Nonsteady Heat Losses to the Ground from a Building with Heated Underground Floor or Slab on Ground

E Levin1,*, A Okunev1,2

1Research Institute of Building Physics (NIISF RAABS), 21 Locomotivny pr., Moscow, 127238, Russia
2State University of Land Use Planning (SULUP), 15 Kazakova str., Moscow, 105064, Russia

E-mail: evlev@list.ru

Abstract. Numerical model and research results of nonsteady heat transfer between building and ground basement are in the article. Two most common cases of heat contact between building and ground basement are compared: building with heated underground floor and building on the slab on ground. Nonsteady heat losses over period about several years of building exploitation are analyzed that made possible to establish a patterns of heat transfer between building and ground with taking into account of ground around of building inertness. Heat losses from building represented using mean values at the one unit of length of building perimeter. In case of building with underground floor calculated nonsteady heat loses of floor and underground wall are shown. Also shown results of nonsteady heat transfer to ground from outdoor air and groundwater. Numerical methodic used in research based on explicit finite-difference method applied to boundary value problem of nonsteady heat transfer in ground. The problem taking into account existence of moveable groundwater without heat transfer calculation in the volume of groundwater.

1. Introduction
Heat loses via ground significantly influences on energy saving of first floors, underground floors and low-rise buildings. Solving of heat transfer task to obtain the heat loses quantities is difficult because of the process complicated and many factors must be taken into account. One of factors is high ground thermal capacity involved in heat transfer. Ground volume acts as heat accumulator operates in nonsteady regime. In ground volume at relatively small depth, close to stationary temperature and heat flows distributions never realizes [1].

Heat transfer in ground basements calculation methods includes analytic [2 – 9] and numerical [1, 8, 10 – 13] ones. The first are easy to use in practice but often gives only estimation results. Analytic methods almost unable to consider in detail heat transfer nonstationarity. Numerical methods have no this disadvantage and making possible to simulate complicated heat transfer processes and they are main instrument to researches and to engineering calculations. Analytical and numerical methods supplemented by experimental data (for example, [11, 13]) are used to develop engineering methods of calculation and for investigations.

With using of analytic and numerical modeling there are number of important tasks have been solved by present time, including the basic laws of heat loss via the ground. For example in [5-7, 9,
10-13] heat transfer in case of slab on ground was studied, in [1] – considered underground floor, and in [14, 15] analytic studies of groundwater influence on building heat loses are represented. In works [1, 8] shown influence of precipitation and moisture migration in ground volume.

At present most precise methodological guidance to calculations of heat loses via ground is European standard ISO 13370. The standard determines stationary heat transfer coefficients calculation for heated building elements in contact with ground; calculations of mean power for heat loses to each month, to warm and cold seasons, and mean by year. The standard allows to take into account flowing groundwater. Nonstationarity in ISO 13370 taken into account with using sine or cosine law and calculated time shifts that assumes constant and calculated very approximate. The heat transfer mode considered be steady-periodical. In case of much lower heat loses via ground in comparison with heat loses via aboveground building envelope this calculation method is good enough for practice. But in case of low-rise buildings in which heat losses via ground quite significant in overall heat balance more detail calculations may be needed.

The aim of this article is to show nonstationary heat transfer via ground including first several years of building exploitation. Buildings with underground floor and with slab on ground are considered.

2. Methods

2.1. Physical and mathematical model

Study was made with solving of boundary value problem with initial conditions. Calculation area includes ground basement under building and part of ground volume around of building involved in heat transfer. Calculation area bordersurfaces are:

1) ground surface around of building;
2) ground surfaces contacting with basement;
3) remoted from the building vertical ground cuts in which horizontal thermal flows are negligible;
4) bottom ground layer which can be in contact with groundwater or deep enough that vertical heat flows on it are negligible (constant layer temperature).

Two-dimension calculation area with using of equivalent building width \( B' \) was used in study [16].

\[
B' = 2A/P,
\]

here \( A \) – horizontal basement area (m\(^2\)), \( P \)– external perimeter (m).

Heat transfer describes by heat conduction equation:

\[
c \frac{\partial T}{\partial t} + \text{div}(-\lambda \nabla T) = 0,
\]

here \( T \) – temperature (K); \( t \) – time (s); \( c \) – specific heat of ground (J/(m\(^3\) K)); \( \lambda \) – effective thermal conductivity of ground (W/(m K)). In the model ground may consist of different layers in which quantities \( c \) and \( \lambda \) are varies but assumed to be constant in each layer.

To boundary value problem solving are used next boundary conditions:

\[
T = \text{const}
\]

– may be used for border 4);

\[
-\lambda \frac{\partial T}{\partial n} = 0
\]

– using for border 3) and 4);

\[
-\lambda \frac{\partial T}{\partial n} = \frac{\alpha (T(t)_{\text{air}} - T)}{\alpha R + 1}
\]

– using for borders 1) and 2). Here \( \alpha \) – heat transfer coefficient to outdoor air (W/m\(^2\) K), \( T_{\text{air}} \) – outdoor temperature that may vary in time (K), \( R \) –insulation thermal resistance (m\(^2\) K)/W.
\[ \lambda_m \frac{\partial T}{\partial x} = \lambda_{m+1} \frac{\partial T}{\partial x} \]  

(6)

– using to borders between different ground layers;

\[ \lambda \frac{\partial T}{\partial n} = \bar{T}^w - T \]  

(7)

– using for border 4) in case of groundwater flowing.

In (7) \( \bar{T}^w \) – groundwater inflow to the calculation area temperature and

\[ \bar{R}^w = \frac{2}{3 \lambda^w} \left( \frac{2a^w}{w} L \right)^{1/2} \]  

(8)

– average groundwater layer thermal resistance, where \( \lambda^w \) – effective thermal conductivity of groundwater layer, \( w \) – mean water flow density \((m^3/m^2s)\), \( a^w = \lambda^w/c^w \) – thermal diffusivity of groundwater layer \((m^2/s)\), \( c^w \) – groundwater layer specific heat, \( L \) - calculation area length in direction of groundwater flow. Thermal resistance (8) is mean value for overall calculation area and estimated by defining of thermal disturbances penetration depth in groundwater layer volume by formula: \( \Delta x \approx (2a^w \Delta t)^{1/2} \). Groundwater temperature constancy assumption is many cases quite correct because on relatively low depth (about 5 meters) and more it is near to mid-annual value [2].

As the initial condition to boundary value problem (2) – (7) has used one–dimension steady–periodical temperature distribution on depth \((x)\) \( T^* (t, x) \) calculated to open ground for climatic given by function \( T(t^*) \):

\[ T(t_0, x, y, z) = T^* (t_0, x) \]  

(9)

For boundary value problem (2) – (9) the Dufort-Frankel finite difference method [17-20] is used. The method is explicit and provide high numerical stability.

3. Results and discussion

Comparison analysis of heat loses to ground from building with heated underground floor and from building with slab on ground are shown below.

Calculation was carried out with using next parameters:

**Underground floor.** Equivalent width \( B' = 14 \text{ m} \). Depth of floor \( h = 2 \text{ m} \). Floor and wall insulation thermal resistance are same \( R_f = R_w = 2.0 \text{ (m}^2\text{K})/\text{W} \). Depth of ground water \( H = 10 \text{ m} \). Groundwater layer thermal resistance \( \bar{R}^w = 0.01 \text{ (m}^2\text{K})/\text{W} \). Such value of thermal resistance corresponds relatively fast groundwater flow with flow density about \( w \approx 10^{-3} - 10^{-4} \text{ m}^3/\text{m}^2\text{s} \).

**Slab on ground.** In this case all parameters except of \( B' \) used same as in case of underground floor. In aim to unchanging heat contact area between building and ground \( B' \) increased to 18 m.

In both cases considered constant indoor temperature +20°C, effective thermal conductivity of ground \( \lambda = 1.5 \text{ W/m K} \) and specific heat \( c = 2 \cdot 10^6 \text{ J/m}^3\text{K} \). Ground surface around of building considered not insulated (also snow cover and fertile layer are not taken into account) that correspond to maximum heat loses in cold year period.

Nonsteady heat losses calculation results to underground floor case are shown graphically on figure 1a. On figure 1b shown comparison of heat losses to both cases (underground floor and slab on ground). Heat loses \((q)\) represented in daily average quantities on unit of building perimeter length \((W/m)\).
Figure 1. Nonsteady heat loses of building. (a) -- detailed heat losses for building with underground floor, (b) -- underground floor and slab on ground comparison.

On figures also shown outdoor temperature year changing. Used data of outdoor temperatures corresponds to the climate of Moscow (Russia). To calculate was assumed:

- before October of first calculation year there are no building on ground and steady-periodical heat transfer between open ground and outdoor air taking place.
- In beginning of October instantly building rises and heating turned on providing constant inner temperature +20°C.

On fig. 1a heat losses of floor \( q_f \) and wall below ground floor \( q_w \) are shown separately. This heat loses slowly became steady-periodical. Transient period for \( q_w \) is about 1.5 years and for \( q_f \) more longer, about 3 years. Comparing \( q_f \) and \( q_w \) changing character and outdoor temperature oscillation it as able to see that there are no synchronization between heat loses and outdoor temperature. Heat loses maximums are shifted from outdoor temperature minimums. Cause of it is the thermal inertia of ground involved in heat transfer. In fig. 1a \( q_f \) maximum delays to outdoor temperature minimum about 2.5 months and \( q_w \) -- about one month. Less delay to \( q_w \) connected with more closer contact with outdoor air. Also from fig. 1a notable that \( q_f > q_w \) that connected with groundwater influence and with floor area 7 times more than wall area.

On fig. 1a also shown heat accumulated by groundwater \( q_{gw} \) in dependence on time. Heat \( q_{gw} \) is calculated from the area of the table of ground water involved in heat exchange with the building. Feature of heat exchange with groundwater is that transient period before steady-periodical regime almost same as for \( q_f \) but maximums of heat accumulation near to outdoor temperature minimums (time delay about half year). Comparison of \( q_{gw} \) c \( q_f \) shows that in considered example heat loses by underground floor mostly absorbed by groundwater. So moveable groundwater existence role on heat loses of building may be quite significant. Also need to notice that at the building heating start time groundwater not absorb but return heat to ground. After constant building heating start groundwater layer begin to absorb heat and quantity of this heat flow is significant.

Need to notice also from fig. 1a that winter outdoor temperature have prominent oscillations but heat loses dependences are smooth and don’t feel momentary outdoor temperature changing due to ground inertia.

Comparison of heat loses for buildings with underground floor and slab on ground is shown on figure 1b. It can be seen that the processes are similar. Main difference is that the transient period before steady-periodical regime establishment for slab on ground may be much longer than in case of underground floor (in calculated case more than year). Delay of maximum heat loss in relation to the
minimum outdoor temperature for case of slab on ground is higher and oscillation of heat loses amplitude is lower. Significant difference between heat loses by floor between two types of building is mostly connected with groundwater influence. In case of slab on ground length between floor and table of groundwater by two meters bigger than in case of underground floor.

4. Conclusions
Buildings with underground floor and with slab on ground nonsteady heat loses to the ground has been studied by numerical simulation. Influence of groundwater on heat loses was taken into account. Main results of study are:
1) Transient period before steady-periodical regime establishes have scale about several years for considered tasks parameters.
2) With similar contact areas between building and ground, groundwater depth and water flow density, insulation and ground parameters this transient period for slab on ground may be much higher and year heat loses changes lower than to underground floor case.
3) In building with underground floor transient period for wall lower than for floor.
4) Most significant part of building heat loses to ground may be absorbed by flowing groundwater that leads to higher overall losses of underground floor comparing to slab on ground;
5) The maximum and minimum heat losses for both types of buildings are delayed with respect to the annual maximums and minimums of the outdoor temperature.

5. References
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