Investigation of heat losses through ground supported floors of historical buildings

Vera Murgul\(^1,2\)

\(^1\)Peter the Great St.Petersburg Polytechnic University, Polytechnicheskaya, 29, St. Petersburg, 195251, Russia
\(^2\)Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: vera.murgul@mail.ru

Abstract. The paper presents the analysis of structural solutions of the foundations of St. Petersburg historical buildings and the obtained findings. The example of the foundation structure is considered and the calculation of the temperature field and heat flows of the exterior enclosing structures of the building (floor, external wall, foundation) and ground according to "ELCUT" software program is performed. The calculation takes into account the actual thermal and physical properties of the ground and the geometric characteristics of the base. When comparing the calculation results with regulatory requirements, it is determined that there is a need to adjust the regulatory documents for calculation of thermal losses through unheated ground supported floors in historical buildings of St. Petersburg. To ensure the regulatory requirements for temperature on the surface of the floor, it is recommended to perform insulation in the area where the floor adjoins to outer walls.

1. Introduction

The microclimate of buildings aimed for various purposes, the condition of the objects located inside, and the well-being of people significantly depend on the thermal conditions of the enclosing structures including the floors, and of the buried parts of the walls for the rooms of basement levels.

A reliable calculation of thermal conditions of the floor and the buried parts of walls is required for choosing heating systems. This enables providing the required parameters of the microclimate with minimal energy consumption. When determining thermal losses through the ground supported floors and the buried parts of the building, the methodology for calculating thermal losses by zones is applied according to the normative documents of Russia [1–4].

The surface of the floor and walls below the ground level is divided into three zones (I–III) 2 m wide, parallel to the outer wall or counted from the ground level when the structures are buried. Therewith one of the zones can start on the wall and proceed on the floor. The rest of the floor is attributed to the IV zone.

For unheated ground supported floors (with coefficient of thermal conductivity \( \lambda \geq 1,2 \) \( \text{W}/(\text{m}\cdot\text{°C}) \) and walls located below the ground level, the adjusted heat transmission resistance of the floors by zones is taken equal to[1]:

- for zone I - \( R_f = 2.1 \) (m\(^2\)-°C)/W;
- for zone II - \( R_\text{II} = 4.3 \text{ (m}^2\cdot\text{°C)/W;} \)
- for zone III - \( R_\text{III} = 8.6 \text{ (m}^2\cdot\text{°C)/W;} \)
- for zone IV - \( R_\text{IV} = 14.2 \text{ (m}^2\cdot\text{°C)/W.} \)

The heat flow rate in the zones is determined from the dependence

\[
q_i = \frac{t_{\text{int}} - t_{\text{ext}}}{R_i}, \text{ W/m}^2, \tag{1}
\]

where \( t_{\text{int}} \) is air temperature in the room, °C; \( t_{\text{ext}} \) is external air temperature, °C; \( R_i \) is adjusted resistance to heat transfer of the \( i \)-th zone of the floor, (m\(^2\cdot\text{°C})/\text{W}.

The works [5, 6] present the results of a survey of structural solutions of 64 foundations in St. Petersburg buildings built within the period from 18th to early 20th centuries. Typical strip and slab foundations of civil and residential buildings with number of floors from 2 to 6, built before the beginning of XX century in St. Petersburg, are shown in Figure 1.

\textbf{Figure 1.} Types of foundations of historical buildings in St Petersburg
Under foundation footing of 44% buildings under consideration there lies silty-clayed soil which serves as a bearing layer. For the rest 56% of buildings the bearing layer consists of sands of different sizes (littoral deposits of sizes from silty to medium, in general).

Foundations of 82% buildings are made of rubble, granite or limestone laying, and only 18% foundations are made with body brick laying. The depth of the foundations surveyed was from 0.3 to 3 m for sandy bases and from 0.7 to 2.5 m for silty-clayed soils. The most frequent depth of foundation is 1.5-2 m. These values are caused by seasonal depth of soil freezing in the region (1.2-1.4 m).

The width of foundation footing varies from 0.5 to 2.8 m for foundations on a sandy base and from 0.8 to 2.3 m for a silty-clayed basis. Foundations with a footing width of 1-1.5 m are the most widespread.

In works [7-9] there is a statement that the adjusted resistance to thermal transfer of floors by zones in [1] does not take into account such important parameters as thermal and physical properties of soils and geometric characteristics of building bases. Therefore, there is a need to verify the applicability of this calculation method for historical buildings in St. Petersburg.

2. Materials and Methods
In order to analyze the effect of the thermal and physical properties of soils and the geometric characteristics of the building bases on the adjusted heat transfer resistance of unheated floors, the calculation of temperature field and thermal flows of the exterior enclosing structures of the building (floor, external wall, foundation) and the ground by zones was computed using ELCUT program. The structure of the floor and the external wall of the building, as well as the materials and layers of the soil body, were chosen and set according to the survey data [10] presented in Figure 2.

![Figure 2. Example of the foundation of a building in St. Petersburg. 1 - brickwork; 2 - rubble laying of limestone; 3 - concrete floor - 90 mm; 4 - ceramic slab - 10 mm; 5 - concrete - 100 mm; 6 -](image)
backfilling - 300 mm; 7 - screed - 30 mm; 8 - brick pavement - 90 mm; 9 - filled soil - 930 mm; 10 - fine sand

When calculating the thermal state of the soil body, the following conditions are taken:
- air temperature inside the room - \( t_{\text{int}} = 20 \, ^{\circ}\text{C} \);
- external air temperature - \( t_{\text{ext}} = -24 \, ^{\circ}\text{C} \);
- snow cover for urban area is not taken into account.

The stationary problem is considered with the design parameters of the internal and external air according to [1, 3]. The delay in the temperature field of the ground under the change in the external air temperature is not taken into account.

Thermal and physical properties of the layers of enclosing structures were taken according to [1]. Soil characteristics were taken from engineering and geological surveys, the thermal and physical properties were determined taking into account ground composition, density and moisture according to [11]. The boundaries of the design area were taken from the condition of providing a one-dimensional heat flow at the boundaries (Figure 3) and placed at a distance of 12 m from the inner surface and the outer surface of the wall. In the ground, an isothermal surface with a temperature of +8 \(^{\circ}\text{C}\) was set at a depth of 5 m from the ground level.

3. Results

The results of the calculation are shown in Figures 3 and 4 in the form of temperature fields and heat flows under design conditions.

The heat flow rate on the floor surface in the direction from the inner surface of the outer wall related to the interior of the room (building) is shown in Figure 5.

![Figure 3. Temperature distribution](image_url)
Figure 4. Distribution of heat flow rates

Figure 5. Comparison of design heat losses (heat flow rates)
(here x, m is the distance along the floor surface from the inner surface of the outer wall)
1 – according to the calculation results; 2 - according to the dependence (1) and the method [1]
The temperature on the surface of the floor and the external wall in the corner equals +14.8 °C, which is much lower than the normalized value for residential buildings (respectively, +18 °C - [1]). The width of the strip where the normalized conditions are not met is 0.6 m.

4. Comparing the calculation results with regulatory requirements

The performed calculation allows to determine the heat flow at any point on the floor surface. Total heat loss through the site can be calculated through integrating

\[ Q = \int q \cdot dF, \cdot \text{W}. \]  

(2)

Table 1 presents the averaged data of calculation of the heat flow rates and the adjusted thermal resistance for unheated floor by zones in comparison with the regulatory requirements [1].

**Table 1. The adjusted resistance to heat transfer and the heat flow rates of unheated ground supported floors**

| The zone of ground supported floor | Adjusted resistance to heat transfer, \( R_i \) (m²·°C)/W | Heat flow rate, \( q_i \), · W/m² |
|-----------------------------------|-----------------------------|-----------------------------|
| Zone I                           | 2.1 / 20.95                | 2.6 / 16.92                 |
| Zone II                          | 4.3 / 10.23                | 6.36 / 6.92                 |
| Zone III                         | 8.6 / 5.12                 | 8.12 / 5.42                 |
| Zone IV                          | 14.2 / 3.10                | 8.79 / 5.01                 |

Comparing the data of Table 1, it can be concluded that for zones I and II the normative value of adjusted resistance to heat transfer is less than calculated (by 24% for zone I, and by 48% for zone II). In zones III and IV the normative value exceeds the calculated value. The greatest difference is observed for the IV zone. According to the calculation results, the difference in the adjusted resistance to heat transfer for zones III and IV is negligible (8%). Zone IV should be excluded from regulatory requirements, therefore the part of the floor remaining after the determination of zone II will be attributed to zone III.

Performing calculations of the temperature field of the exterior enclosing structures of the building (floor, external wall, foundation) and ground allows to determine heat flows and thermal losses more certainly.

The difference of calculation results from regulatory requirements will be the greater, the smaller the width of the building or the higher the density and humidity of the ground.

5. Conclusions

1. The performed calculation of the thermal state of exterior enclosing structures (external wall and the unheated ground supported floor) and the soil body differs from the regulatory requirements by a more rigorous thermal and physical justification, taking into account the actual heat transfer resistance of building structures and the ground.
2. The results of the calculation determine the need to exclude zone IV of unheated floor when calculating heat losses through the floor structure.
3. In order to ensure the normative requirements for the temperature on a floor surface, it is recommended to perform thermal insulation at least 0.6 m wide in the area where the floor adjoins to outside walls.

References
[1] Russian State Standard SP 50.13330.2012
[2] Russian State Standard SP 60.13330.2016
[3] Russian State Standard SP 131.13330.2012
[4] Russian State Standard TSN 50-302-2004
[5] Mangushev R A, Osokin A I 2009 Zhilishchnoye stroitel'stvo, 2, pp 46–48
[6] Mangushev R A, Osokin A I 2010 Geotekhnika Sankt-Peterburga (Moscow, ASV) 259 p
[7] Dyachech P I, Makarevich S A 1992 Vodosnabzhentye i sanitarnaya tekhnika, 8, pp 22–23
[8] Dyachech, P I 2007 Energetika, 3, pp 77-86
[9] Sotnikov A G 2010 AVOK, 8, pp 62-67
[10] URL: http://www.ozis-venture.ru/pdf/Detailed_inspection_of_public_building.pdf (01.01.2018)
[11] Konovoj A (Ed.) 1989 Teplofizicheskiye raschety ob"yektov narodnogo khozyaystva, razmeshchayemykh v gornykh vyrabotkah (Moscow, Institut tekhnicheskoy teplofiziki AN USSR, Stroyizdat) 80 p.