Ground Coupled Heat and Moisture Transfer from Buildings Basement

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Abstract: - In this paper are presented the effects of moisture on the heat transfer to the ground, a building with a basement located at a depth of 2 [m]. For this, they studied the effects of precipitation, groundwater depth and foundation insulation, on the ground heat transfer through the building foundation. In order to illustrate the dependence of heat transfer on thermal conductivity of soil, regarding its moisture content were compared results obtained by two different ways, respectively : 1) with a two-dimensional (2D) finite element heat and moisture transfer program; 2) with a simple heat conduction model.

Key-Words: -Ground Coupled Heat and Moisture Transfer, Basement Heat Transfer, Heat Loss

1 Introduction

The ground acts as an continuous absorbing heat environment from buildings basements, especially when those are not properly insulated. Therefore, in many cases the heat loss to the ground is a significant part of the total heat loss of a building. Heat transfer by conduction to the ground is determined by the thermal conductivity of the soil, which in turn is influenced by three parameters namely: soil type, amount of soil moisture and soil temperature.

This paper has two objectives: 1) to study how varies the heat transfer from foundation to ground with the: soil type, rainfall on soil surface, conditions related to the season and the depth of groundwater, 2) to determine how comprehensive a simple heat conduction model can explain the thermodynamic properties variations with soil moisture changes.

Ground coupled heat transfer from buildings foundations has been extensively studied, with analytical, numerical and experimental methods. In many cases, ground heat transfer modeling has made the following simplifying assumptions:

- constant soil properties;
- a given value of the soil thermal conductivity;
- a simplified treatment of the surface energy balance;
- has not included precipitation or ground water table considerations.

Delsante and Stokes [2] have attempted to provide analytical solutions of slab-on-grade problem. Shen [6, 7], developed a simplified thermal analysis of earth-sheltered buildings using a Fourier-series boudary method and perform detailed simulations of coupled heat and moisture transfer. Claesson and Hagentoft [1] developed analytical procedures to predict heat loss from slab-on-grade floors. Krarti, Claridge and al. [4, 5] developed a semi-analytical solution for two and three-dimensional rectangular slab-on-grade floors using the Interzone Temperature Profile Estimation (ITPE) technique.

2 Computational Parameters and Boundary Conditions

The studied parameters were: precipitation onto the soil surface (with and without precipitation), ground water depth (9, 6, and 3 m), basement uninsulated (insulated and uninsulated basement) and the weather season (with summer and winter conditions). Was used in calculations the general basement configuration of a building whose geometry and boundary conditions used are shown in Fig. 1.

The used boundary conditions were [3]:

- the ground surface boundary conditions: a long wave emittance of 0.9, and a reflectance of 0.23.

- above the floor boundary conditions: constant air temperature, respectively 20 [°C];
- the convective heat transfer coefficients for the basement wall equal to 8.0 [W/m^{2}K] and from the floor equal to 5.8 [W/m^{2}K];
- along the sides boundary conditions: zero heat and moisture fluxes;
- the bottom boundary conditions, representing a ground water table depth of 9 [m], was maintained at a matric potential ψ = 0.0 m (i.e. saturated soil) and T = 10 [°C].

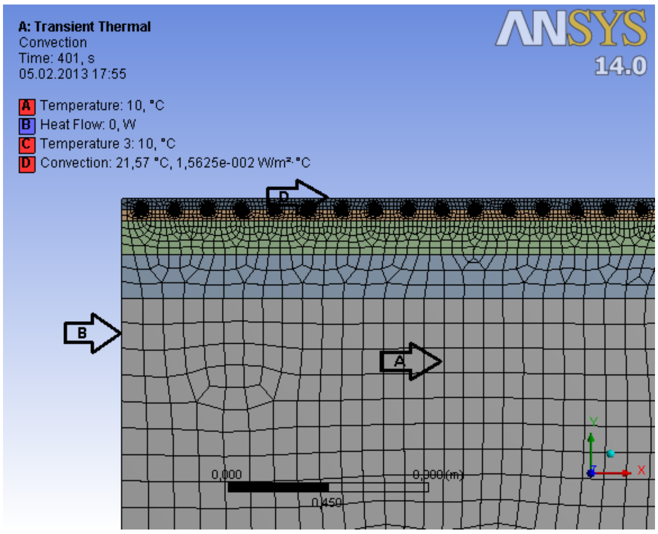

Fig.1.Mesh and boundary conditions used for the basement simulations.

The thermal conductivity of the soil is calculated as a function of soil type, moisture content, and temperature. Moisture transport within the gravel under the slab was neglected. The concrete, gravel and insulation material properties used in the simulations are shown in Table 1.

Material	thick. (cm)	ρ (kg/m^3)	k (W/mK)	cp (J/kgK)
Concrete floor	10	2400	1.7	840
Concrete wall	25	2400	1.7	840
Gravel	15	1800	1.5	840
Insulation	5	40	0.042	1460

Table 1. Material properties used for ground heat transfer simulations.

In order to obtain the initial conditions for summer simulations (initial temperature and humidity) we have started with a vertical linear distribution, for both temperature and humidity. Then a two years initialization period followed, when we have calculated the soil temperature and humidity by means of sinusoidal varying weather conditions and adding 25 mm of rain each week. Summer simulations have followed a 90 days period (3 months).

In order to obtain the initial conditions for winter simulations (initial temperature and humidity) we have started with the data obtained after simulating two years of summer, and, with the winter conditions detailed in Table 2. Winter meteorological parameters (Table 2) were determined by running a year from the initial conditions. Winter simulations were carried out for a period of 30 days (a month). Daily atmospheric conditions used in calculus (solar radiation, temperature and wind speed) are given by equations (1), (2) and (3). Coefficients used in equations (1), (2) and (3) are detailed in Table 2. Have been simulated two seasonal meteorological conditions: summer and winter. Solar radiation was considered zero if the values given by equation (1) were negative. [3]

$$G = G_m + G_a \cdot sin\left(\pi\left(\frac{2t}{24} - \frac{1}{2}\right)\right) (1)$$

$$T = T_m + T_a \cdot sin\left(\pi\left(\frac{2t}{24} - \frac{2}{3}\right)\right) (2)$$

$$u = u_m + u_a \cdot sin\left(\pi\left(\frac{6t}{24} - \frac{1}{2}\right)\right) (3)$$

Meteorological parameters for heat transfer through soil used in the simulations are shown in Table 2 [3].

Variable	Units	Summer	Winter
G_m	Wh/m^2	0.0	0.0
G_a	Wh/m^2	900	450
$T_{drybulb-m}$	ºC	15	0.0
$T_{drybulb-a}$	ºC	10	5
$T_{dewpoint-m}$	ºC	7.5	-1
$T_{dewpoint-a}$	ºC	5	4
u_m	m/s	4	4
u_a	m/s	2	2
precip. (slab base)	mm	25 50	25

Table 2. Weather parameters used for ground heat transfer simulations.

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3. Results

3.1. Effect of Precipitation and Insulation on Basement Heat Transfer

The study of the effect of precipitation and insulation on heat transfer from the basement to the soil was performed for both summer and winter conditions. This translated into a number of eight cases, as shown in Table 3.

nr.	Case
1	Summer-rain-insulation
2	Summer-dry-insulation
3	Summer-rain-no insulation
4	Summer-dry-no insulation
5	Winter-rain-insulation
6	Winter-dry-insulation
7	Winter-rain-no insulation
8	Winter-dry-no insulation

Table 4. Cases to show effects of surface moisture on ground-coupled heat transfer from basements.

Rain situations resulted by adding 40 mm of rain on day 7th of simulations. Daily heat losses of basement wall for the summer situations are represented in Fig. 2.

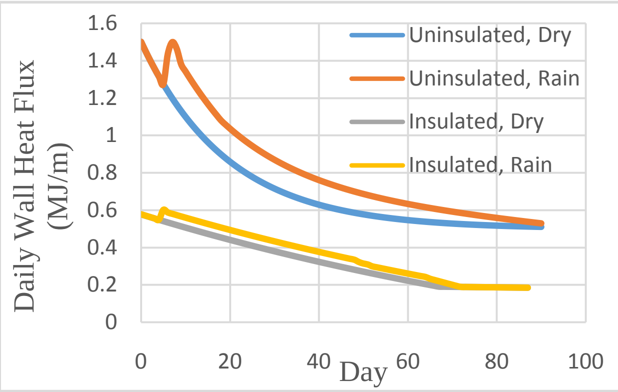

Figure 2. Daily basement wall heat loss for the summer cases with 40 mm of rain on day 7.

For the summer situation, by analyzing the chart we can make the following observations:

- The continuous decrement of heat losses during summer period, for both situations (insulated and uninsulated) occurs because the soil gradually dry;
- Because the basement is located at -2 m, the heat losses are only slightly affected by rain on the soil surface;
- When rain is added, the heat losses through the uninsulated wall increases more that those through the insulated wall;
- During summer time, heat losses through basement floor represented approximately 65% from total heat losses, thus being larger than those through walls;
- Insulating the basement walls has the most important effect on reducing the heat losses in both situations: with and without rain. This reduction is about 50%.

For the winter situation, that is not represented in Fig. 6 chart one can make the following observations:

- Total heat losses both for the uninsulated and insulated basement haven't been influenced by the addition of rain on the soil surface;
- As in the summer situation, basement wall insulation has the most important influence on the reduction of heat losses. In the winter situation this reduction is greater than the reduction in the summer situation, being approximately 70%.

3.2. Effect of Ground Water Depth on Basement Heat Transfer

To study the effects of ground water depth on the heat transfer, the water table was simulated at depths of 9 [m], 6 [m], and 3[m].

The water table temperature was considered as:

- With the water table at 9 [m] and 6 [m] depth, the summer temperature was assumed to be 10 [ºC] and the winter temperature assumed to be 7 [ºC];
- With the water table at 3 [m] depth, the summer temperature was assumed to be 10 [ºC] and the winter temperature assumed to be 5 [ºC].

The average daily heat losses using the winter conditions for the three different water table depths, are showed in Figure 3.

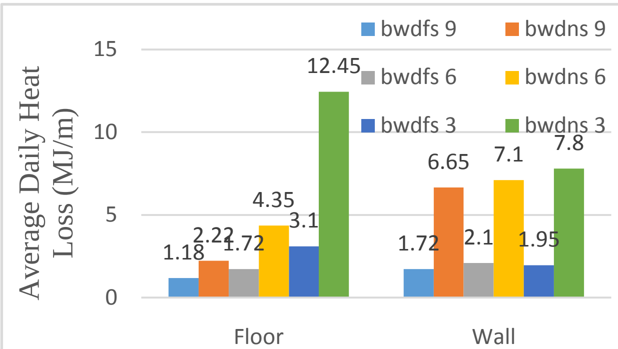

Figure 3. Average daily basement heat losses for winter insulated and uninsulated cases with ground water depths of 9 m, 6 m and 3 m.

From the graph shown in Figure 3, results the followings:

1) the water table depth has the largest effect on the floor heat losses, respectively:

- the increases in the total heat loss from the 9 [m] depth to the 6 [m] depth are 121% for the insulated cases and and 132% for the uninsulated cases;
- the increases in the total heat loss from the 9 [m] depth to the 3 [m] depth are 156% for the insulated cases and and 228% for the uninsulated cases.

2) the wall heat losses are also much higher for the uninsulated cases than the insulated cases.

3.3. Comparison of the Heat Transfer Model with a Heat and Moisture Transfer Model

From the comparison of the heat transfer model with a heat and moisture transfer model, were performed simulations using hourly weather data (solar radiation, temperature, humidity and precipitation), measured in 2011 in Bra□ov, Romania. The computational parameters and boundary conditions that was considered:

- the water table was considered at -6 [m] depth;
- insulation was considered to the outside of the basement wall extending 1.0 [m] down from the top. Thickness insulation was 5 [cm]. Thermal resistance of wall was: R = 1,39 [m^2K/W];

The used boundary conditions were [3]:

- the ground surface boundary conditions: vegetation height of 10 [cm], a long wave emittance of 0.9, and a reflectance of 0.23;
- above the floor boundary conditions: constant air temperature, respectively 20 [°C]; the convective heat transfer coefficients for the basement wall equal to 8.0 [W/m^2K] and from the floor equal to 5.8 [W/m^2K];
- along the sides boundary conditions: zero heat and moisture fluxes;
- the bottom boundary conditions, representing a ground water table depth of 9[m], was maintained at a matric potential ψ = 0.0 m (i.e. saturated soil) and T = 10 [°C].

The working procedure has been as follows:

It has been done a simulation with the heat and mass transfer model and a simulation with the heat transfer model, using the thermal conductivity of soil k = 1,80 [W/m K]. This is the thermal conductivity of soil at the critic humidity value φk = 0,09, representing approximately value of wilting point of the soil. Comparing these two simulations has resulted that the annual energy loss using a heat transfer model with a soil thermal conductivity of k = 1.80 [W/m K] is lower than the energy loss predicted by the heat and mass transfer model.

Further simulations were performed with the heat transfer model using higher values of thermal conductivity of the soil, until the annual energy losses obtained with the two models (heat transfer model and heat and mass transfer model) had similar values. Thus determined the thermal conductivity of the soil for the annual energy loss using a heat transfer model are close to those obtained with the heat and mass transfer model, respectively k = 2,04 [W/m K].

The results of the three simulations are shown in the graph in Figure 4.

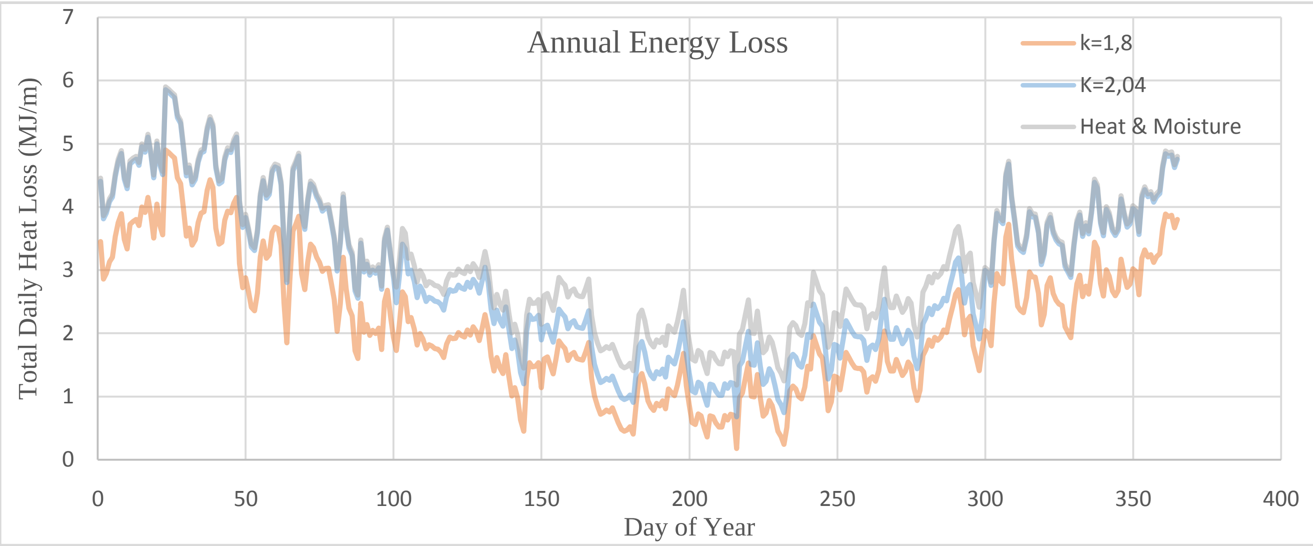

Figure 4. Daily total basement heat loss values determined by the heat and moisture transfer model and the heat transfer model

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4. Summary and Conclusions

In this paper the effects of moisture on the heat transfer to the ground, a building with a basement located at a depth of 2 [m] was investigated using a heat and mass transfer model. The conclusions of this study are:

- The effect of precipitation is the increasing of the thermal conductivity of the soil around buildings, which contributes to increased heat transfer by conduction, from the building foundation to the ground. This effect is greater in summer conditions, especially if the building is not insulated foundation.
- Ground surface conditions has a greater influence over the heat transfer through basement walls than through the grade slab.
- The depth of the ground water has an important influence over the heat transfer between buildings and ground, especially in basement structures and more so if the basement it isn't insulated.
- Also, to illustrate the dependence of heat transfer on thermal conductivity of soil, regarding the moisture content, in the paper was conducted a comparison between the annual energy losses obtained in two ways, namely: using a bi-dimensional finite element heat and mass transfer software, and a simple conduction based heat transfer model. Comparing the results it can be concluded that the simple model of heat conduction can provide as good a solution as a model of heat and mass transfer, subject to the adoption (selection) of the value of the thermal conductivity of the soil.

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