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COMPUTATIONAL ANALYSIS OF THE EFFECTS OF GROUNDWATER ON HEAT FLOW BELOW BUILDINGS

A mathematical model for describing nonstationary heat flow below a building and its immediate surroundings has been developed using the method of elementary balances. The model was completed for the following two situations: the presence and the absence of groundwater. Annual heat exchange between the building and the surrounding soil was obtained from the calculations. Heat flow to the surrounding subsurface turned out to be at least 20% larger when groundwater is present than in the case where groundwater is not present. The analysis showed that a horizontal thermal insulation is the best method for reducing heat loss and improving the building microclimate.

1. INTRODUCTION

It is well established that groundwater significantly impacts heat exchange between a building and the surrounding soil. This phenomenon, however, has not been sufficiently described in quantitative terms. Thus, the impact of groundwater is often neglected in heat loss calculations. The mathematical model of conduction center consisting of floor, foundation, and soil layers was created for the calculations, while the method of elementary balances was used to define the temperature areas.

2. METHODOLOGY

The shaft well, whose temperature and groundwater level were measured for several years, was located in the southern part of Lesser Poland voivodeship, in the commune of Spytkowice. The well was constructed by digging and lowering the well cas-

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ing. The well encompasses artesian, fissure groundwater in the Beloweskie beds composed of clastic flysch rocks of marine origin. The geological profile consists of a 2 m top layer of loamy Holocene covering with sandstone debris. Weathered, Palaeogenic Beloweskie beds of sandstone and slate are located below the sandstone debris and found deeper, towards the well bottom. The artesian, intersticial-fissure aquifer in the well had a weak, confined subartesian water-table [1], [2].

The boundary conditions for the calculations were based on measurements of air temperature, water temperature in the well, and the depth of the water-table. The measurements were carried out over a period of 15 months (Oct.1, 1987–Dec. 31, 1988). The preceding calculations, being essential for obtaining the initial temperature distribution in the soil, were done in the last three months of 1987. Thermal conditions on the surface of the ground surrounding the building were defined based on the air temperature. The indoor 20 °C temperature was assumed to be constant during the year.

A building without a basement was used for the analysis. It had a floor area of 100 m^2 and three variants of thermal insulation: variant I – without insulation; variant II – with vertical insulation of the foundation (5 cm XPS); variant III – with horizontal insulation under the floor (5 cm XPS). Basic physical properties of the materials used were defined according to data from professional literature [3], [4] (table 1). The physical properties of the soil were estimated from the soil geological structure around the well.

Table 1

Material properties used for calculations

Material	λ (W·(m·K)$^{-1}$)	ρ (kg·m^{-3})	c (J·(kg·K)$^{-1}$)
Floor, foundation wall (concrete)	1.5	2200	840
Bed (damp sand and gravel)	1.6	1700	1000
Compact clay (moist)	1.6	1900	1500
Thermal insulation (extruded polystyrene)	0.035	45	1000

A thermal field of the floor area was determined in order to establish the heat exchange between the building and its floor. This required a complete solution of the problem of nonstationary heat flow in the soil under and around the building. The heat conduction area is three-dimensional and theoretically unlimited; although at some distance from the building the horizontal heat flow diminishes and disappears. If groundwater is found at a depth above the area with fixed temperature within a year, the groundwater temperature and location will determine the thermal conditions of the lower parts of the soil layers (constant-head boundary condition).

These assumptions allow a volume of limited size to be isolated from unlimited space. A cuboid consisting of the soil under the floor, foundation walls, and other elements placed above and below the ground becomes a natural area conducting heat. The outer effects on this system (boundary conditions) are determined by two areas on the upper surface. One is the surface of the floor inside the building, while the second is the surface of the ground around the building influenced by the weather. Figure 1 presents an isolated soil medium, where heat flow from the building to the soil occurs. It is assumed that a horizontal heat flow disappears at a distance not exceeding half the building width. For this reason it is assumed that on the lateral surfaces of cuboid the adiabatic process takes place.

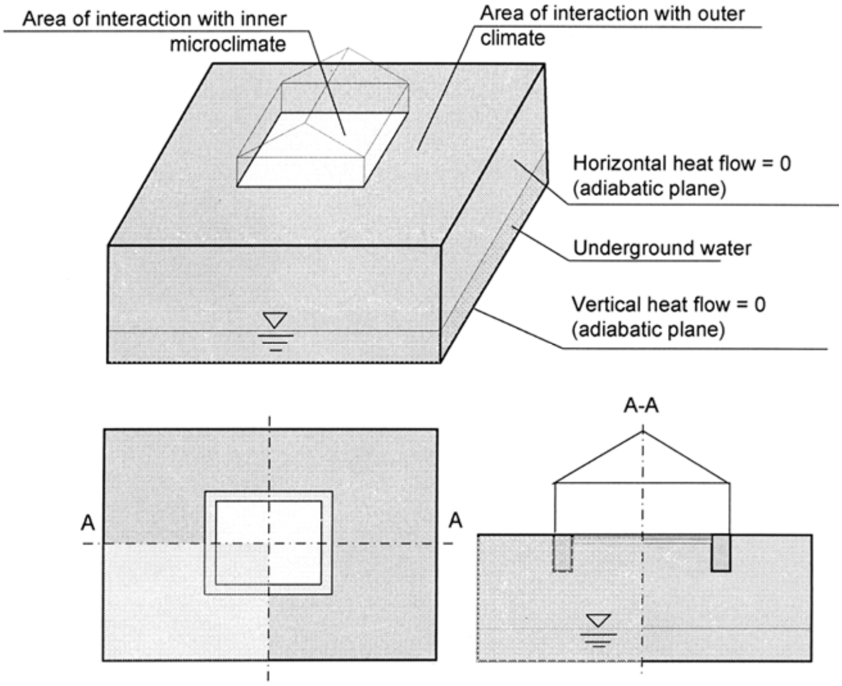

Fig. 1. Physical and geometric model of ground medium for calculation of heat flow (shadowed areas indicate the possibility of narrowing the space due to layout symmetry)

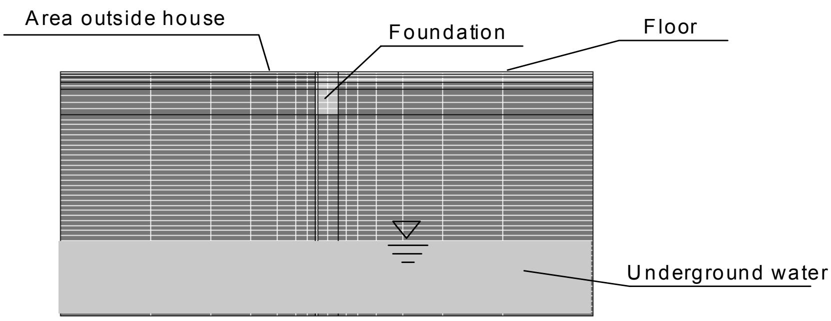

Fig. 2. Division of ground medium into balance-differential elements

The analysis of nonstationary, three-dimensional heat flow in the soil medium was completed using the method of elementary balances [5] and assuming variable physical conditions of the medium, depending on location (parquetry, thermal insulation, foundation, soil). The variable partitioning of the soil medium and geometrical and physical symmetry were used to reduce the number of differential elements (figure 2).

For comparison, the calculation with identical boundary and soil conditions was conducted, neglecting the groundwater effect.

3. RESULTS AND THEIR ANALYSIS

The example of the distribution of soil temperatures on January 19, 1988, when the water table lay closest to the bottom, is shown in figure 3 (1.19 m below ground level).

The annual boundary conditions (air temperature, level and temperature of groundwater) together with the results of the heat flow calculation and the floor tem-

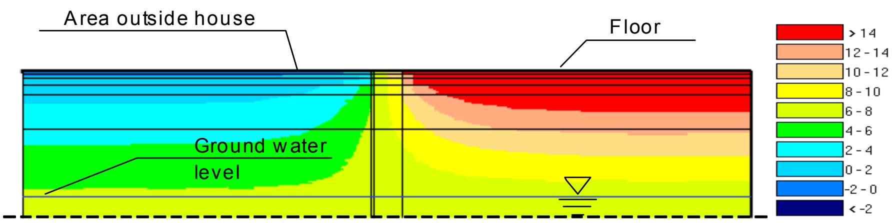

Fig. 3. Temperature pattern in the ground medium on January 19, 1988

Table 2

Mean heat flow and floor temperature with and without the impact of groundwater. In brackets, there are the differences (in percentages) of the same variant but without the impact of groundwater

Case	Heat flow (W)	Floor temperature (°C)
Calculation without groundwater		
Variant I – no thermal insulation	836	18.56
Variant II – vertical foundation insulation	688	18.83
Variant III – horizontal floor insulation	489	19.17
Calculation with groundwater		
Variant I – no thermal insulation	1210 (+45)	17.88
Variant II – vertical foundation insulation	1098 (+60)	18.08
Variant III – horizontal floor insulation	596 (+22)	18.93

perature for the three shell insulation situations are depicted graphically in figure 4. Table 2 presents the results of annual average heat loss and the temperature of the floor surface for the three variants of thermal insulation both with and without taking groundwater into consideration.

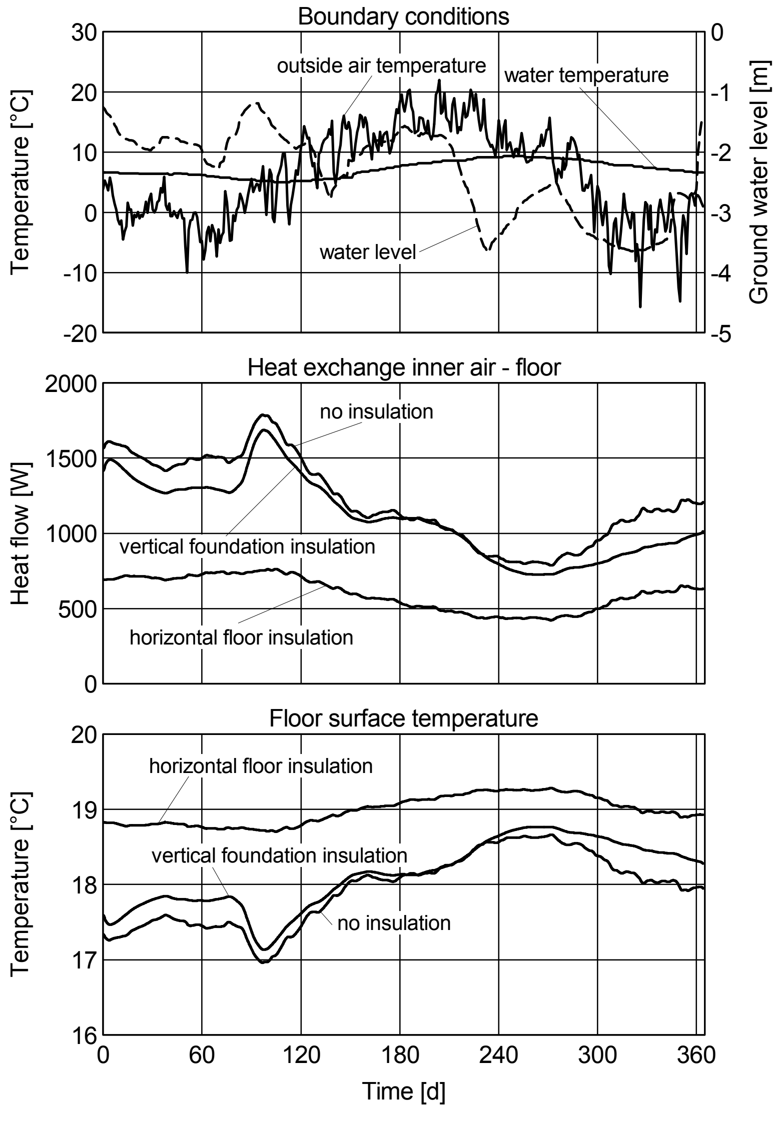

Fig. 4. Boundary conditions (upper diagram), heat exchange between inner air and floor (middle diagram) and floor surface temperature (lower diagram)

4. DISCUSSION OF THE RESULTS

The model to define three-dimensional, nonstationary heat flow in the soil with a variable groundwater level was based on the Fourier law of heat conduction in continuous media. The boundary conditions were formulated from the results of air temperature measurements and the measurements of depth and temperature of groundwater over an extended period of time. Although the results obtained based on this model are more precise than those achieved using approximate methods (for example, method [6]), some simplifying assumptions were made. The influence of solar radiation, evaporation, snow cover, etc., on the soil surface outside the building was neglected. Moreover, actual physical properties of the materials could be slightly different from the values assumed in the calculation. For example, thermal properties of the soil were estimated using macroscopic tests, and the parameters of other materials came from professional literature. Thus, the results seem to be reliable; in relation to absolute values they should be interpreted approximately. From the calculations, the simplifying assumptions should not produce deviations larger than 3–5% [7], [8]. Comparing the results obtained for the three thermal insulation variants analyzed with and without taking groundwater into account and using the same assumptions eliminate those differences. This makes the interpretation of results more reliable.

The assumptions about the geometry of the soil medium model were confirmed by calculations. Soil temperature isotherms outside the building ran horizontally at a smaller distance from the building than it was assumed (figure 3). This is the result of almost the same temperature of underground water occurring at a considerably shallower depth compared with the depth of non-irrigated soil, whose temperature does not fluctuate during a year. This phenomenon causes a great amount of heat loss to groundwater below the central part of the floor. For this reason, heat loss to the soil is higher when the water table is high (figure 4). The results show that overall heat loss to the soil with groundwater present, irrespective of the shell thermal insulation, is much larger compared with the heat loss in the case where groundwater is absent (table 2).

5. CONCLUSIONS

Based on the analysis of the results obtained using the model designed and the assumptions made, it is possible to draw the following conclusions:

1. The depth of the water table and the groundwater temperature have a large impact on the amount of heat loss to the ground as well as on the temperature of the floor. According to the analysis, heat loss to the ground is significantly greater and the floor temperature lower when the water table is high. Heat loss, however, can be greatly reduced by horizontal floor insulation (variant III).

2. Vertical foundation insulation minimizes a heat loss; although in the case of groundwater it plays a minor role since the major part of heat flow is to the groundwater.

3. The annual average heat loss with groundwater present is by 45% greater in the case without any thermal insulation (variant I), 60% greater with vertical foundation insulation (variant II), and 22% greater with floor insulation (variant III) compared with the case where groundwater is not present. The occurrence of groundwater leads to a higher energy consumption for heating and a deterioration of the microclimate due to a reduction in the floor temperature.

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ANALIZA OBLICZENIOWA WPŁYWU WODY PODZIEMNEJ NA PRZEPŁYW CIEPŁA POD BUDYNKAMI

Opracowano model matematyczny oparty na metodzie bilansów elementarnych, aby ustalić niestacjonarny przepływ ciepła w gruncie pod budynkiem i w jego otoczeniu, nie uwzględniając wpływu wody podziemnej i uwzględniając go. W wyniku obliczeń otrzymano roczny obraz wymiany ciepła między budynkiem a gruntem pod podłogą. Przepływ ciepła do gruntu wodą podziemną okazał się o co najmniej 20% większy w porównaniu z przypadkiem, gdy brak wody podziemnej. Analiza porównawcza wykazała, że najlepszym sposobem redukcji strat ciepła i poprawy mikroklimatu budynku jest zastosowanie poziomej izolacji termicznej podłogi.