A GENERALIZED METHOD TO ESTIMATE THE THERMAL PERFORMANCE OF EARTH CONTACT WALLS AND FLOORS

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ABSTRACT

A procedure is proposed that extends the Temperature Profile or Decremented Average Ground Temperature method (DAGT) into a more flexible form that can account for below grade wall and floor heat losses within a simple set of algorithms based on steady state heat transfer and plane geometry. The method can be used to model basements, slab on grade and crawlspace floor types. A significant improvement in the procedure results from estimating the decrement factors based on foundation depth. Performance of unheated spaces can be estimated using a zone temperature equilibrium model. Effects of soil conductivity, heat capacity and earth contact cooling effects are explicitly modeled. Provisions are made for estimating the effects of air infiltration and internal heat gains in the below grade space. The model gives good agreement with other methods such as the shape factor method of Mitalas and the dimensionless parameter method of Yard.

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INTRODUCTION

Presently, the only accurate method for predicting the thermal performance of the earth contact portion of buildings is through the use of finite element, finite difference orboundary element computer analysis. These models can account for the multi-dimensional nature of heat transfer and the effect of soil mass and temperature on performance. Use of these models is neither simple or fast, and the very large three dimensional arrays require considerable computing capacity.

Commonly used methods for estimating below grade heat loss include the Mitalas and Yard algorithms. These calculations are based on correlating to detailed numberical models and give reasonably accurate results when compared to monitored basement performance. However, the methods are cumbersome in calculation and suffer in flexibility such that a number of empirical correlation coefficients are necessary to estimate heat loss from different floor types such as basements and slabs. Unheated spaces, such as crawlspaces, cannot be modeled directly.

THE GROUND TEMPERATURE PROFILE METHOD

The familiar equation for steady state heat flow for above grade surfaces exposed to exterior ambient air temperatures is:

$$Qa = U * Aa * (Troom - Tambient) \qquad [1]$$

where

Qa = Above grade heat loss (Btu/hr)
U = U-value of Surface (Btu/hr F.)
Aa = Area of Above grade surface (sq ft)
Tambient = Ambient air temperature (F.)
Troom = Interior room air temperature (F.)

Except for the decrement factor, the specification for heat loss below grade is identical to the steady state equation for above grade surfaces:

$$Qw = FD * U * Aw * (Troom - Tsoil,d) \qquad [2]$$

<u>where</u>

Qw = Heat loss from below grade wall (Btu/hr F.)
FD = Decrement factor (dimensionless)
U = U-value of wall (Btu/hr/sq ft F.)
Aw = Area of the below grade wall (sq ft)
Troom = Average indoor below grade room temperature (F.)
Tsoil = Undisturbed ground temperature at depth 'd'

The undisturbed ground temperature relationship estimates the temperature of the soil at depth. It has been used by several researchers and proved accurate against field observations (Kusuda and Achenbach, 1965).

$$T\,(x,t) = Tm - (As * e^{-x\sqrt{\pi/365}}) * \cos\left(\frac{360}{365} * \left(DAY - DAY\ 0 - \frac{x}{2} * \sqrt{365/\pi\alpha}\right)\right) \qquad [3]$$

<u>where</u>

T (x,t) = Soil temperature at depth 'x' and time 't'
Tm = Annual mean deep ground temperature (F.)
As = Annual surface temperature amplitude (F.)
α = Soil diffusivity (Sq ft/day)
DAY = Julian date (January 1st = 1)
DAY 0 = Phase constant (Julian date of phase constant)

The annual mean ground temperature is very similar to typical well water temperatures in most locations. A regression performed on well water temperatures in the U.S. (Collins, 1925) has shown a reasonable approximation to be:

$$Tm = .987\ (TA) + 2.74 \qquad [4]$$

<u>where</u>

TA = Average annual air temperature at location (F.)

A statistical analysis of climatic data by Kusuda and Achenbach suggests a phase constant of 0.6 radian, or 35 days for most U.S. locations. The annual surface temperature amplitude can be approximated in most locations as half the difference between the average January and July temperatures. However, this may vary in areas with heavy snows or bare soil. Actual soil surface temperature amplitude should be used when available.

The soil diffusivity varies considerably with the soil type. TABLE I lists important soil properties for the method. A diffusivity of 0.4 - 0.7 square feet per day will be adequate for most locations.

TABLE I. THERMAL PROPERTIES OF SOIL

Material	Density (lb/cu ft)	Specific Heat (Btu/lb F)	Thermal Conductivity (Btu/hr/ft F)	Thermal Diffusivity (sq ft/day)
Wet Soil	117	.30	1.40	.96
Heavy Damp Soil	131	.23	.75	.60
Heavy Soil Dry	125	.20	.50	.48
Light Soil Damp	100	.25	.50	.48
Light Soil Dry	90	.20	.20	.26

Source: Akridge and Poulos (1982)

Below Grade Walls

The key to the success of the Profile method in emulating detailed computer results, is its formulation of a decrement factor that accounts for the effects of heat storage in soil around the below grade structure. For this reason, heat losses from below grade walls are typically less than would be estimated in a conventional heat loss calculation against undisturbed ground temperatures at depth. The theoretical structure of the decrement factor is:

$$FD = R / (R + ERs / k) \qquad [5]$$

where

R = R-value of the insulation or components in the below grade surface (hr - sq ft/Btu)
ERs = Effective field distance of soil heat flow path (ft)
k = Soil conductivity (Btu/hr ft-F)

Thus, the value 'FD' approaches unity at very high insulation levels or high values of soil conductivity. This indicates that little heat is stored in the soil since it's rate of transfer is greatly reduced by the presence of insulation or is readily conducted away by the high soil conductivity. As the effective field distance approaches infinity, the decrement factor approaches zero. Newly constructed below grade structures initially have a 'FD' value of unity which decreases as heat flows into the soil raising its temperature and reducing the temperature difference across the surface of the walls or floor. Eventually, the value of the decrement factor reaches a constant value after the below grade structure has also arrived at a long term thermal equilibrium. Typically, this will take several months.

In the original Poulos thesis, the decrement factors were empirically determined for different insulation and soil types. Substituting into equation [5] Labs (1984) has found that all of Poulos's decrement factors reduce to the simple relationship:

$$FDw = R / (R + 3.7/k) \qquad [6]$$

This implies an effective heat flow path field distance of 3.7 feet. Subsequent to the original work, Akridge has determined that the decrement factors are sensitive to the depth of the below grade wall. As one would expect, the decrement factor approaches unity as the depth of the berm decreases to grade level. Since Shipp and Broderick (1983) found excellent agreement between the radial heat flow path method of Boileau and Latta and a finite difference simulation approach, the latter was used to see if it could be used to estimate the effective field distance for the soil heat flow path. The heat flow path length can be described at any point along the below grade wall as the quarter circle distance from the wall to the soil surface above. Integrating over the depth of the wall, Kusuda has shown that the average wall U-value including the resistance of the radial heat flow path through the soil can be estimated as:

$$Uw = (2/\pi) * k/D * \mathrm{Log}\,[1 + 1/Rw/(2/\pi * k/D)] \qquad [7]$$

where

Rw = the R-value (hr sqft/Btu) of the wall insulation

We can then use this relationship to estimate the decrement factor:

$$FDw = Rw / (1/Uw) \qquad [8]$$

Since the decrement factors were originally determined for a wall with a 10 foot depth, we can determine how well this expression is able to duplicate the decrement factors. Specifically, we find that the radial heat flow path method estimates the values in Poulos' tables--within 15% of the actual values given. This method has the advantage of being more general, since decrement factors can be created that are not specific to the configuration depth used for the original work.

Slab Floors

The original DAGT method as proposed by Poulos provided no solution for estimating floor heat losses. Theoretically, the horizontal plane loses heat to the undisturbed ground temperature at depth 'd'. However, the effect of heat storage under on earth contact floor is considerable since the slab width tends to thermally isolate the floor from the upper soil (Kimura, Shukuya and Tanabe, 1983). Heat flux from basement floors has been found to not be directly affected by ambient outdoor air temperature, but instead to the soil thermal regime at depth (Shipp and Broderick, 1983). Any effective method must account for both the effective resistance of soil under the slab as well as heat storage effects and the directional change in heat flow during summer months.

Claesson and Eftring (1980) have found that an analog for steady state thermal resistance from a horizontal earth contact plane can be approximated as:

$$ERy = r/k \sqrt{1-\left(\frac{y}{r}\right)^{2}} \qquad [9]$$

where

ERy = Effective thermal resistance of the soil underneath the slab at distance 'y' from the slab edge (hr sqft/Btu)
k = Soil Conductivity (Btu/hr F.)
r = Slab half width (ft)

This indicates that the resistance of the soil can be expressed as a property proportional to the slab quarter width. While the researchers have indicated that this method gives an exact solution only for an optimal distribution of insulation (tapered from the slab edge to its center), use of uniform insulation schemes showed errors in heat loss estimation of only about 10% when estimated against a numerical model. Given the uncertainties of soil conductivity at depth, this level of error is considered acceptable for this detail of estimation. Heat conducts through the ground in a uniform three dimensional pattern. As Boileau and Latta determined in 1968, this is best represented in a two dimensional fashion as concentric radial heat flow paths. Integrating equation [9] under the entire width of the slab and making allowance for increasing thermal resistance with slab depth gives the average thermal resistance of the soil:

$$ERs = \pi/4 * (r + D)/k \qquad [10]$$

where

ERs = Effective average soil heat flow path length under a slab with width 'W' and depth 'D' (hr sqft/Btu)
π = 3.1416

This can in turn be substituted into equation [5] to find the appropriate decrement factor for floors:

$$FDf = R / (R + ERs/k) \qquad [11]$$

The heat loss can be approximated by the length of the half circle of the quarter width of the slab and its resistance to the undisturbed ground temperature at the depth of the slab. During summer months the direction of heat flow will change with the slab losing heat to the deep ground (D + W/4). Typically, this transition occurrs during the fall and summer (Kimura, Shukuya and Tanabe, 1983). In modeling this effect with the method, two temperatures are estimated for each period for the two depths (D and D + W/4). The lower ground temperature is chosen for the loss calculation.

Air Infiltration

Air infiltration in basements is perhaps half of that occurring in the above grade space per unit volume. Most of this air infiltration is concentrated in the band joist area. Of course the level of air change can be considerably greater in ventilated crawlspaces. It is modeled as:

$$Qi = VOL * .018 * ADR * ACH * (Ti - Tamb) \qquad [12]$$

where

Qi = Heat loss due to air infiltration (Btu/hr F)
VOL = Volume of the basement (cubic feet)
ADR = Air density ratio with respect to sea level
ACH = Air changes per hour in the below grade space

Internal Heat Gains

Its internal heat gains in a below grade space can have a substantial effect on its auxiliary heat load. There are two common types of internal heat gains--standby losses from hot water systems and heat losses from central warm air furnaces and associated ductwork.

Hot water tank standby losses are estimated as:

$$Qhw = UAw * (Thw - Tb) \qquad [13]$$

where

Qhw = Hot water tank standby losses (Btu/hr)
UAw = Hot water tank heat loss coefficient (Btu/hr F.)
Thw = Temperature of hot water (F.)
Tb = Below grade space temperature (F.)

The hot water system UA includes pipe losses and can vary from 10.0 Btu/hr-F. for a tank without exterior insulation to less than 3.0 Btu/hr-F. for a tank with exterior insulation, bottom insulation board and pipe insulation. Losses from ductwork is estimated in a similar fashion (Kusuda and Saitoh, 1980):

$$Qd = Ad * Ud * Opfr * (Td - Tb) \tag{14}$$

where

Qd = Duct heat losses (Btu/hr)
Ad = Area of the ductwork (sqft) (typically five times the length)
Ud = U-value of the ductwork (1.0 for uninsulated; .48 for insulated ducts)
Opfr = Fraction of time the system is operating. This is typically the average hourly heat load for the entire house divided by the system heating capacity (Btu/hr). It should be determined for each time increment.
Td = Temperature of ducts (approximately 120 F., 105 F. for heat pumps)
Tb = Below grade space temperature (F.)

Unheated Below Grade Spaces

Two common types of below grade spaces, the unheated basement and the ventilated crawlspace present a special analytic problem. Often heat loss cannot be directly solved since total heat loss is a dynamic function of the interrelation of space equilibrium temperature, heat flow through the common area and temperature dependent internal gains.

A zone temperature model has been created that allows the basement to be simulated as an unheated space. This is accomplished by estimating an equilibrium temperature in the unheated space such that heat flow through the common area (typically R-4 joists) is balanced by losses from the below grade space net the internal gains within the space.

$$Qf = Qw + Qf + Qv - Qint \tag{15}$$

where

Qf = Heat losses through the common floor (Btu/hr)
Qw = Heat losses from below grade walls (Btu/hr)
Qf = Heat losses from below grade floors (Btu/hr)
Qv = Heat losses from air infiltration (Btu/hr)
Qint = Heat gains from hot water tank or furnace (Btu/hr)

It is possible to directly estimate the temperature in an unheated below grade space with the Profile method through the use of the conventional heat balance equation:

$$T_b = \frac{T_{room}\,(UA_{common}) + T_a\,(UA_{awa} + UA_{infil}) + T_g\,(UA_{wa} * FD_w) + T_{dg}\,(UA_f * FD_f) + Q_{int}}{UA_{common} + UA_{awa} + UA_{infil} + UA_{wa} * FD_w + UA_f * FD_f} \qquad [16]$$

where

Tb = temperature in unheated below grade space (F.)
Troom = temperature in heated space (F.)
Ta = outside ambient temperature (F.)
Tg = ground temperature at average wall depth (F.)
Tdg = ground temperature at slab floor depth (F.)
UAcommon = heat loss coefficient for common area (Btu/hr-F.)
UAawa = heat loss coefficient for above grade wall area (Btu/hr-F.)
UAinfil = heat loss coefficient for air infiltration (Btu/hr-F.)
UAw = heat loss coefficient for below grade wall (Btu/hr-F.)
UAf = heat loss coefficient for slab floor (Btu/hr-F.)
FDw = below grade wall decrement factor (dimensionless)
FDf = slab floor decrement factor (dimensionless)
Qint = internal heat gains in below grade space (Btu/hr)

This makes it possible to explicitly model the performance of unheated basements and crawlspaces. An iterative procedure is necessary when internal gains are temperature dependent such as those from ductwork.

USING THE METHOD

The proposed method is simple to use. The most difficult aspect is the calculation of the undisturbed ground temperature. This is estimated for the weather and soil conditions at the appropriate location for three depths--the half depth of the below grade wall, and the depth of the slab floor and the depth plus the slab floor quarter width. We chose an uninsulated basement for our calculation example since studies have shown the greatest disagreement between methods for this case (MacDonald et. al., 1985).

To illustrate, we will calculate heat loss for the month of January for a basement with seven feet below grade and no insulation on the interior walls. There is one foot of exposed concrete above grade also uninsulated. The slab floor is uninsulated and has a length of 45 feet and a width of 30 feet. The added R-value of the concrete and interior air films is 1.5 hr sqft/Btu for both the walls and floors. The interior will be maintained at 70 degrees. The basement is reasonably air tight with the average air infiltration rate estimated to be .15 air changes per hour and the air density ratio for Missoula estimated at .90. A hot water tank is located in the basement with a system heat loss coefficient of 5.0 Btu/hr F. and a 140 degree hot water set temperature. Soil conductivity is assumed to be 0.6935 Btu/ft F. (consistent with Mitalas' medium conductivity case) with a diffusivity of 0.6 sqft/day. The air and ground temperatures are given for Missoula, Montana in TABLE II.

TABLE II. MONTHLY AIR AND GROUND TEMPERATURES IN MISSOULA, MONTANA

Month	Ambient	3.5 ft	7 ft	14.5 ft
Jan	20.8	34.9	42.1	47.8
Feb	27.2	31.2	38.0	45.8
Mar	33.3	31.4	36.0	43.8
Apr	43.9	35.5	36.7	42.3
May	52.2	42.3	39.8	41.8
Jun	58.9	50.1	44.5	42.4
Jul	66.6	56.8	49.6	43.9
Aug	65.0	60.5	53.7	45.9
Sep	55.3	60.3	55.7	47.9
Oct	44.1	56.3	55.0	49.4
Nov	32.3	49.4	51.9	49.9
Dec	24.7	41.6	47.2	49.3

Average Ground Temperature = 45.9 F.
Average Ground Temperature Amplitude = 22.9 F.

CALCULATION PROCEDURE

1. Estimate Decrement Factors for Below Grade Walls and Floors:

For walls:

$Uw = (2/\pi) * k/D * Log [1 + 1/R /(2/\pi * k/D)]$
$Uw = .1544$
$FDw = R/ (1/UW)$
$FDw = 1.5/6.4757 = .2316$

For floors:

$FDf = R/ [R + W/2 + D * \pi /4/k)$
$FDf = 1.5/ (1.5 + 22 * .7854/.6935) = .0568$

2. Estimate the Hourly Heat Loss for the Wall Above Grade:

$Qwa = 1/R * Awa * (Troom - Tamb)$
$Qwa = 1/1.5 * 150 * (70 - 20.8) = 4,920$ Btu/hr

3. Estimate the Hourly Heat Loss for the Walls Below Grade:

$Qw = FD * 1/R * Aw * (Troom - Tsoil,d)$
$Qw = .2316 * 1/1.5 * 1,050 * (70.0 - 34.9) = 5,690$ Btu/hr

4. Estimate the Hourly Heat Loss for the Floor:

Qf = FD * 1/R * Af * (Troom - Tsoil,d)
Qf = .0568 * 1/1.5 * 1,350 * (70.0 - 42.1) = 1,426 Btu/hr

5. Estimate Infiltration Heat Loss:

Qv = Vo * .018 * ADR * ACH 8 (Troom - Ta)
Qv = 10,800 * .018 * .9 * .15 * (70 - 20.8) = 1,231 Btu/hr

6. Estimate the Internal Heat Gains:

Qint = UAhw * (Thw - Tb)
Qint = 5.0 * (140 - 70) = 350 Btu/hr

7. Estimate the Total Monthly Heat Loss:

Qt = (Qwa + Qw + Qf + Qv - Qint) * 24 hrs * 31 Days
Qt = 9,656,851 Btu or 2,829 kWh

This process is continued for each month until the calculations are completed for one year. The results of the annual calculation is summarized in Table III.

Table III. EXAMPLE ANNUAL CALCULATION FOR BASEMENT

Month	Above	Wall	Floor	Infilt	Int Gains	Total
			Watts/hr			
Jan	1,442	1,667	418	378	102	3,803
Feb	1,254	1,843	479	329	102	3,803
Mar	1,075	1,832	508	282	102	3,590
Apr	756	1,638	499	200	102	3,000
May	522	1,313	452	136	102	2,321
Jun	325	943	413	85	102	1,664
Jul	100	627	391	26	102	1,042
Aug	146	451	361	38	102	894
Sep	431	461	330	113	102	1,233
Oct	759	654	309	199	102	1,819
Nov	1,105	979	301	289	102	2,572
Dec	1,327	1,349	341	348	102	3,263

October - April Heat Loss = 15,852 kWh

Results for Various Floor Types

Four floor types have been analyzed using the model. These include both heated and unheated basements, crawlspaces and slab on grade configurations. Each has been analyzed with no insulation and R-19 on basement walls and crawlspaces joists and R-5 under the entire slab in the case of the slab on grade. The configuration chacteristics are identical to the previous example. A greater air change rate of 0.3 ACH is assumed for the unvented crawlspace. The joist floor is assumed to have an uninsulated R- value of 4.0 hrsqft/Btu. The slab insulation for the basement types include the R-19 wall insulation as well. Results are summarized in Table IV:

TABLE IV. HEATING ENERGY USE OF FLOOR TYPES, MISSOULA, MONTANA
October - April
kWh

Configuration	R-0 Wall R-0 Slab	R-19 Wall R-0 Slab	R-19 Wall R-5 Slab
Heated Basement	15,852	5,122	4,792
Inheated Basement	7,973	3,829	3,630
Crawlspace	7,974	2,944	2,496*
Slab on Grade	5,502	NA	3,411

*Both R-19 under joists and R-5 crawlspace wall insulation.

The results indicate the relative efficacy of the various techniques. These results can be used with an economic model to choose appropriate levels of foundation insulation (Parker, 1986).

Uninsulated basements, either heated or unheated consume a large quantity of heat. An insulated crawlspace floor offers the best thermal performance of the options. Slab insulation appears to offer reasonable thermal savings for heated basements or slab on grade construction. Even then, because of the form of the effective soil heat flow path distance, the most cost effective insulation will be around the slab perimeter.

Comparison with the Mitalas and Yard Methods

Study of the Profile method against the Mitalas and Yard methods has shown good agreement for basement types over a variety of climates. Using the above basement parameters, Figure 1 compares the hourly predicted heat loss in watts per hour for the described insulated basement in Missoula, Montana. Although a slight difference is noted in the fall months, the three methods yield similar results. Figures 2 and 3 show results of the three methods for the basement walls and floors. Again agreement is fairly good. Most of the differences can be explained by variation in estimated heat load for the floors. The floor shape factors in the Mitalas method that govern

Figure 1:

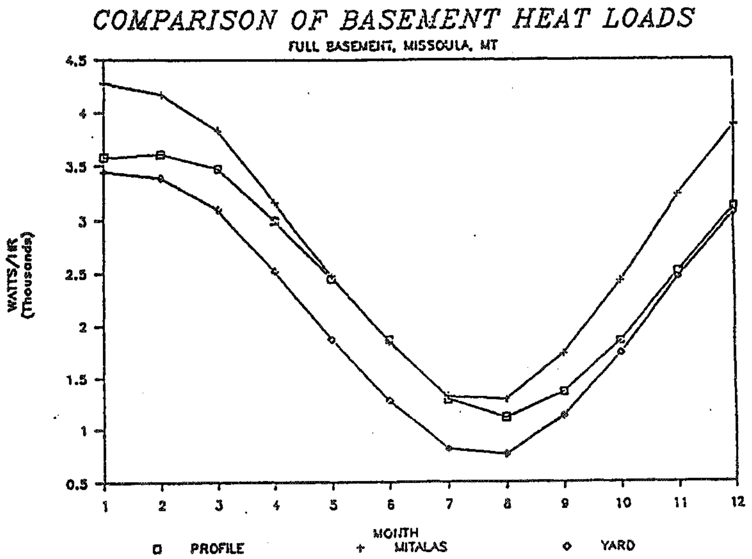


Figure 2:

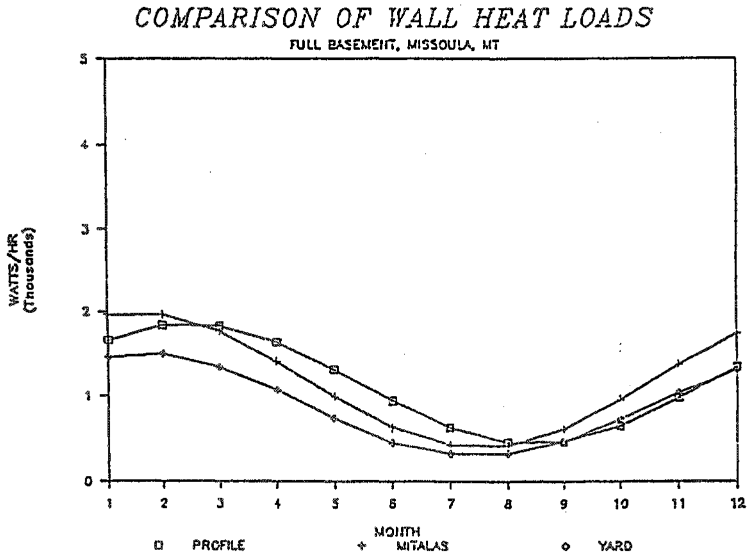
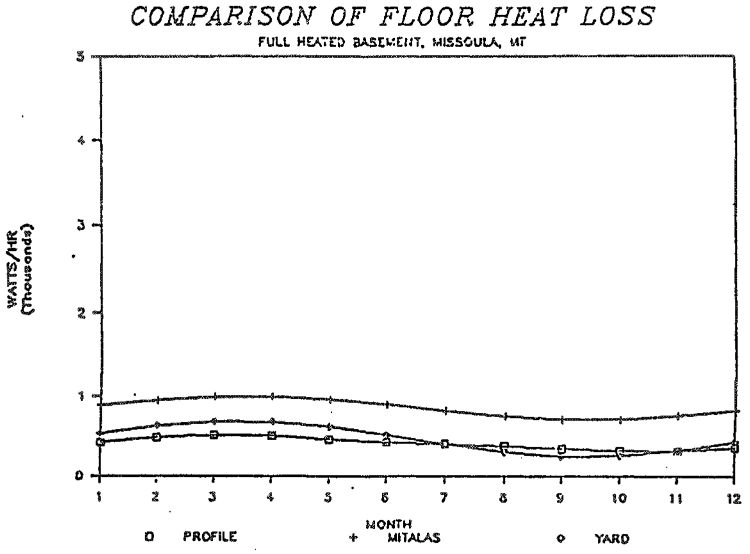


Figure 3:



conductivity were arbitrarily increased by 50% to agree with monitored results (Mitalas, 1982). Also, Mitalas assumes that the deep soil conductivity is 12.5% greater than that of the upper soil. The Yard method does not contain such adjustments and consequently agrees better with the results of the Profile method.

Limitations

The method includes a number of simplifications. The model is essentially a two dimensional representation of a three dimensional heat flow phenomenon. Real basements with corners will lose more heat since the area adjacent to the corners have a lower effective field distance to the undisturbed ground temperature due to the "fin effect". Also, the proposed method cannot estimate performance for vertical perimeter insulation for slabs or other 'L' shaped insulation schemes in common use.

The fact that slabs are most typically insulated along the perimeter makes it desirable to increase the various insulation segments in the model. A five segment model is a practical representation with upper and lower wall segments and also perimeter and center segments for the slab floor. This can be accomplished by merely increasing the estimated ground temperature depths and the calculation segments in the model.

The aforementioned disparity between estimated and measured heat flux through basement floors needs more scrutiny. Effects of proximity to the water table on in situ soil conductivity, mass transfer and soil moisture phase change effects are poorly understood and probably responsible for most of the observed discrepancies.

SUMMARY

A general method for estimating heat loads from various floor types has been illustrated. The Profile method is based on extension of the Decremented Average Ground Temperature method (DAGT) into a more flexible framework that can estimate losses from below grade walls and floors of varying depths. A simple set of algorithms can be used to estimate heating and cooling loads for basements, crawlspaces and slab on grade floor types. Effects of soil conductivity, soil heat capacity and earth contact cooling can be explicitly modeled. The model gives good agreement with other methods such as the shape factor method of Mitalas (1982) and the dimensionless parameter method of Yard (1984).

References

Akridge and Poulos, 1982. A Simple Manual Method for Calculating Thermal Losses from Underground Walls, Georgia Institute of Technology, Atlanta, GA.

Boileau, G.G. and Latta, J.K., 1968. Calculation of Basement Heat Loss, National Research Council of Canada, Tech Paper #92, Ottawa, ONT.

Claesson, J. and Eftring, B., 1980. Optimal Distribution of Thermal Insulation and Ground Heat Losses, D33:1980, Swedish Council of Building Research, Stockholm.

Collins, W.D., 1925. "Temperature of Water Available for Industrial Use in the United States," U.S.G.S. Water Supply Paper #520, Washington, D.C.

Kimura, Shukuya and Tanabe, 1983. "Estimation of Annual Heat Loss and Heat Gain from Earth Contact Floors and Walls with Insulation in Temperate Climate Regions," 1983 Conference on Earth Sheltered Buildings, Waseda University, Tokyo, Japan.

Kusuda T. and Achenbach, P.R., 1965. Earth Temperatures and Thermal Diffusivity at Selected Stations in the United States, Report 9493, National Bureau of Standards, Washington D.C.

Kusuda, T., and Saitoh, T., 1980. Simplified Heating and Cooling Energy Analysis Calculations for Residential Applications, National Bureau of Standards, NBSIR 80-1961, Washington D.C.

Labs, K., 1984. "Experiences and Expectations of Earth Coupled Buildings Research," Proceedings of the Passive and Low Energy Alternatives International Conference, Mexico City, Aug., 1984.

MacDonald, G.R., Claridge, D.E. and Oatman, P.E., 1985. "A Comparison of Seven Basement Heat Loss Calculation Methods Suitable for Variable Base Degree Day Calculations," ASHRAE Transactions, Vol. 31, Pt. 1.

Mitalas, G.P., 1982. Basement Heat Loss Studies at DBR/NRC, National Research Council of Canada, Ottawa, ONT.

Parker, D.S., 1986. "Economic Optimization of Foundation Insulation Levels," Proceedings of the 11th Passive Solar Conference, Boulder, CO.

Shipp, P.H. and Broderick, T.B., 1983. "Comparison of Annual Heating Loads for Various Basement Wall Insulation Strategies by Using Transient and Steady State Models," Thermal Insulation, Materials, and Systems for Energy Conservation in the '80s, Special Pub STP 789, ASTM, Philadelphia, PA.

Yard, D.C., Gibson, M., Mitchell, J.W., 1984. "Simplified Relations for Heat Loss from Basements," ASHRAE Transactions, Vol. 90, Pt. 1.