Modern studies of heat losses of a building basement through a soil mass

Kirill Zubarev[1,2,3*] and *Yulia* Zobnina[1]

[1]National research Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, 129337 Moscow, Russia
[2]Research Institute of Building Physics of Russian Academy of Architecture and Construction Science, 21, Lokomotivny proezd, 127238 Moscow, Russia
[3]Peoples' Friendship University of Russia (RUDN University), 6, Miklukho-Maklaya str., 117198 Moscow, Russia

Abstract. This study aims at considering the methods of calculating heat losses to the soil through the floor structures of the basement. Classical methods of calculating heat losses through the soil according to the updated set of rules are presented. Modern methods of calculation based on mathematical modeling have been studied. A full-scale experiment of one of the developed methods that proves the possibility of its application and the need for further enhancement has been considered. Methods for estimating the resistance to the heat transfer through the soil are introduced. The method of "concentric circles" is presented in comparison with the given values in Set of Rules 50.13330.2012. A comparative analysis of new methods with standard methods for calculating heat losses to the soil through the basement floor structures was carried out. Such methods as calculation "by zones" based on the principle of dividing the basement floor into strips have been studied. Various options for the building basement insulation that can affect the heat losses of the building have been considered. An analysis of the factors influencing heat loss such as the type of soil, the geometric dimensions of the building, the actual heat transfer resistance of the insulation, the temperature regime of the room and the presence of insulation has been presented. The formulas for calculating the complex heat-shielding characteristic in accordance with modern changes in the regulatory documentation are given.

1 Introduction

A number of heat losses occur in any building through a variety of structural elements such as roof, exterior walls, windows, ventilation and basement floors.

The relevance of the study is dictated by the complexity of calculating heat loss to the soil through the basement of the building. The problem is caused by the unsteady-state thermal regime of the soil mass to which the floor structures are adjacent [1-20].

* Corresponding author: zubarevkirill93@mail.ru

When calculating, it is necessary to take into account the features of floor insulation and thermal conditions, which requires the development of new methods that can most accurately determine heat losses [1-20].

2 Classic method of calculating heat losses through the soil

Calculation of heat losses is carried out in accordance with Set of Rules 60.13330.2020 Heating, ventilation and air conditioning, Appendix A. Heating and ventilation consumption for adverse conditions is determined taking into consideration paragraph 5.1 of above mentioned set of rules and Set of Rules 131.13330.2020 Building climatology according to the formula:

$$Q_{hv}^{con} = \sum_n (Q_{tr_n} + Q_{vent_n} + Q_{\inf_n} + Q_{chm_n} - Q_{h_n}). \quad (1)$$

where Q_{tr_n} – transmission heat losses necessary to compensate heat transfer through the building envelope of the n-th room, W; Q_{vent_n} – heat consumption to heat the desired amount of supply air for the n-th room, W; $Q_{\inf_n}$ – infiltration heat losses formed due to the air permeability properties of the enclosing structures of the nth room, W; Q_{chm_n} – heat consumption for heating materials, equipment and vehicles brought into the nth room of the building, W; Q_{h_n} – domestic heat inputs of the n-th room of the building that are characteristic of the design mode (for the most unfavorable conditions), W.

In her manual, the researcher Malyavina E.G. describes a simplified method of calculating the resistance to a heat transfer of a structure based on dividing the surface of the floor and walls that are in contact with the ground into strips 2 meters wide. Zones are numbered along the wall from ground level. If there is no such wall, the floor strip closest to the outer wall is taken. The next strips will be zones 2 and 3, whereas the rest of the floor will be zone 4. Figure 1 shows the layout of the building basement [2].

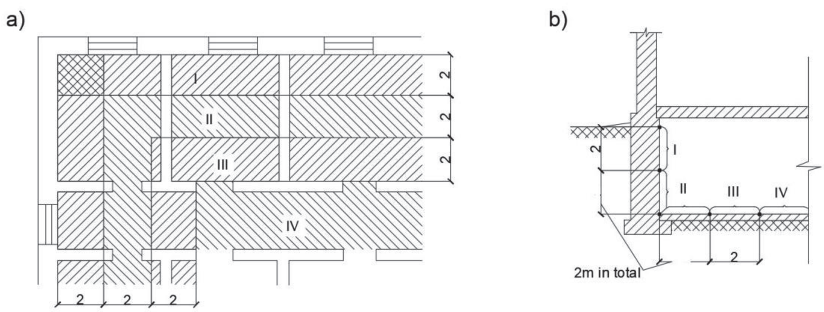

Fig. 1. a – division of floor surfaces into design zones 1-4; b – division of buried parts into settlement zones 1-4 according to Malyavina E.G. [2].

If there are no insulating layers of materials with a thermal conductivity coefficient of 1÷1.2 $W/(m \cdot {}^\circ C)$ in the composition of the floor, such floor should be considered uninsulated. For each zone of an uninsulated floor, standard values of heat transfer resistance are accepted. For the zone 1 – $R_I = 2.1\ m^2 \cdot {}^\circ C/W$; for the zone 2 – $R_{II} = 4.3\ m^2 \cdot {}^\circ C/W$

; for the zone 3 – $R_{III} = 8.6\ m^2 \cdot ^\circ C / W$; for the zone 4 – $R_{IV} = 14.2\ m^2 \cdot ^\circ C / W$. In cases of insulated floor, the resistance to heat transfer in a separate zone is usually calculated according to the formula [2]:

$$R_{if} = R_{unf} + \sum \frac{\delta_{i.l.}}{\lambda_{i.l.}}. \quad (2)$$

where R_{if} – resistance to heat transfer of the considered zone of an uninsulated floor, $m^2 \cdot {}^\circ C / W$; $\delta_{i.l.}$ – insulation layer thickness, m; $\lambda_{i.f.}$ – coefficient of thermal conductivity of the insulating layer material, $W / (m^2 \cdot {}^\circ C)$ [2].

If the floor is on floor joists, the resistance to the heat transfer should be calculated using the following formula [2]:

$$R_l = 1.18 R_{y.n.}. \quad (3)$$

Thus, not only the described method can significantly simplify the calculations of heat losses to the soil, but also allow us to take into account the insulating material of the structure [2].

3 Modern changes of regulatory documents in the calculation of a complex heat-shielding characteristic through the soil

The specific heat-shielding characteristic of a building is the amount of heat equal to the loss of thermal energy through the heat-shielding shell of the building of a unit of heated volume per unit of time with a temperature drop of 1 $^\circ C$.

In accordance with Set of Rules 50.13330.2012 Thermal protection of buildings, Appendix G, the specific heat-shielding characteristic is calculated using the formula:

$$k_h = \frac{1}{V_h} \sum_i \left(n_{t,i} \frac{A_{f,i}}{R^r_{sh,i}} \right) = K_{comp} K_{total}. \quad (4)$$

where $R^r_{sh,i}$ – reduced resistance to heat transfer of the i-th fragment of the heat-shielding shell of the building, $(m^2 \cdot {}^\circ C) / W$; $A_{f,i}$ – the area of the corresponding fragment of the heat-shielding shell of the building, m^2 ; V_h – heated volume of the building, m^3 ; $n_{t,i}$ – coefficient taking into account the difference between the internal or external temperature of the structure from those accepted in the HDD calculation; K_{total} – overall building heat transfer coefficient, $W / (m^2 \cdot {}^\circ C)$; K_{comp} – overall building heat transfer coefficient, m^{-1} .

It is important to take into account that the specific heat-shielding characteristic should not exceed the normalized value.

https://doi.org/10.1051/e3sconf/202338906007

Also, the specific heat-shielding characteristic can be found by means of characteristics of the elements that make up all the structures of the building shell according to the formula:

$$k_h = \frac{1}{V_h}\left[\Sigma\left(n_{t,i}\right)\frac{A_{f,i}}{R_{sh,i}^{con}} + \Sigma n_{t,j} L_j \psi_j + \Sigma n_{t,k} N_k \psi_k\right]. \quad (5)$$

where L_j – total length of linear inhomogeneity of the j-th type throughout the building shell, м; N_k – the total number of point inhomogeneities of the k-th type throughout the building shell, pcs; $R_{sh,i}^{con}$ – conditional resistance to heat transfer of a homogeneous part of a fragment of the heat-shielding shell of the building of i-th type, $(m^2 \cdot {}^\circ C)/W$; ψ_j – specific linear heat losses by means of linear thermal inhomogeneity of the j-th type, $W/(m^2 \cdot {}^\circ C)$; $A_{f,i}$ – the area of the corresponding fragment of the heat-shielding shell of the building, $м^2$; $n_{t,k}$ – coefficient that takes into account the difference between the internal or external temperature of the structure from those accepted in the calculation of the HDD.

4 Scientific methods of assessing the resistance to heat transfer through the soil

In his study, O.D. Samarin considered a simplified method of calculating a stationary two-dimensional temperature field of the soil mass, the key point of which is to select a quarter of an infinite array enclosed between the ground surface plane and the outer wall surface plane. The calculation scheme of heat transfer through the soil mass is demonstrated in Figure 2 [3-4].

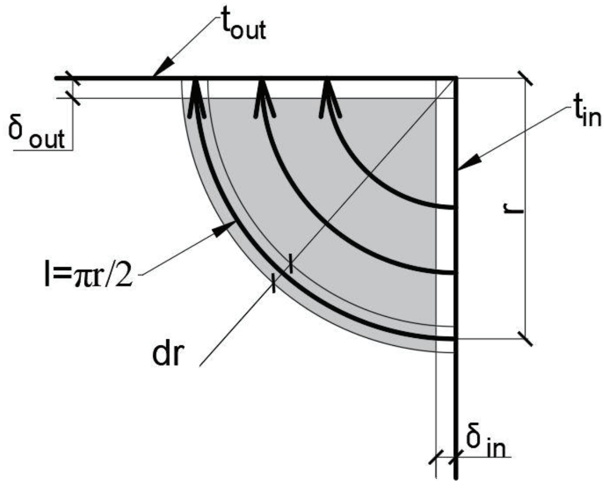

Fig. 2. Calculation scheme of heat transfer through the soil mass according to O.D. Samarin [3-4].

Supplementary conditional layers that take into account the heat exchange from the basement and outside air are introduced. To calculate heat fluxes and transfer resistances, the temperature at the boundaries of the auxiliary layers is taken. As a solution to the problem, the author proposes the method of sources and sinks. A point vortex acts as a source [3-4].

The total linear heat flux is found by the formula [3-4]:

$$Q_{1-2} = \int_{r_1}^{r_2} \frac{2\lambda}{\pi r}(t_{in} - t_{out})dr = \frac{2\lambda}{\pi}(t_{in} - t_{out})\ln\left(\frac{r_2}{r_1}\right). \quad (6)$$

where λ – average thermal conductivity of soil, W/(m · K), r_1 – radius of the first concentric circle, м; r_2 – radius of the second concentric circle, м; t_{in} – indoor air temperature in the basement, K; t_{out} – design outdoor temperature, K [3-4].

Next, we can calculate the average value of the resistance to heat transfer for a section of the wall surface with a width of according to the formula [3-4]:

$$R_{1-2} = \frac{(t_{in} - t_{out})A_{1-2}}{Q_{1-2}} = \frac{\pi(r_2 - r_1)}{2\lambda\ln(r_2 / r_1)} = \frac{\pi\delta}{2\lambda\ln(r_2 / r_1)}. \quad (7)$$

where t_{in} – indoor air temperature in the basement, K; t_{out} – design outdoor temperature, K; A_{1-2} – surface area of a wall between two concentric circles r_1 and r_2, $м^2$ [3-4].

The author conducts a comparative analysis of the calculation results according to the formula and the values given in Set of Rules 50.13330.2012 (Fig. 3).

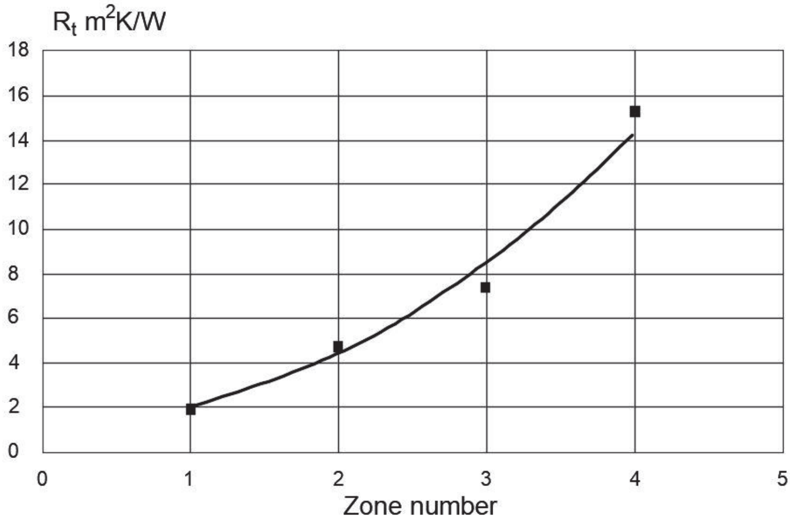

Fig. 3. Comparison of the calculation results according to O.D. Samarin's formula and the requirements of Set of Rules 50.13330.2012 according to Samarin's data [3-4].

The method of dividing the soil into concentric circles described by Samarin O.D. is more accurate and as simple as the method presented in Set of Rules 50.13330.2012. Calculations and comparative analysis performed by Samarin O.D. showed the versatility of the calculation formula.

5 Mathematical modeling of heat transfer through the soil mass of the building basement

The researcher Gnezdilova E.A. has considered a mathematical model of non-stationary thermal soil and adjacent structures. Her study is based on the differential equation of thermal conductivity in the soil [5]:

$$c\rho \frac{\partial t}{\partial z} = \frac{\partial}{\partial x}\left[\lambda \frac{\partial t}{\partial x}\right], z. < 0 \qquad (8)$$

where c – specific heat capacity of soil, $J/(kg \cdot {}^{\circ}C)$; ρ – specific heat capacity of soil kg/m^3; λ – soil thermal conductivity, $W/(m \cdot {}^{\circ}C)$; z – time with origin, c; $t(x,z)$ – temperature at any point x along the depth of the soil and at any time z from the origin, ${}^{\circ}C$ [5].

A method of calculating the heat equation in finite differences was considered. A calculation of one-dimensional soil field has been performed. The boundary conditions on the earth surface that describe the solar radiation absorbed by the soil, heat exchange with the atmosphere, and long-wave radiation were taken into account. Moreover, in order to solve the problem, the author introduced a non-uniform difference grid for compiling difference equations for elementary layers, which made it possible to compose implicit difference schemes for heat equation and soil boundary conditions. After calculating the sweep coefficients, the author determined the temperature values at the lowest point of the soil area under consideration, as well as at all nodes up to the day surface of the soil [5].

During the study, the influence of freezing and thawing of moisture in the pores of the soil was taken into account by the method of smoothing of the coefficients [5].

When passing to a plane problem, the soil boundaries were chosen by the locally one-dimensional method in order to maximally reduce the artificial limitation of the heat flux from the building due to a small volume of soil. This will allow us not to distort the temperature field [5].

A program for performing calculations using technical support was compiled based on above mentioned method [5].

A full-scale experiment was set up to apply this method in real conditions. The aim was to measure the heat loss of the floor over the ground in real conditions and compare them to the calculated data. During the experiment, heat flux density and temperature sensors were installed. The results obtained formed the basis of a comparative analysis, as a result of which it was possible to provide confirmation of the suitability of this development for identifying the thermal regime of enclosing structures that have direct contact with the ground surface [5].

 https://doi.org/10.1051/e3sconf/202338906007

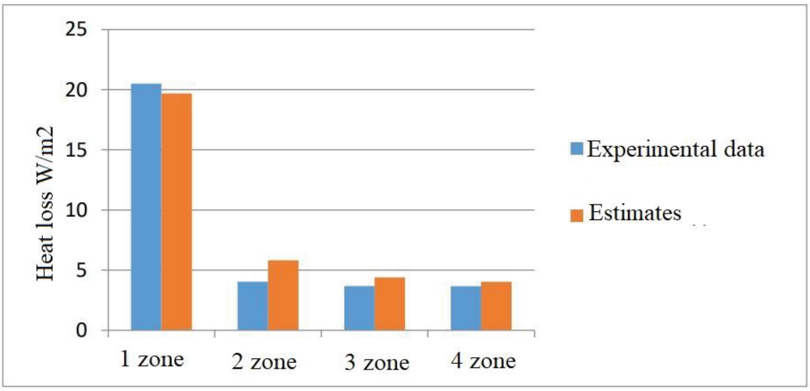

Fig. 4. Comparison of the calculated and experimentally obtained values of maximum heat loss in 4 zones according to E.A. Gnezdilova [5].

The discrepancy between the results was not more than 10 %, which also indicates the suitability and reliability of the developed method [5].

Gnezdilova E.A. also gives a method of mathematical modeling of the thermal regime of floors on the ground with indirect insulation to determine the factors that most affect the amount of heat loss [5].

The technique is based on the temperature field of the soil mass, which is formed together with the floor structure adjacent to the soil [5].

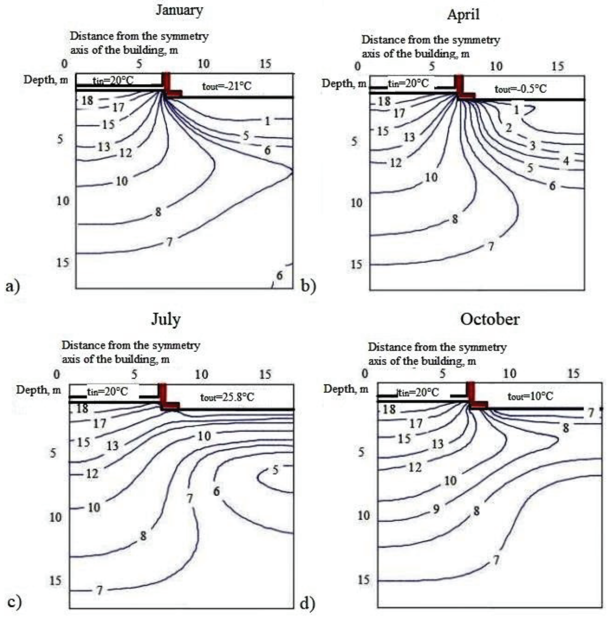

Fig. 5. Temperature field of the soil with adjacent building structures during the year with the insulation of the blind area of the building: a – in January, b – in April, c – in July, d – in October according to E.A. Gnezdilova [5].

For the convenience and the possibility of comparing the results to the classical methods, the author proposes to move on to the zonal calculation method [5].

Having considered the options for different types of insulation of the building basement (floors, walls, blind areas), Gnezdilova E.A. comes to the conclusion that the geometric parameters of the structure, the type of soil, the actual resistance to the heat transfer of the insulation and the temperature regime of the room have the greatest influence on heat losses. The researcher also notes a tendency to reduce the resistance to the heat transfer of the structures that are built on sandy soils [5].

Insulation of the attached floor area is an effective measure for any building and structure. Moreover, an important aspect is also the prevention of soil heating from a warm room, which increases heat losses in the closest calculation zone [5].

6 Conclusion

As a result of considering a great variety of methods for calculating heat losses through floor structures into the soil, two main simplified methods that are classic and popular can be distinguished, namely the method of partitioning into zones and the method of concentric circles. The partitioning method is also specified in Set of Rules 50.13330.2012 Thermal protection of buildings. When using it, inaccuracies in the calculations do not have critical values. Nevertheless, the method of concentric circles appeared to be more extensive in order to take into account numerous heterogeneous factors in the interaction of soil and floor structures [1-5].

Thus, E.A. Gnezdilova’s study has a great perspective. Due to the fact, that the results of the methodology developed by her are close to the results of classical methods, they are of great interest. However, the method still requires further improvement in terms of correction factors, as well as tests [1-5].

References

1. Yu.Ya. Kuvshinov, O.D. Samarin, Fundamentals of ensuring the microclimate of buildings (2012) (In Russian) (Moscow, Publisher of the Association of Civil Engineering Universities, 2012)
2. E.G. Malyavina, Heat loss of the building: a reference guide (2007) (In Russian) (Moscow, Publisher of the AVOK-PRESS, 2007)
3. O.D. Samarin, Substantiation of the simplified method of determining heat losses through underground parts of building enclosures, Vestnik MGSU, 1, pp. 118–126 (2016)
4. K.P. Zubarev, A.I. Borodulina, A.R. Gallyamova, Theoretical and Experimental method for determing the heat transfer resistance. Literature review, Construction Materials Russia, 6, pp. 9-14 (2021) DOI: 10.31659/0585-430X-2021-792-6-9-14
5. E.A. Gnezdilova, Improving the calculation of heat loss through floors on the ground with modern insulation designs, (2021) (Moscow, Ph.D. theses, 2021) (In Russian)
6. N. Kozhukhova, N. Kadyshev, A. Cherevatova, E. Voitovich, K. Lushin, Reasonability of Application of Slags from Metallurgy Industry in Road Construction. Advances in Intelligent Systems and Computing, 692, pp. 776–782 (2018) https://doi.org/10.1007/978-3-319-70987-1_82
7. N. Parfentyeva, O. Samarin, K. Lushin, S. Paulauskaite, K. Valancius, Temperature efficiency of rotary heat recovery units in ventilation and air conditioning. In 8th International Conference on Environmental Engineering, ICEE, pp. 799–801 (2011)

8. I. Vorobyeva, The prognosis of the diabetic retinopathy using computer science and biotechnology. E3S Web of Conferences 203, 01028 (2020). https://doi.org/10.1051/e3sconf/202020301028
9. I.V. Vorobyeva, Mathematical modeling in diabetic retinopathy. E3S Web of Conferences 224, 03020 (2020) https://doi.org/10.1051/e3sconf/202022403020
10. I.V. Vorobyeva, Prediction of the course of primary open-angle glaucoma in combination with diabetic retinopathy using a mathematical model. E3S Web of Conferences 224, 03021 (2020) https://doi.org/10.1051/e3sconf/202022403021
11. I.V. Vorobyeva, Assessment of the development of primary open-angle glaucoma and diabetic retinopathy using digital medicine. E3S Web of Conferences 224, 03022 (2020) https://doi.org/10.1051/e3sconf/202022403022
12. M. Rynkovskaya, Analysis of displacements in beam structures and shells with middle developable surfaces. MATEC Web of Conferences 108, 16001 (2017) https://doi.org/10.1051/matecconf/201710816001
13. M. Rynkovskaya, Plastic Deformations Occuring in Shells with Developable Middle Surfaces during Bending. IOP Conference Series: Materials Science and Engineering 371(1), 012054 (2018) DOI 1088/1757-899X/371/1/012054
14. M.R. Petrichenko, T.A. Musorina, Fractional differentiation operation in the Fourier boundary problems. St. Petersburg State Polytechnical University Journal: Physics and Mathematics 13(2), 41–52 (2020) DOI: 10.18721/JPM.13204
15. T. Musorina, O. Gamayunova, M. Petrichenko, E. Soloveva, Boundary Layer of the Wall Temperature Field. Advances in Intelligent Systems and Computing 1116 AISC, 429–437 (2020) https://doi.org/10.1007/978-3-030-37919-3_42
16. O. Gamayunova, M. Petrichenko, A. Mottaeva, Thermotechnical calculation of enclosing structures of a standard type residential building. Journal of Physics: Conference Series 1614(1), 012066 (2020) DOI 10.1088/1742-6596/1614/1/012066
17. O. Gamayunova, R. Golov, Potential of energy saving on transport. E3S Web of Conferences 135, 02025 (2019) https://doi.org/10.1051/e3sconf/201913502025
18. V.I. Bespalov, E.V. Kotlyarova, Features of the negative impact of modern infrastructure facilities in urbanized areas on the environment. IOP Conference Series: Earth and Environmental Sciencethis 937(4) (2021) DOI 10.1088/1755-1315/937/4/042036
19. V. Bespalov, E.Kotlyarova, Methodological bases for assessing the level of environmental safety of dynamically developing urbanized territories. IOP Conference Series: Materials Science and Engineering, International Scientific and Practical Conference Environmental Risks and Safety in Mechanical Engineering, ERSME 2020, 012101 (2020) DOI:10.1088/1757-899X/1001/1/012101
20. V. Bespalov, E. Kotlyarova, Improving the environmental assessment of objects in the system of construction engineering. E3S Web of Conferences. Topical Problems of Green Architecture, Civil and Environmental Engineering, TPACEE 2019, 01009 (2020) https://doi.org/10.1051/e3sconf/202016401009