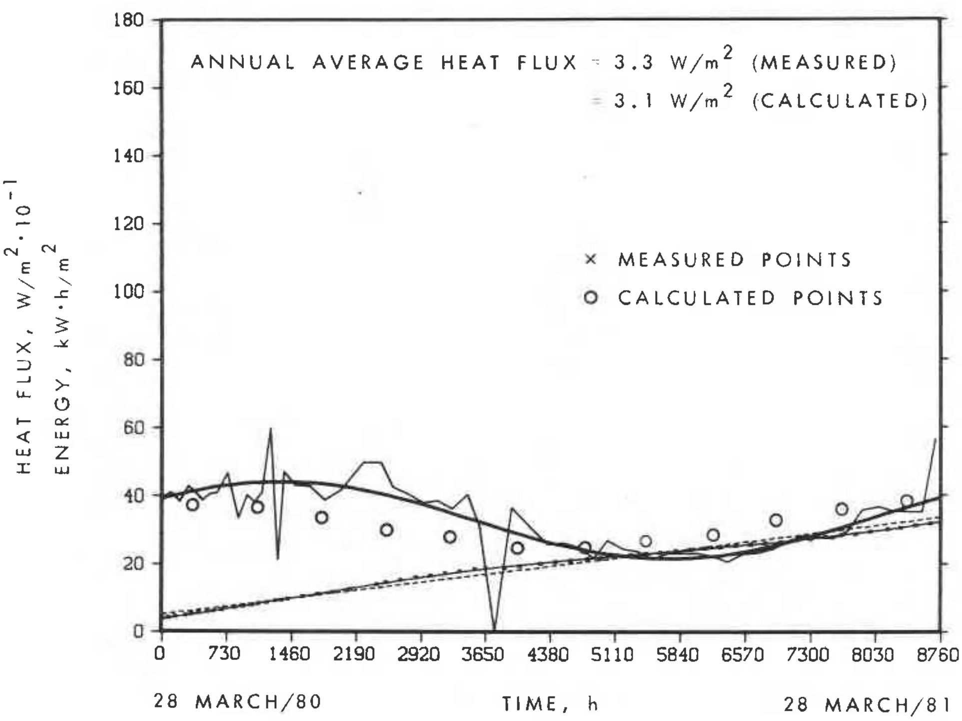


FIGURE 12

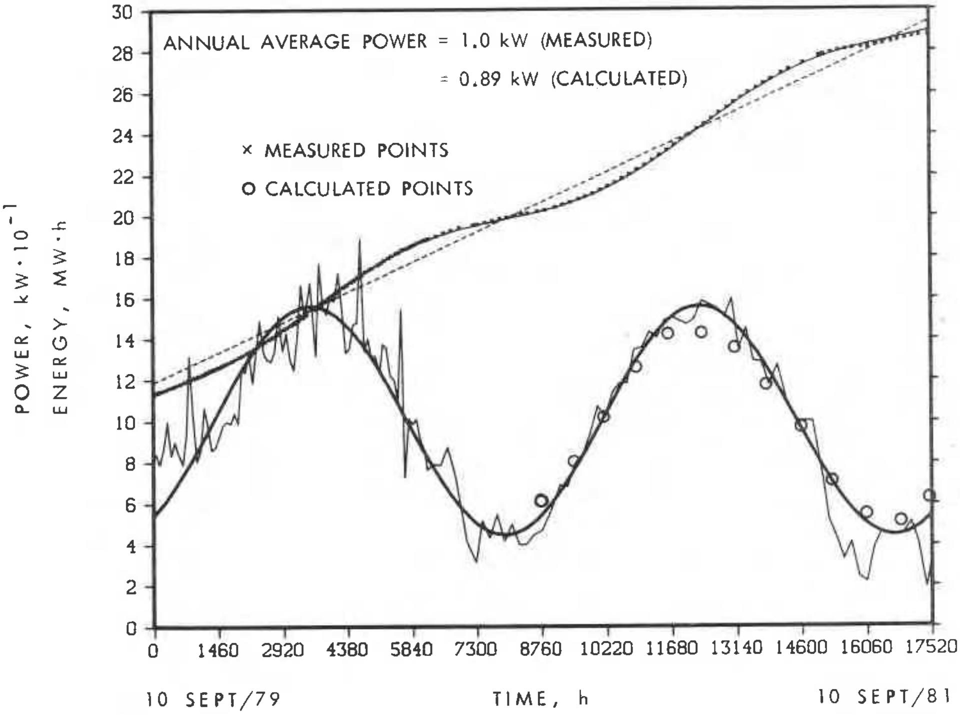


FIGURE 13

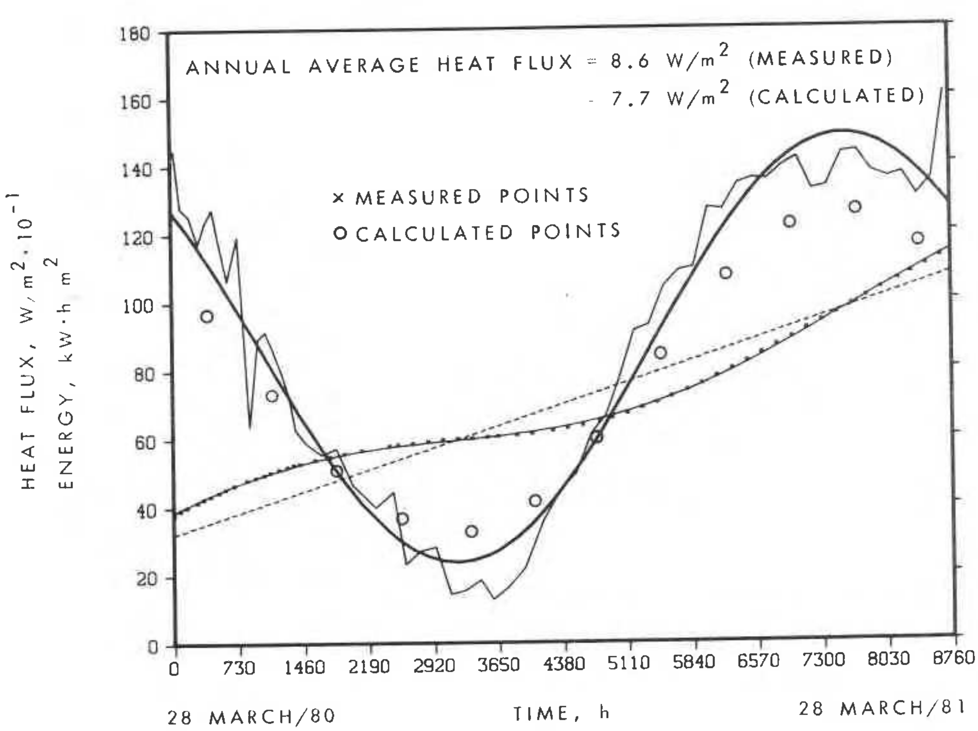


FIGURE 14

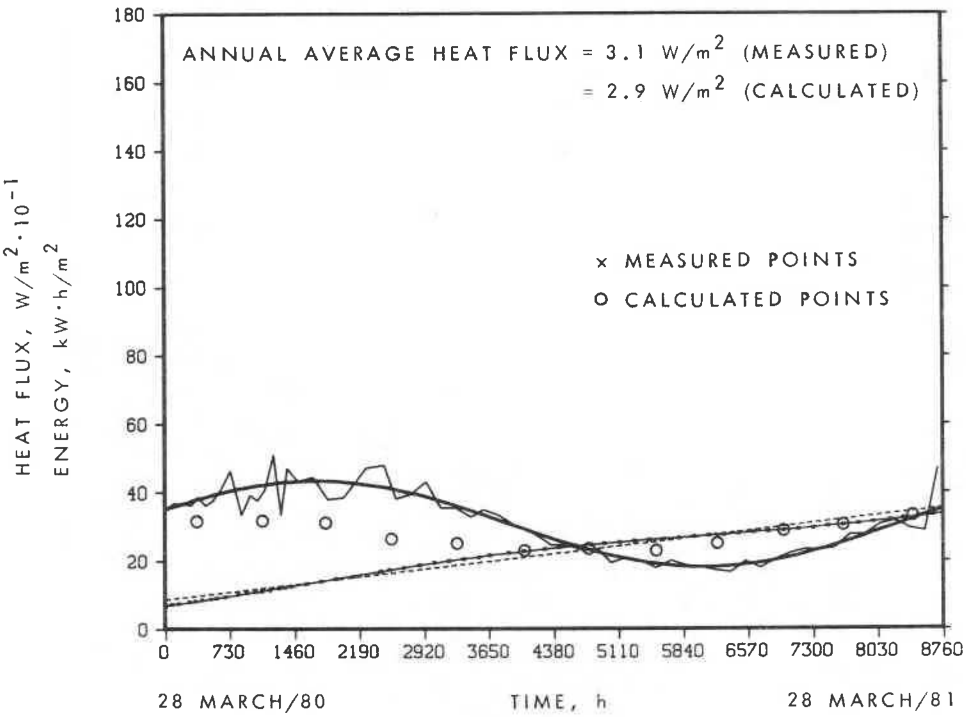

ANNUAL AVERAGE HEAT FLUX = 3.1 W/m2 (MEASURED)
= 2.9 W/m2 (CALCULATED)
× MEASURED POINTS
O CALCULATED POINTS
HEAT FLUX, W/m2·10-1
ENERGY, kW·h/m2
180
160
140
120
100
80
60
40
20
0
0
730
1460
2190
2920
3650
4380
5110
5840
6570
7300
8030
8760
28 MARCH/80
TIME, h
28 MARCH/81

FIGURE 15

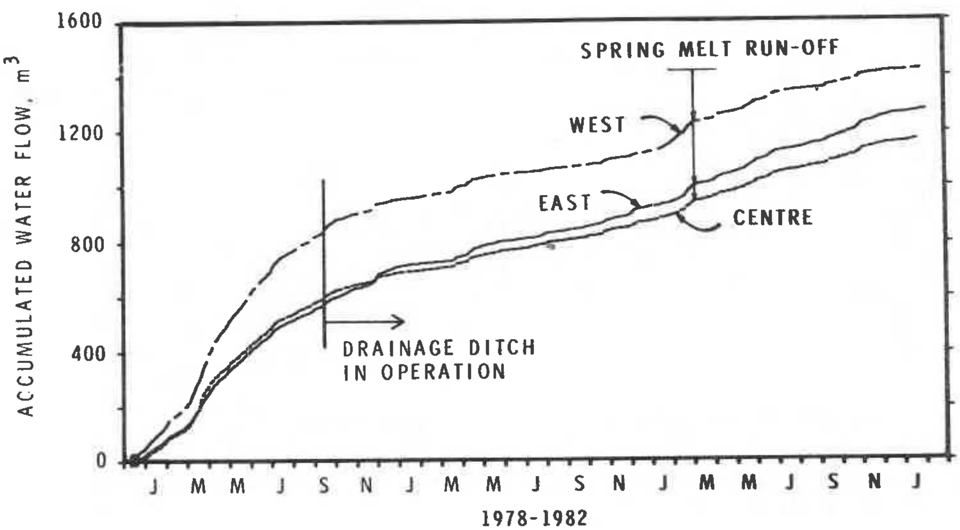


FIGURE 16

WATER FLOW AT FOOTING DRAINS OF DBR/NRC TEST BASEMENTS (DEC/78 TO FEB/82)

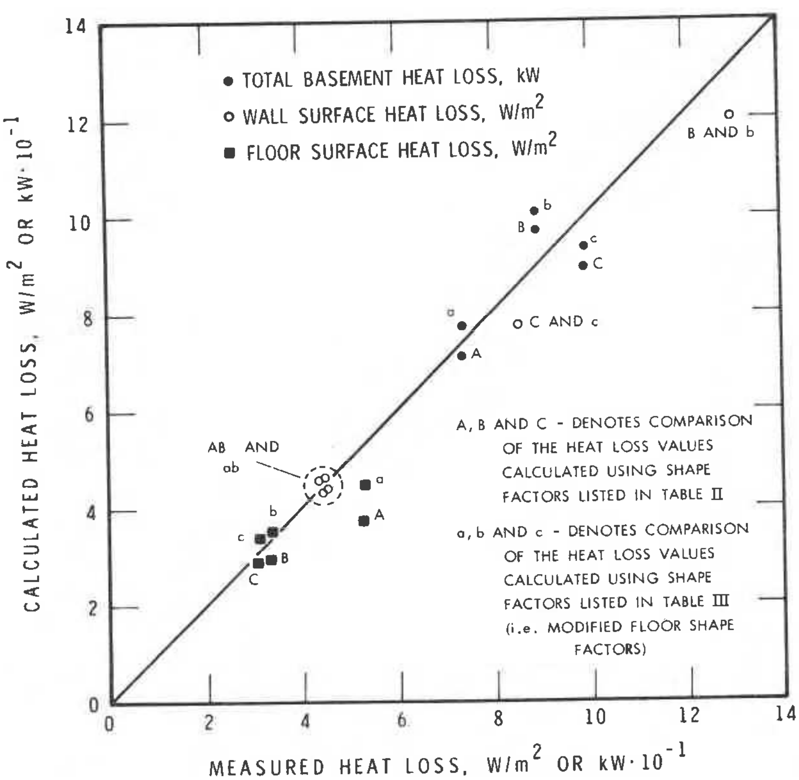


FIGURE 17

COMPARISON OF MEASURED AND CALCULATED STEADY STATE HEAT LOSS FOR DBR/NRC BASEMENTS A, B AND C

APPENDIX A

COMPUTER PROGRAMS USED IN CALCULATIONS

Two computer programs were used for basement heat loss calculations:

1) ANSYS Engineering Analysis System developed by Swanson Analysis Systems, Inc., and available on "Cybernet" service at Control Data Corp.

2) TWO DEPEP distributed by INSL and available at NRC Computation Centre on IBM 360 computer system.

For a detailed description of these programs see the following User's Manuals:

(1) Cybernetic Services: ANSYS (Rev. 3) USER'S INFORMATION MANUAL, Control Data.

(2) International Mathematical and Statistical Libraries Inc. TWO DEPEP USER'S MANUAL.

The ANSYS program was used for all steady-state computations of basement heat loss. Periodic heat conduction calculations were performed using the TWO DEPEP programs.

The main purpose of using the two programs was to check for possible errors in input data, modeling, computations, etc. This check was carried out by using both programs independently to calculate the heat flux at the inside surface of the basement, for exactly the same physical description of the basement section. This check was performed for two cases, one of which is shown in Figure A-1. The comparison indicates that the two programs were used correctly, i.e., no mistakes were made in their application nor in entering the basement physical data.

The difference in the heat flux values shown in Figure A-1 is due to the different approach used in the application of the two programs for modeling the thermal insulation. For the ANSYS program, the insulation cover on the inside of the wall surface was represented by an array of finite elements; for the TWO DEPEP programs the insulation cover was represented by an appropriate change of surface coefficient values. It is assumed that the finite element representation of the insulation cover is more exact and, therefore, all the S and V factor calculations were performed with the ANSYS program.

The finite element model of the basement for the two-dimensional section used about 500 elements, and the three-dimensional section (i.e., corners) used about 5000 elements. The two-dimensional model was changed by about 300 elements (from 500 to 200) and recalculated. The results with the reduced elements were essentially identical to those with 500, indicating that even 200 elements are sufficient to model the two-dimensional heat conduction of the basement.

The calculation procedure was as follows: both programs were used to calculate temperatures for assumed basement physical model and boundary conditions; then the surface heat flux values were calculated using "Post Processing" programs written specially for the shape factor calculations.

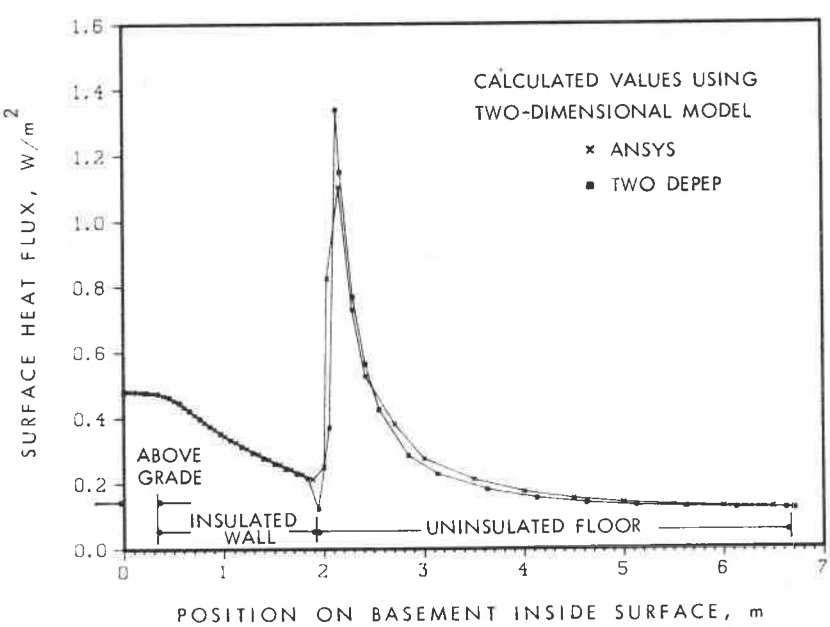


FIGURE A-1

APPENDIX B

SAMPLE CALCULATION OF BASEMENT HEAT LOSS

The following example calculates the heat loss from one of the DBR/NRC test basements described in Appendix C, namely basement A with insulation over the full height of the basement wall on the inside surface.

Step 1 - The given input data are:

(a) Basement dimensions:

- length, L = 9.2 m
- width, W = 8.5 m
- total wall height, H = 2.13 m
- height of wall above grade, D = 0.38 m

(b) Insulation:

- above-grade, U = 0.53 $W/(m^2 \cdot K)$
- insulation resistance, R = 1.55 $m^2 \cdot K/W$
- height of insulation cover, M = 2.13 m (full height)
- floor is uninsulated

(c) Temperatures (see Refs. 12 and 13):

- basement space temperature, Θ_B = 21°C
- ground surface temperature (from Table I)

$$= \Theta_G + \Theta_v \cdot \sin (30(m + 8))$$

$$= 8.9 + 11.4 \cdot \sin (30(m + 8))$$

See Table B1 for monthly values of outside air and variable component of ground surface temperatures.

Step 2 - For a detached home, the area segments are calculated as follows:

perimeter, G	$= 2(9.2 + 8.5)$	$= 35.4$ m
$A_1 = G \cdot D$	$= (35.4)(0.38)$	$= 13.5$ m^2
$A_2 = G\ (0.6)$	$= (35.4)(0.6)$	$= 21.2$ m^2
$A_3 = G(H-D-0.6)$	$= 35.4(2.13) - 0.38 - 0.6)$	$= 40.7$ m^2
$A_4 = G - 4$	$= 35.4 - 4$	$= 31.4$ m^2
$A_5 = (L - 2)(W - 2)$	$= (9.2-2)(8.5-2)$	$= 46.8$ m^2

Step 3 - Because the soil surrounding the basement was clay, the lower values of thermal conductivities were used to extract the following basement factors from Table II:

	n=2	n=3	n=4	n=5
S	$(0.58 + 1.10R)^{-1}$	$(1.23 + 1.45R)^{-1}$	$(2.05 + 0.066R)^{-1}$	0.15
V	$(0.58 + 1.12R)^{-1}$	$(1.34 + 1.55R)^{-1}$	$(2.77 - 0.11R)^{-1}$	0.07
σ	0.9	0.7	0.4	0.3
Δt	0	-1	-2	-4
C	0	0.6	2.4	0.5

Substituting $R = 1.55$ (m^2•K)/W and Δt_n, and remembering that $(t + \Delta t_n) = (m + 8 + \Delta t_n)$,

					Units:
S	0.44	0.29	0.51	0.15	W/(m^2•K)
V	0.43	0.27	0.38	0.07	W/(m^2•K)
σ	0.9	0.7	0.4	0.3	Dimensionless
$(t+\Delta t)$	m+8	m+7	m+6	m+4	Month
C	0	0.6 m^2	2.4 m^2	0.5	Dimensionless

Step 4 - Using the allowance factors from Table II, the corner allowances X_n, are:

(a) $X_1 = X_2 = 0$

(b) $X_3 = i \cdot C_3 = 4(0.6) = 2.4$ m^2

(c) $X_4 = i \cdot C_4 = 4(2.4) = 9.6$ m^2

(d) $X_5 = C_5 \cdot V_5 = 0.5(0.07) = 0.035$ W/(m^2•K)

Step 5 - The monthly heat loss (power) values of the five basement segments are:

$$q_{1,m} = A_1 \cdot U \cdot (\Theta_B - \Theta_{o,m}) = 13.5(0.53)(21-\Theta_{o,m}) = 7.2(21-\Theta_{o,m})$$

$$q_{2,m} = A_2[S_2 \cdot (\Theta_B - \Theta_G) - V_2 \cdot \sigma_2 \cdot \Theta_v \cdot \sin(30(m + 8))]$$

$$= 21.2[0.44(21 - 8.9) - 0.43(0.9)(11.4) \sin(30(m + 8))]$$

$$= 113 - 94 \sin(30(m + 8))$$

$$q_{3,m} = (A_3 + X_3) \cdot [S_3(\Theta_B - \Theta_G) - V_3 \cdot \sigma_3 \cdot \Theta_v \cdot \sin(30(m + 7))]$$

$$= (40.7 + 2.4) \cdot [0.29(21 - 8.9) - 0.27(0.7)(11.4) \sin(30(m + 7))]$$

$$= 151 - 93 \sin(30(m + 7))$$

$$q_{4,m} = (A_4 + X_4 \cdot V_4/S_4) \cdot S_4(\Theta_B - \Theta_G) - (A_4 + X_4) \cdot V_4 \cdot \sigma_4 \cdot \Theta_v \cdot \sin(30(m + 6))$$

$$= (31.4 \cdot 0.51 + 9.6)(0.38)(21 - 8.9) - (31.4 + 9.6)(0.38)(0.4)(11.4) \sin(30(m + 6))$$

$$= 238 - 71 \sin(30(m + 6))$$

$$q_{5,m} = A_5[(S_5 + X_5)(\Theta_B - \Theta_G) - (V_5 + X_5) \cdot \sigma_5 \cdot \Theta_v \cdot \sin(30(m + 4))]$$

$$= 46.8[(0.15 + 0.035)(21 - 8.9) - (0.07 + 0.035)(0.3)(11.4) \sin(30(m + 4))]$$

$$= 105 - 16.8 \sin(30(m + 4))$$

The average heat loss values for the five basement segments for each month of the year are listed in Table B2. In addition, the total basement average values and the annual average values for each segment are given.

The annual average heat loss rate was 714 W. The annual heat loss (energy) from the whole basement would be,

$$Q_T = \frac{714}{1000} \times 12 \times 730 = 6256 \text{ kW} \cdot \text{h} = 22.5 \text{ GJ}$$

Table B1. Monthly Values of Outdoor Air and Variable Components of Ground Surface Temperatures for Ottawa

Month	Month Number, m	$\Theta_{o,m}$	11.4 sin (30(m + 8))
January	1	-11	-11.4
February	2	-9	-9.9
March	3	-3	-5.7
April	4	6	0
May	5	13	5.7
June	6	18	9.9
July	7	21	11.4
August	8	19	9.9
September	9	15	5.7
October	10	9	0
November	11	2	-5.7
December	12	-7	-9.9

Table B2. Average Basement Heat Loss, W, by Months and Segments

Month	$q_{1,m}$ Wall Above grade	$q_{2,m}$ Wall 0.6 m below grade	$q_{3,m}$ Floor Bottom section	$q_{4,m}$ Floor 1 m strip	$q_{5,m}$ Floor Centre	TOTAL
1	230	207	232	274	97	1040
2	216	194	244	299	105	1056
3	173	160	232	309	114	988
4	108	113	198	299	120	836
5	58	66	151	274	122	671
6	22	32	104	238	120	516
7	0	19	70	203	114	406
8	14	32	58	177	105	386
9	43	66	70	167	97	443
10	86	113	104	177	90	570
11	137	160	151	203	88	739
12	202	194	198	238	90	922
Avg.	107	113	151	238	105	714

Measured basement annual average heat loss = 740 W

APPENDIX C

DBR/NRC TEST BASEMENTS

Basements A, B and C

A picture and a description of the three test basements constructed on the DBR/NRC campus in Ottawa are shown in Figures C1 and C2. The three basements are of identical construction except for the insulation systems. Each basement is segmented into three thermally-separated sections: north, middle, and south.

Basement A (east) is insulated on the inside over the full height of the wall. Basement B (centre) is insulated on the inside from the top of the wall down to an elevation 0.6 m below grade. Basement C (west) is insulated on the outside, down 0.73 m from the top of the wall and out 1.4 m. The thermal and physical properties of the materials used in the basement construction are listed in Table C1.

Extraneous heat loss from the basement to the space above was reduced to negligible proportions by insulating the basement ceiling ($R = 5.3\ m^2K/W$) and by maintaining the air temperature above the basement equal to the basement air temperature.

Controlled electrical heaters were used in each of the segments in the three basements to maintain the interior temperature constant at 21°C. The electrical energy input to the three segments plus the total electrical energy input to the basement were recorded on a weekly basis.

Three calorimeters were used in each basement to measure the interior basement surface heat flux at selected test areas. The electric heaters in the calorimeters were controlled to maintain a zero air temperature difference between calorimeter and basement. Their energy inputs were recorded weekly.

The water collected by the footing drains in each basement was measured by a water flowmeter installed in series with the sump pump. Thermohygrographs were used to maintain a continuous record of temperature and humidity in each basement segment. Outdoor conditions were extracted from the meteorological records collected by the Atmospheric Environment Service, Canada (AES).

Basement D

This is the basement of an experimental house located near the Ottawa International Airport; details are shown in Figure C3. One section of the basement was partitioned off and was maintained at 23°C during the study period.

The soil surrounding the basement could be described as gravel or glacial till. Using a thermal conductivity probe (C-1, C-2), soil conductivity values of 1.1, 0.6, and 1.4 $W/(m^2 \cdot K)$ were measured. The high value was measured at a distance of 10 m from the basement; the lower values were measured within 0.5 m of the basement.

The water table near the basement was quite high; it was measured at about 1 m below the floor level. Occasionally, a level difference of about 0.3 m was measured from one side of the basement to the other, indicating some flow.

Three calorimeters were used to measure the interior surface heat flux of the floor, the north wall and the west wall. The electrical energy inputs to the calorimeter heaters were recorded weekly.

References

C-1. Slusarchuk, W.A. and P.H. Foulger. Development and calibration of thermal conductivity probe apparatus for use in the field and laboratory. Nat. Res. Council Canada, Dir. Bldg. Res., DBR Tech. Paper 388 (NRCC 13267), Ottawa, 1973.

C-2. Goodrich, L.E. Transient probe apparatus for soil thermal conductivity measurements. In Procs., Symposium on Permafrost Field Methods and Permafrost Geophysics, W.J. Scott and R.J.E. Brown, eds. Nat. Res. Council Canada, Assoc. Com. Geotech. Res., Tech. Memo 124, p. 44-55, June 1979.

Table C1. Thermal and Physical Properties of the Materials Used in DBR/NRC Basements A, B and C

Material	Thermal Conductivity W/(m•K)	Density, kg/m^3	Specific Heat, kJ/(kg•K)
Concrete	1.73	2243	0.84
Glass Fibre Insulation	0.0433	32	0.84
Foam Styrene Insulation	0.029	35	1.21
Sand	1.73	2242	0.84
Wood	0.12	513	1.38
Gypsum Board	0.16	800	0.84
<u>Soil</u>: Leda Clay			
(a) Values measured with conductivity probe.	1.07 0.88 0.81 0.76	1490 @ 42% moisture	Volumetric specific heat = 2.63 MJ/(m^3•K)
Average =	0.88		
(b) Conductivities measured using hot plate	0.706		

Figure C1. DBR/NRC Test Basements (view from the east).

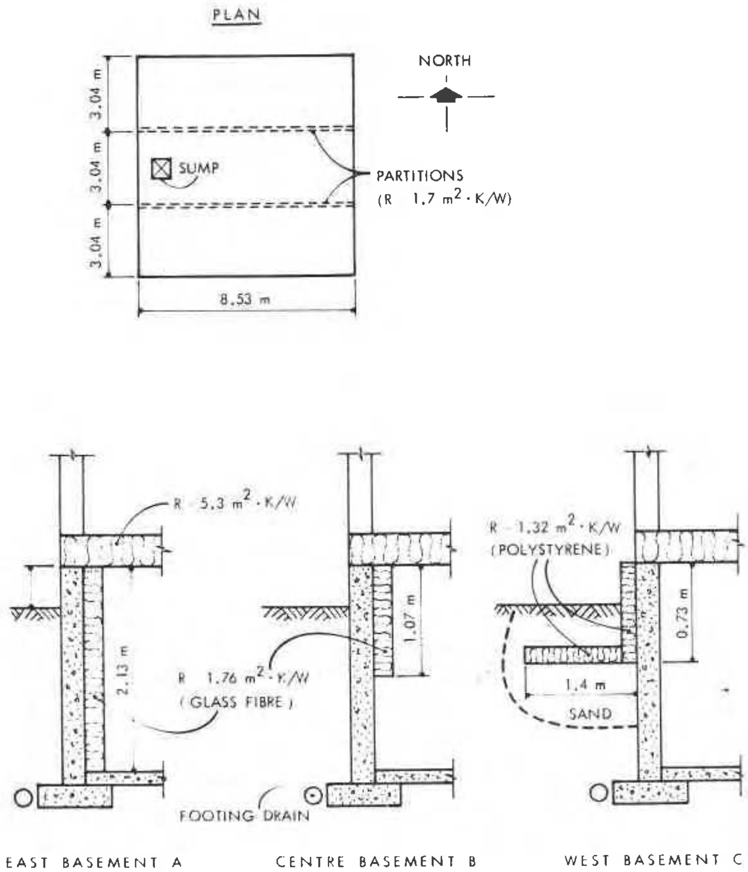


FIGURE C2

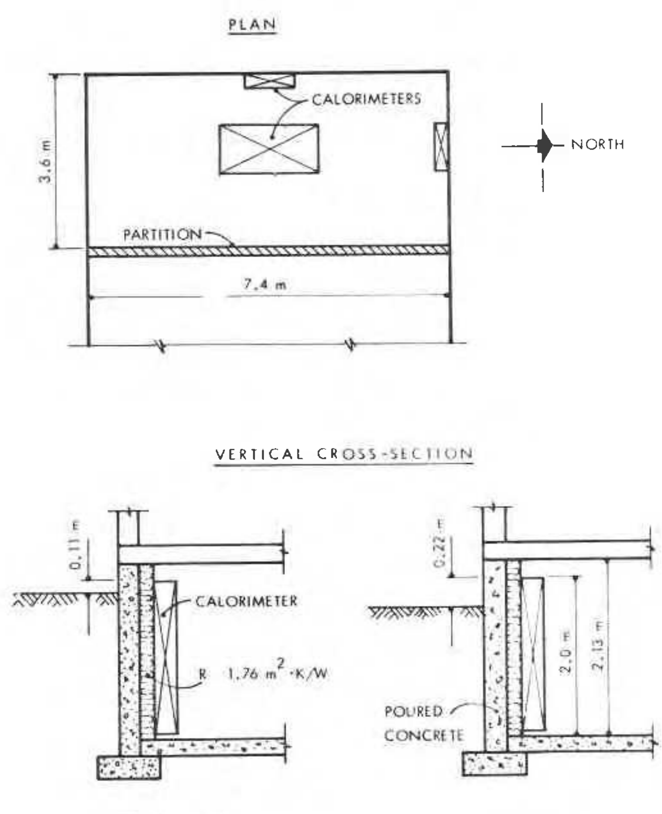


FIGURE C3