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Publisher's version / Version de l'éditeur:

ASHRAE Transactions, 89, 1B, pp. 420-437, 1983

National Research Council Canada — Conseil national de recherches Canada

CALCULATION OF BASEMENT HEAT LOSS

by G.P. Mitalas

Reprinted from
ASHRAE Transactions, 1983
Vol. 89, Part 1B
p. 420 - 437

DBR Paper No. 1198
Division of Building Research

Price $1.75 OTTAWA NRCC 23378

Canada

RÉSUMÉ

Un simple calcul permet de déterminer le taux maximum de perte de chaleur et la perte de chaleur totale par le sous-sol durant la saison de chauffe. La méthode suppose que la variation des pertes de chaleur par le sous-sol pendant l'année est un facteur important du bilan énergétique de la maison; elle a recours à des données expérimentales et analytiques pour déterminer un certain nombre de facteurs qui sont ensuite utilisés pour le calcul des pertes de chaleur par le sous-sol. Cette communication est une compilation des sections pertinentes d'une publication qui décrit en détail plusieurs études entreprises par la Division des recherches en bâtiment du Conseil nation [illegible] pertes de chaleur par le so [illegible]

AC-83-09 No. 3

Calculation of Basement Heat Loss

G.P. Mitalas
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ABSTRACT

A simple calculation makes it possible to determine the maximum rate of heat loss from a basement and the total basement heat loss over the heating season. The procedure assumes that variation of basement heat loss during the year is a significant factor in the house heat balance; and it utilizes analytical as well as experimental data to develop a set of factors that are then used in the calculation of basement heat loss. This paper is a compilation of the pertinent sections of a publication describing in detail several studies undertaken by the Division of Building Research of the National Research Council of Canada on basement heat loss.[1]

BASEMENT MODEL

Fig. 1 shows a physical model of the six elements involved in the heat loss from a basement: outside environment, basement wall above grade, basement wall and floor below grade, ground surface adjacent to the basement, lower thermal boundary at a constant temperature equal to the mean ground temperature, and the conducting soil between the basement, the ground surface, and the lower thermal boundary. The model assumes that there is sufficient groundwater flow to maintain a constant temperature at some depth below the basement floor.

Below-Grade Heat Loss

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

$$Q(t) = \sum^{N} A_n \cdot q_n(t) \quad (1)$$

where

N = 4, number of segments of 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 instantaneous heat flux, $q_n(t)$, can be approximated by

$$q_n(t) = q_{a,n} + q_{v,n} \cdot \sin(\omega t) \quad (2)$$

where

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

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

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ω = angular velocity of the first harmonic

t = time

The amplitude values for the first and second harmonics of the ground surface temperature for several locations in Canada, are shown in Table 1.[2] As the second harmonic is relatively small and the second and higher heat flux harmonics are attenuated more than the first, the annual ground surface temperature variation can be approximated using only the first harmonic of the annual cycle.

The heat conduction through a linear thermal system is directly proportional to the temperature difference across the system and the over-all conductance. The two components of $q_n(t)$ given by Eq 2 can therefore be expressed as

$$q_{a,n} = S_n \cdot (\theta_B - \theta_G) \tag{3}$$

and

$$q_{v,n}(t) = V_n \cdot \sigma_n \cdot \theta_v \cdot \sin(\omega(t+\Delta t_n)) \tag{4}$$

where

S_n = shape factor for the steady-state heat loss component

θ_B = basement air temperature

θ_G = ground surface temperature averaged over time and area, equalling 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 the 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, i.e., $S_n = S_{n,s} + S_{n,G}$, where $S_{n,s}$ is conductance to the ground surface adjacent to the basement, and $S_{n,G}$ is conductance to the hypothetical lower boundary plane at mean ground temperature, as indicated in Figure 2.

The shape factor, V_n, represents the over-all conductance for periodic heat flow between the basement interior surface segment, n, and the ground surface, and, therefore, V_n equals $S_{n,s}$.

DETERMINATION OF BASEMENT HEAT LOSS FACTORS

The cross-sectional model of the basement and surrounding ground (Fig. 1) and finite-element numerical methods for heat conduction calculations were used to determine the S_n, V_n, σ_n and Δt_n factors. It assumes that two-dimensional heat conduction prevails around the basement. Factors not taken directly into account by this model include:

- The time variation in temperature and the level of groundwater,
- The flow of rain or meltwater into the soil surrounding the basement,
- The spatial variation of ground temperature around a basement due to solar effects, adjacent buildings, and variations in the snowcover,
- 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 soil above and below the basement floor level.

Analysis of the calculated shape factors indicates that in most cases the basement insulation thermal resistance, R, and the shape factors for the range $1 \leq R \leq 5$ can be related by

$$S_n(R) = 1/(a_n + b_n \cdot R) \qquad (5)$$

and

$$V_n(R) = 1/(c_n + d_n \cdot R) \qquad (6)$$

where

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

a_n, b_n, c_n, and d_n = constants specific to the basement thermal insulation system

The expressions of S_n and V_n for several basement insulation systems and for soil conductivity values are listed in Tab. 2. Determination of these S_n and V_n factors and expressions that relate S_n, V_n and R were based on the interior surface heat-flux profiles calculated using finite-element numerical methods for heat-conduction calculations.

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 listed in Tab. 2.

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

Based on the surface heat flux values calculated at a corner for two levels of basement insulation, a set of corner allowance factors, C_n, was derived for all of the basement insulation systems listed in Tab. 2.

CALCULATION OF BASEMENT HEAT LOSS

The inside surface of the basement (Figs. 1 and 2) is made up of 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,
- A5 = inside surface area of the remainder of the floor.

The wall below grade was divided into two segments because the thermal conduction between the ground surface and the upper wall segment is significantly greater than the thermal conduction between ground surface and the lower wall segment. The basement floor was divided into two regions because heat-flux calculations show that floor heat flux adjacent to the wall differs substantially from that through the remainder of the floor.

The factors for the partially insulated walls were calculated assuming a vertical dimension (M - D) of 0.6 m for A2; 0.6 m was selected because that is the amount of basement insulation recommended in several provincial building codes. The factors for these cases can, however, be used to calculate the losses from other partially insulated walls where $D < M < H$.

The following summarizes the steps to be taken in calculating heat loss for a specific basement:

Step 1. Provide the required input data for:

Inside basement dimensions -

length, L,
width, W, where $W < L$,
total height of wall, H,
height of wall above grade, D.

basement insulation -

over-all thermal resistance of wall above grade R_T,
over-all thermal conductance of wall above grade U ($U = 1/R_T$),
resistance value of insulation, R,
height of insulation coverage of wall, M,
extent of insulation coverage of floor (i.e., none, 1 m wide strip adjacent to wall, or full coverage).

Temperature -

basement space temperature, θ_B,
mean ground temperature, θ_G (see Tab. 1 or Ref 2),
amplitude of the first harmonic of the ground surface temperature variation, θ_V, and the timing of the first surface temperature harmonic (see Tab. 1),
monthly average outdoor air temperature, $\theta_{o,m}$, where m identifies the month.[3]

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

The basement under consideration must be subdivided into sections, depending on its shape and on the number of insulation systems used for insulation. Sections that are insulated differently must be considered separately.

Square basements may be regarded as having two identical end sections. Rectangular basements may be considered as having two identical end sections with three-dimensional heat flow occurring at the corners and a middle section with two-dimensional heat flow. The heat loss through the end sections is calculated using corner allowance factors, and the heat flow through the middle section is calculated assuming two-dimensional conditions (i.e., no corner allowance).

The three-dimensional heat flow of irregularly shaped basements (such as an L shaped basement) cannot be accommodated by this simple method. It is suggested that a detached basement could be considered as having four corners only, since the three-dimensional heat flow effect at an inside corner wall will be the opposite of that at an outside corner and should therefore compensate. An L shaped basement can be treated as a rectangular one, using actual L-shaped center floor area.

Basement with single insulation system -

for both end sections, $G_E = 4\ W$

for the middle section, $G_M = 2L - 2W$

for the entire basement, $G = G_E + G_M$

where

G = perimeter, W = width, L = length.

Subscripts E, M and no subscript refer to end sections, middle section, and entire basement, respectively.

$A_{1E} = G_E \cdot (D)$

$A_{1M} = G_M \cdot (D)$

$A_{4E} = G_E - 4$

$A_{4M} = G_M$

$A_{5E} = W \cdot W - A_{4E}$

$A_{5M} = G_M \cdot (W - 2)/2$

Basement with insulation partially covering the wall -

$$A_{2E} = G_E \cdot (M - D)$$

$$A_{2M} = G_M \cdot (M - D)$$

$$A_{3E} = G_E \cdot (H - M)$$

$$A_{3M} = G_M \cdot (H - M)$$

Basement with insulation covering the entire wall -

$$A_{2E} = G_E \cdot (0.6)$$

$$A_{2M} = G_M \cdot (0.6)$$

$$A_{3E} = G_E \cdot (H - D - 0.6)$$

$$A_{3M} = G_M \cdot (H - D - 0.6)$$

Although both A2 and A3 are covered by insulation, they are treated separately because of the manner in which the factors were derived for Tab. 2.

Step 3. Select an appropriate value of soil thermal conductivity:

For the particular R value of basement insulation, obtain the factors a_n, b_n, c_n and d_n, C_n, σ_n and Δt_n from Tab. 2 and calculate S_n and V_n. (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 allowance, X_n:

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

2) For the bottom segment of the wall,

$$X_3 = i \cdot C_3$$

where i = number of corners being considered.

3) For the 1 m strip of floor,

$$X_4 = i \cdot C_4$$

4) For the central area of floor,

$$X_5 = C_5 \cdot V_5$$

Step 5. Calculate the areas of the segments constituting the floor and walls of the entire basement, including the corner allowance factors:

(Because of the difference in corner allowance for steady-state and variable floor heat loss components and because the corner allowance is in terms of area, the floor area values for the steady-state and variable component calculations are different.)

$$A_1 = A_{1E} + A_{1M}$$

$$A_2 = A_{2E} + A_{2M}$$

$$A_3 = A_{3E} + A_{3M} + X_3$$

$$A_{4s} = A_{4E} + A_{4M} + X_4 \cdot V_4 / S_4$$

$$A_{4v} = A_{4E} + A_{4M} + X_4$$

$$A_{5s} = A_{5E} \cdot (1 + X_5 / S_5) + A_{5M}$$

$$A_{5v} = A_{5E} \cdot (1 + X_5 / V_5) + A_{5M}$$

<u>where</u>

subscript "s" indicates surface area value to be used in calculating the steady-state component

subscript "v" indicates surface area value to be used in calculating the variable basement heat-loss component

<u>Step 6</u>. Calculate the monthly average heat-loss rate (power) through the five basement segments:

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

$$q_{2,m} = A_2 \cdot [S_2 \cdot (\theta_B - \theta_G) - V_2 \cdot \sigma_2 \cdot \theta_v \cdot \sin(30(m+\Delta t_2))]$$

$$q_{3,m} = A_3 \cdot [S_3 \cdot (\theta_B - \theta_G) - V_3 \cdot \sigma_3 \cdot \theta_v \cdot \sin(30(m+\Delta t_3))]$$

$$q_{4,m} = A_{4,s} \cdot S_4 \cdot (\theta_B - \theta_G) - A_{4,v} \cdot V_4 \cdot \sigma_4 \cdot \theta_v \cdot \sin(30(m+\Delta t_4))$$

$$q_{5,m} = A_{5,s} \cdot S_5 \cdot (\theta_B - \theta_G) - A_{5v} \cdot V_5 \cdot \sigma_5 \cdot \theta_v \cdot \sin(30(m+\Delta t_5))$$

<u>where</u>

"30" has units in deg/month

Δt_n = time in months

m identifies the month

<u>Step 7</u>. Calculate the annual heat loss (energy) from the below-grade basement (Q_T):

$$Q_T = \sum_{m=1}^{12} (730) \cdot (3600) \sum_{n=2}^{5} q_{n,m} \cdot (10^{-6}), \qquad \text{(MJ)}$$

<u>where</u>

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

<u>Step 8</u>. Calculate the below-grade basement heat loss over the winter period, Q_w:

$$Q_w = \sum_{m_1}^{12+m_2} (730) \cdot (3600) \cdot \sum_{n=2}^{5} q_{n,m} (10^{-6}), \qquad \text{(MJ)}$$

<u>where</u>

m_1 = start of winter season,

m_2 = end of winter season.

Alternatively, the above equation can be rearranged as follows:

$$Q_w = \Big((\theta_B - \theta_G) \cdot \sum_{n=2}^{5} A_n \cdot S_n \cdot (m_2 - m_1)$$

$$+ \theta_v \cdot \sum_{n=2}^{5} A_n \cdot V_n \cdot \sigma_n \cdot \sum_{m_1}^{12+m_2} \sin \omega(m+8+\Delta t_n)\Big) \cdot (2.628), \qquad (MJ)$$

Step 9. Calculate the heat loss from full basement:

The full basement heat loss is simply the sum of the below-grade and above-grade basement heat losses. A sample calculation of basement heat loss is given in App. A.

CONCLUSION

Various simplifying assumptions have been made in deriving a simple method of calculating basement heat loss. For verification, values of basement heat loss obtained by means of this method were compared with actual measured values.[1] The comparison suggests the following:

1. Annual variation of ground surface temperature can be accommodated satisfactorily by using a periodic heat flow calculation approach, i.e., by using amplitude attenuation and time-delay factors. Because the predicted basement heat loss is not a strong function of these factors, an approximate accounting of amplitude reduction and time lag is sufficient; the factors do not have to be calculated for every case. A value θ_G = 11.5°C may be used for many locations in Canada where the ground surface temperature variation is not known.

2. 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.

3. The simplified method can predict both the total basement heat loss and the heat loss through sections of the basement within ±10% of measured values, with the exception of poorly insulated basements in which soil provides a substantial portion of the total thermal resistance between basement and surrounding soil. For these, an accurate determination of soil thermal conductivity is required to establish appropriate shape factors by interpolation or extrapolation of the listed values.

4. 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 around and under the basement, the tabulated shape factors for the steady-state heat loss component of the floor could be arbitrarily increased by assuming a decreased ground thermal resistance beneath the floor. A decrease of 30% to 70% in ground thermal resistance may be assumed, depending on the perceived severity of the groundwater effect.

5. The simple basement heat loss calculation method does not take account of factors that influence variation in mean ground temperature around the basement.

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3. "Canadian Normals Temperature 1941-1970," Vol. 1-SI, Environment Canada, Downsview, Ontario, 1975. (UDC 551-552[71]).

ACKNOWLEDGEMENT

This paper is a contribution from the Division of Building Research, National Research Council Canada, and is published with the approval of the Director of the Division.

(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
G	basement perimeter
H	total height of basement wall
k_{lower}, 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
Q_T	annual basement heat loss from the below-grade basement
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

Subscripts

a   denotes steady-state component

E   denotes end section

m   month number (1 to 12)

M   denotes middle section

n   denotes the segment of the interior surface of basement

v   denotes variable component

Greek Symbols

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, equalling mean ground temperature

$\theta_{o,m}$ monthly value of outdoor air temperature

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

TABLE 1.

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, Labr.	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
Mean	8.5	11.5	1.9

* In all cases the minimum ground surface temperature occurs in January. If January is designated as m = 1, then the surface temperature 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. It follows that first harmonic variation of the surface, n, heat flux can be expressed as

$$\sin(30(m+8+\Delta t_n)).$$

APPENDIX A

Sample Calculation of Basement Heat Loss

The following example calculation is for the heat loss from one of the DBR/NRC test basements, that with insulation over the full height on the inside surface of the basement wall.

Step 1. The given input data are:

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

Insulation -

above grade, $1/R_T = U = 0.53\ W/(m^2 \cdot K)$

insulation resistance, $R = 1.55\ m^2 \cdot K/W$

height of insulation cover, M = 2.13 m (full height)

floor is uninsulated

Temperatures -

basement space temperature, $\theta_B = 21°C$

ground surface temperature (from Tab. 1)

$= \theta_G + \theta_v \cdot \sin(\omega t) = 8.9 + 11.4 \cdot \sin(30(m + 8))$

outside air temperature.[3] (For Ottawa θ_o, m = -11, -9, -3, 6, 13, 18, 21, 19, 15, 9, 2, -7°C M = 1 to 12)

Step 2. The area segments are calculated as follows:

G_E = (4)(8.5) = 34 m

G_M = (2)(9.2 - 8.5) = 1.4 m

G = 34 + 1.4 = 35.4 m

A_{1E} = (34)(0.38) = 12.92 m^2

A_{1m} = (1.4)(0.38) = 0.53 m^2

A_{4E} = 34 - 4 = 30 m^2

A_{4M} = 1.4 m^2

A_{5E} = (8.5)(8.5) - 30 = 42.25 m^2

A_{5M} = (1.4) × (8.5 - 2)/(2) = 4.55 m^2

A_{2E} = 34 . 0.6 = 20.4 m^2

A_{2M} = (1.4)(0.6) = 0.84 m^2

A_{3E} = (34)(2.13 - 0.38 - 0.6) = 39.1 m^2

A_{3M} = (1.4)(2.13 - 0.38 - 0.6) = 1.61 m^2

Step 3. Because the soil surrounding the basement is clay, the lower values of thermal conductivity were used to obtain the following basement factors from Tab. 2, Sect. A. For insulation system No. 3 the factors are:

Area Segment:	n = 2	n = 3	n = 4	n = 5
S	$(0.58 + 1.10R)^{-1}$	$(1.23 + 1.45R)^{-1}$	$(1.81 + 0.054R)^{-1}$	0.19
	$(0.58 + 1.12R)^{-1}$	$(1.34 + 1.55R)^{-1}$	$(2.77 - 0.11R)^{-1}$	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 $R = 1.55\ m^2 \cdot K/W$ and Δt_n, and noting that $(t + \Delta t_n) = (m + 8 + \Delta t_n)$,

Area Segment:	n = 2	n = 3	n = 4	n = 5	
S	0.44	0.29	0.58	0.19	$W/(m^2 \cdot K)$
V	0.43	0.27	0.38	0.07	$W/(m^2 \cdot K)$
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

* C value has different unit, as noted.

Step 4. Using the allowance factors from Tab. 2, the corner allowances, X, are:

$X_1 = X_2 = 0$

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

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

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

Step 5. Calculate the areas of the segments that include corner allowance factors:

$A_1 = 12.92 + 0.53 = 13.5\ m^2$

$A_2 = 20.4 + 0.84 = 21.2\ m^2$

$A_3 = 39.1 + 1.61 + 2.4 = 43.1\ m^2$

$A_{4s} = 30 + 1.4 + 9.6\ (0.38)/(0.58) = 37.7\ m^2$

$A_{4v} = 30 + 1.4 + 9.6 = 41.0\ m^2$

$A_{5s} = (42.25)[1 + (0.035)/(0.19)] + 4.55 = 54.6\ m^2$

$A_{5v} = (42.25)[1 + (0.035)/(0.07)] + 4.55 = 67.9\ m^2$

Step 6. The monthly heat loss (power) values of the five basement segments are:

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

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

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

$$= 112 - 93 \sin(30(m + 8))$$

$$q_{3,m} = A_3[S_3(\theta_B - \theta_G) - V_3 \cdot \sigma_3 \cdot \theta_v \cdot \sin(30(m + 7))]$$

$$= 43.1[0.29(21 - 8.9) - 0.27(0.7)(11.4) \sin(30(m + 7))]$$

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

$$q_{4,m} = A_{4s} \cdot S_4 \cdot (\theta_B - \theta_G) - A_{4v} \cdot V_4 \cdot \sigma_4 \cdot \theta_v \cdot \sin(30(m + 6))$$

$$= (37.7)\ (0.58\ (21 - 8.9) - (41.0)(0.38)(0.4)(11.4) \sin(30(m + 6))$$

$$= 265 - 71 \sin(30(m + 6))$$

$$q_{5,m} = A_{5s} \cdot S_5 \cdot (\theta_B - \theta_G) - A_{5v} \cdot V_5 \cdot \sigma_5 \cdot \theta_v \cdot \sin(30(m + 4))$$

$$= (54.6) \cdot (0.19)(21 - 8.9) - [67.9\ (0.07)(0.3)(11.4) \sin(30(m + 4)]$$

$$= 126 - 16.3 \sin(30(m + 4))$$

In summary, the monthly heat losses of the five basement segments are:

$$q_{1,m} = 7.2\ (21 - \theta_{o,m})$$

$$q_{2,m} = 112 - 93 \sin(30\ (m + 8))$$

$$q_{3,m} = 151 - 93 \sin(30\ (m + 7))$$

$$q_{4,m} = 265 - 71 \sin(30\ (m + 6))$$

$$q_{5,m} = 126 - 16 \sin(30\ (m + 4))$$

The average heat loss values for the five basement segments for each month of the year, the total basement average values, and the annual average values for each segment are listed in Tab. A-1.

The annual average heat loss rate was 762 W. The annual heat loss (energy) from the whole basement would be

$$\frac{762}{1000} \times 12 \times 730 = 6675 \text{ kWh} = 24 \text{ GJ}$$

As a matter of interest, the measured and calculated values are plotted in Fig. A-1 where

Curve (1) = measured energy consumption

Curve (2) = sinusoidal power curve obtained using the measured energy values

TABLE A-1.

Average Basement Heat Loss by Months and Segments, W

Month	$q_{1,m}$	$q_{2,m}$	$q_{3,m}$	$q_{4,m}$	$q_{5,m}$	TOTAL
	Wall			Floor		
	Above Grade	0.6 m below Grade	Bottom Section	1 m Strip	Centre	
1	230	207	232	301	118	1088
2	216	194	244	326	126	1104*
3	173	160	232	336	134	1035
4	108	113	198	326	140	883
5	58	66	151	301	142	718
6	22	32	104	265	140	563
7	0	19	70	230	134	453
8	14	32	58	204	126	434
9	43	66	70	194	118	491
10	86	113	104	204	112	619
11	137	160	151	230	110	788
12	202	194	198	265	112	971
Avg	107	113	151	265	126	762***
Winter Season Loss** (GJ)	3.0	3.0	3.6	5.2	2.2	17.0

* Maximum rate of heat loss from basement

** Winter season loss: m = 10 to 4 inclusive

*** Measured basement annual average heat loss (power) = 740 W

Measured basement annual heat loss (energy) = 23.3 GJ

Calculated basement annual heat loss (energy) = 24 GJ

Table 2. Shape, Amplitude Attenuation, Time Lag and Corner Allowance Factors for Basement Heat Loss Calculations

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

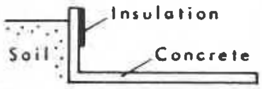
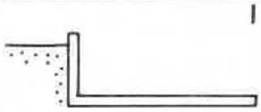
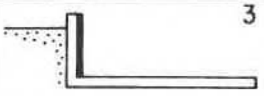
$\sigma_2 = 0.9$ $\Delta t_2 = 0$
$\sigma_3 = 0.7$ $\Delta t_3 = -1$
$\sigma_4 = 0.4$ $\Delta t_4 = -2$
$\sigma_5 = 0.3$ $\Delta t_5 = -4$

Units:

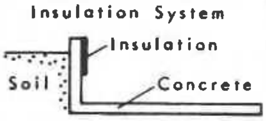
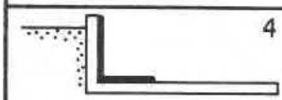
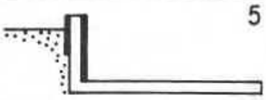
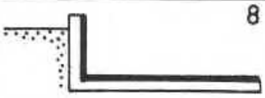
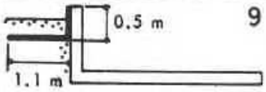
S, $W/(m^2 \cdot K)$ R, $m^2.K/W$
V, $W/(m^2 \cdot K)$ σ, dimensionless
C, m^2 or dimensionless Δt, month

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

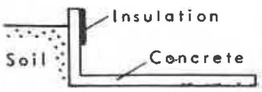
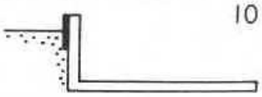
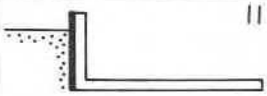
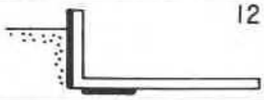
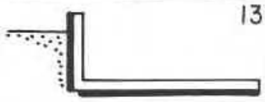
SECTION A: SOIL THERMAL CONDUCTIVITY: k upper = 0.8 W/(m.K); k lower = 0.9 W/(m.K)

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=	1.9	0.74	0.42	0.17
	V=	1.9	0.65	0.24	0.05
	C=	0	1.0	2.6	0.5
2 	S=	$(0.53 + 1.42 \cdot R)^{-1}$	$(1.06 - 0.013 \cdot R)^{-1}$	0.41	0.18
	V=	$(0.53 + 1.43 \cdot R)^{-1}$	$(1.15 - 0.016 \cdot R)^{-1}$	0.25	0.05
	C=	0	1.0	2.6	0.5
3 	S=	$(0.58 + 1.10 \cdot R)^{-1}$	$(1.23 + 1.45 \cdot R)^{-1}$	$(1.81 - 0.054 \cdot R)^{-1}$	0.19
	V=	$(0.58 + 1.12 \cdot R)^{-1}$	$(1.34 + 1.55 \cdot R)^{-1}$	$(2.77 - 0.11 \cdot R)^{-1}$	0.07
	C=	0	0.6	2.4	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: 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
					
 10	S=	$(1.41 + 0.41\cdot R)^{-1}$	$(1.52 + 0.0047\cdot R)^{-1}$	0.42	0.17
	V=	$(1.42 + 0.42\cdot R)^{-1}$	$(1.72 + 0.006\cdot R)^{-1}$	0.25	0.05
	C=	0	1.0	2.6	0.5
 11	S=	$(0.73 + 1.08\cdot R)^{-1}$	$(1.92 + 0.30\cdot R)^{-1}$	0.43	0.18
	V=	$(0.72 + 1.11\cdot R)^{-1}$	$(2.16 + 0.40\cdot R)^{-1}$	0.25	0.06
	C=	0	0.6	2.4	0.5
 12	S=	$(0.74 + 1.07\cdot R)^{-1}$	$(1.88 + 0.26\cdot R)^{-1}$	$(2.99 + 0.11\cdot R)^{-1}$	0.19
	V=	$(0.74 + 1.1\cdot R)^{-1}$	$(2.14 + 0.36\cdot R)^{-1}$	$(4.91 + 0.14\cdot R)^{-1}$	0.07
	C=	0	0.6	2.4	0.5
 13	S=	$(0.76 + 1.05\cdot R)^{-1}$	$(1.91 + 0.17\cdot R)^{-1}$	$(2.80 + 0.064\cdot R)^{-1}$	$(5.47 + 1.05\cdot R)^{-1}$
	V=	$(0.75 + 1.09\cdot R)^{-1}$	$(2.18 + 0.28\cdot R)^{-1}$	$(4.74 + 0.12\cdot R)^{-1}$	$(17.07 + 2.9\cdot R)^{-1}$
	C=	0	0.6	2.4	0.5

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

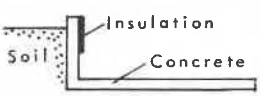
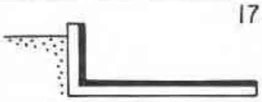
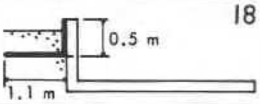
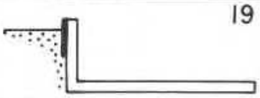
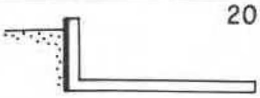
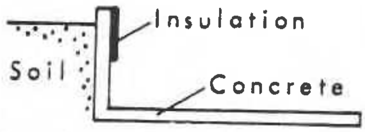
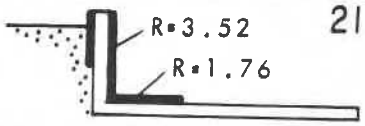
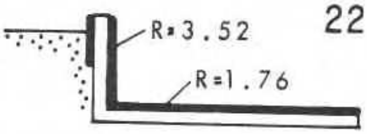
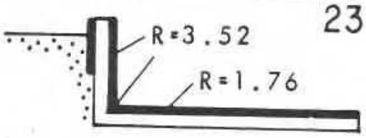
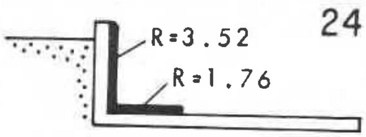
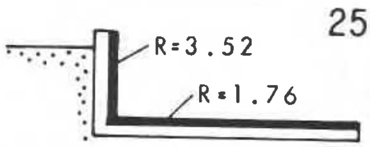
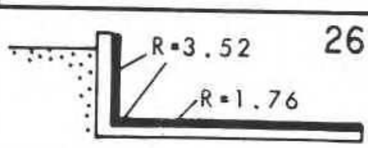
Insulation System	S_n, V_n, and C_n Factors	Wall Segments: Top strip just below grade, n = 2	Wall Segments: Bottom strip, n = 3	Floor Segments: 1 m strip adjacent to wall, n = 4	Floor Segments: Centre n = 5
					
 14	S=	$(0.48 + 1.37\cdot R)^{-1}$	$(0.85 - 0.008\cdot R)^{-1}$	0.59	0.27
	V=	$(0.48 + 1.38\cdot R)^{-1}$	$(0.93 - 0.0094\cdot R)^{-1}$	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

Table 2. Continued

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		Floor Segments	
		Top strip just below grade n = 2	Bottom strip n = 3	1 m strip adjacent to wall n = 4	Centre n = 5
	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
	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
	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
	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
	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
	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

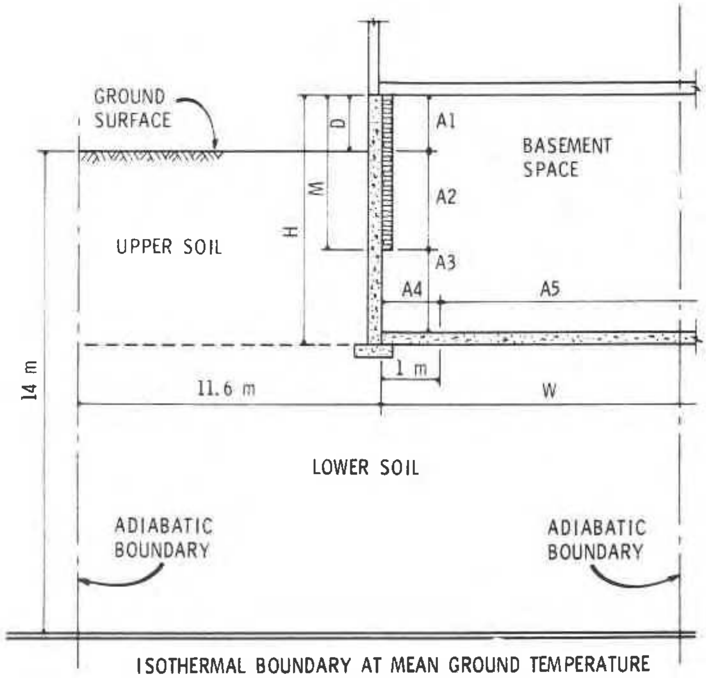


Figure 1. Basement model

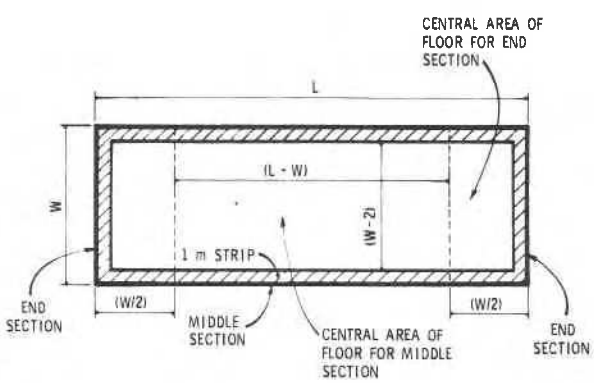


Figure 2. Floor plan of rectangular basement

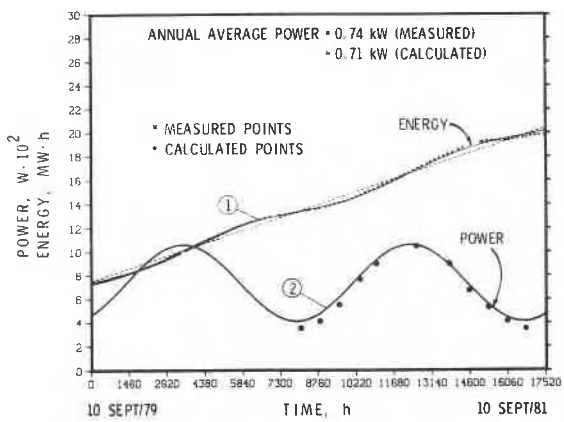


Figure A-1. Basement heat loss, DBR/NRC test basement