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THE INFLUCENCE OF THERMAL BRIDGES ON THE OPERATION OF UNDERFLOOR HEATING SYSTEM

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ABSTRACT: The work determines the influence of the presence of thermal bridges within the pipes of underfloor heating on its performance: thermal efficiency, surface temperature and heat losses. Three types of building partitions with thermal bridges are considered: the external wall, the external wall with the insulated and uninsulated balcony slab. The analysis was made for variable heat resistance of thermal insulation and floor finishing layer, variable pipe spacing, temperature of the heating medium and outside air. The calculation was carried out with the use of computer software using boundary element method (BEM). It was found that considering three types of thermal bridges in the floor heating model does not significantly affect the thermal efficiency of the floor heating and its average surface temperature. The effect of considering the thermal bridges on the amount of heat losses to the room below was observed.

KEY WORDS: thermal efficiency, surface temperature, heat losses, surface heating systems

Introduction

Radiant floor heating is widely used in residential buildings, industrial, sports and medical objects. It has a special application in buildings with large cubic capacity and heights, in rooms with large glazing and with high infiltration rate, in which traditional heating systems based on convection radiators are uneconomical (Raimundo et. al, 1995). The floor heating heats and provides the optimal air temperature only in the zone of human residence (up to a height of 2 m), therefore there is no need to heat the entire airspace.

In the design process of surface heating systems, apart from the hydraulic calculations, pipe dimensioning and determination of thermal efficiency, one of the most important issues is the design of building partitions which are integrated with them. A surface heating should be designed in this way to minimize the amount of heat loss to the environment on its other side. In accordance with the applicable guidelines for the design of surface heating systems (set of standards PN-EN 1264 and PN-EN ISO 11855), heat losses to the room below the floor heating slab are taken into account in the thermal efficiency calculations. Heat losses affect the mass flow of the heating medium. In the design process are not taken into account heat losses through building partitions adjacent to the radiator plate and through the connection points of the building partitions, i.e. thermal bridges.

The analysis of the influence of thermal bridges on the performance of surface heating systems, including floor heating, was not the object of many research works. The heat losses of a floor heating located in the slab-on-ground floor, below and above the ground level with regard to the external wall, were examined in (Chuangchid, Krarti, 2001; Weitzmann et. al, 2005; Żukowski, 2009). The value of the linear heat transfer coefficient for connection of the heated ground floor slab and the external wall was calculated in (Weitzmann et. al, 2005). It has been shown that the thermal energy losses through foundations constitute a significant part of total heat losses in single-family buildings with surface heating systems and their impact should not be neglected in the design process of buildings (Chuangchid, Krarti, 2001; Weitzmann et. al, 2005). The issue of the influence of a floor heating located in the inter-floor ceiling on the value of heat losses through the external partition and the value of linear heat transfer coefficient for three types of thermal bridges was analyzed in work (Werner-Juszczuk, 2015). The analysis included the connection of the external wall with the ceiling, the connection of the external wall with insulated balcony slab and the connection of a door with the balcony slab. The calculations were carried out for variable pipe spacing, water temperature and constant temperature of external, internal

air, thermal resistance of the finishing layer, the insulation of the external wall and insulation below the floor heating pipes.

This paper deals with the analysis of the influence of thermal bridges on the operating parameters of a floor heating, i.e. thermal efficiency, surface temperature and heat losses to the room below. The analysis of the heat exchange process in the floor heating plate adjacent to the external wall was performed, taking into account the impact of three thermal bridges: connection of the external wall with the inter-floor ceiling and connection of the external wall with an insulated and uninsulated balcony slab.

The calculations were made with the computer software using the boundary element method (BEM).

Research methods

Assumptions regarding the construction of floor heating and building partitions:
- type A of a floor heating,
- pipe PE-Xc, 18x2 mm, λ = 0.35 W/(m·K),
- thermal resistance of the floor covering $R_{\lambda,b}$ = 0.05; 0.1; 0.15 (m²·K/W),
- the screed thickness above the pipes 45 mm,
- pipe spacing W = 0.1; 0.15; 0.2; 0.25 m,
- supply temperature of the heating medium T_V = 30, 35, 40, 45, 50°C,
- cooling rate of the heating medium 5 K,
- the average flow speed of the heating medium 0.4 m/s,
- the inside air temperature in room with the floor heating and below this room $T_i = T_e$ = 20°C,
- the thickness of the edge insulation 8 mm, λ = 0.042 W/(m·K),
- distance between the pipes and edge insulation 50 mm,
- outside air temperature T_a = −20°C, −10°C, 0°C,
- heat transfer coefficient of the external wall U = 0.20; 0.23; 0.25 W/(m²·K) (maximum values meeting standards (WT, 2013) for buildings built after 1.01.2014, 2017, 2021),
- thermal conduction coefficient and dimensions of building materials according to table 1.

The following building structures are taken into consideration:
- the inter-floor ceiling with the floor heating (figure 1),
- the connection of external wall with floor heating slab (figure 2) – the thermal bridge I,

- the connection of external wall with the uninsulated balcony slab and floor heating plate (figure 3) – the thermal bridge II,
- the connection of external wall with the insulated balcony slab and floor heating plate (figure 4) – the thermal bridge III.

Table 1. Description of the elements of building structures

No.	Element	λ [W/(m·K)]	Dimension [m]	No.	Element	λ [W/(m·K)]	Dimension [m]
1	reinforced concrete slab	1.7	0.15	8	thermal insulation	0.042	variable
2	thermal insulation	0.04	0.03	9	plaster	0.8	0.02
3	screed	1.2	0.066	10	reinforced concrete beam	1.7	0.25x0.25
4	plaster	0.82	0.015	11	thermal insulation	0.042	0.05
5	floor covering	variable	variable	12	screed	1.2	0.04
6	edge thermal insulation	0.042	0.008	13	thermal insulation	0.042	0.05
7	silicate brick hollow	0.8	0.25	14	balcony reinforced concrete slab	1.7	0.12

Source: author's own work.

The dimensions of thermal bridges were adopted, maintaining the minimum required dimensions specified in PN–EN ISO 10211, that is 1.5 m in the vertical axis and a minimum of 1.5 m in the horizontal axis depending on the pipe spacing (figure 1–4).

The heat transfer coefficients on the surfaces of floor heating are determined from formulas (1) and (2):

- the upper surface of floor heating slab:

$$\alpha = 8.92 \cdot (T_{F,m} - T_i)^{0.1} \tag{1}$$

- the bottom surface of the floor heating slab:

$$\alpha = 1.163 \cdot (T_{F,m,e} - T_i)^{1/3} + 0.025 \cdot (T_{F,m,e} - T_i) + 0.055 \cdot T_e + 4.05 \tag{2}$$

where:

$T_{F,m}$ – the mean temperature of the upper surface of floor heating slab [°C],
$T_{F,m,e}$ – the mean temperature of the bottom surface of floor heating slab [°C].

The heat transfer resistance on the surfaces of other building partitions was derived from PN–EN ISO 6946. The heat exchange process at the water – pipe interface was described according to formulas presented in work (Werner-Juszczuk, 2016).
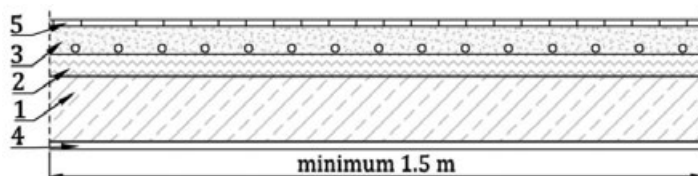

Figure 1. Scheme of inter-floor ceiling with the floor heating (markings according to table 1)
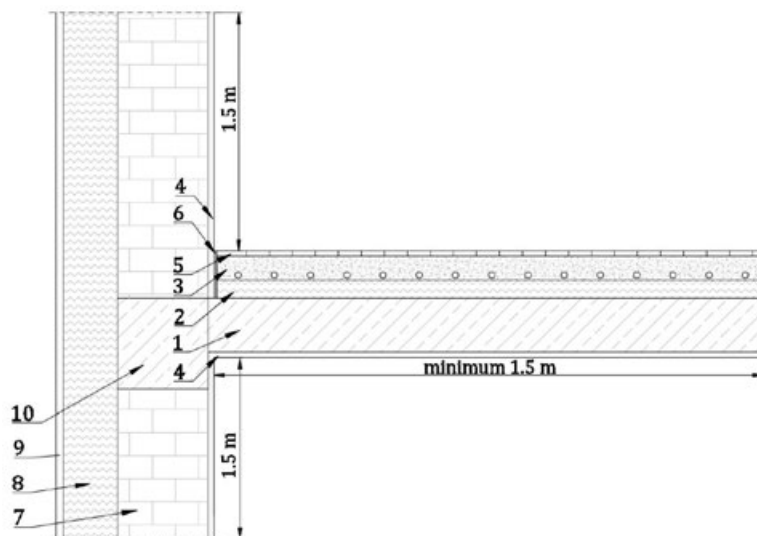
Source: author's own work.

Figure 2. Scheme of thermal bridge I – the connection of external wall and floor heating slab (markings according to table 1)

Source: author's own work.
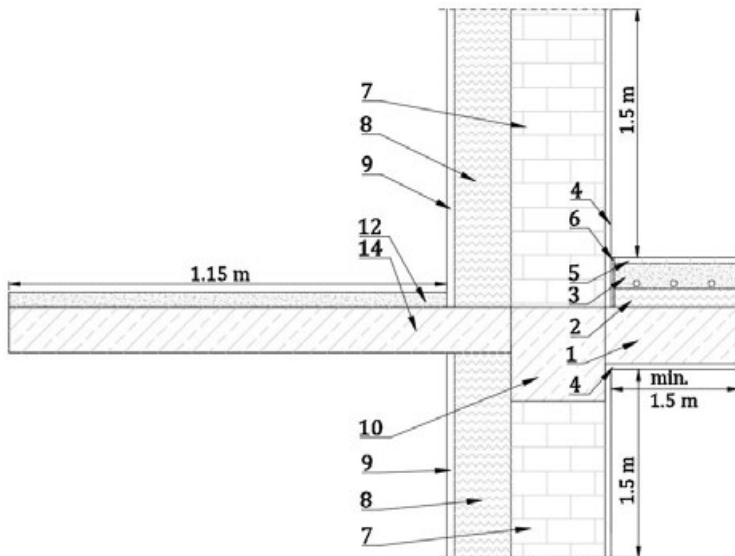
Figure 3. Scheme of thermal bridge II – connection of the external wall with the uninsulated balcony slab and floor heating plate (markings according to table 1)
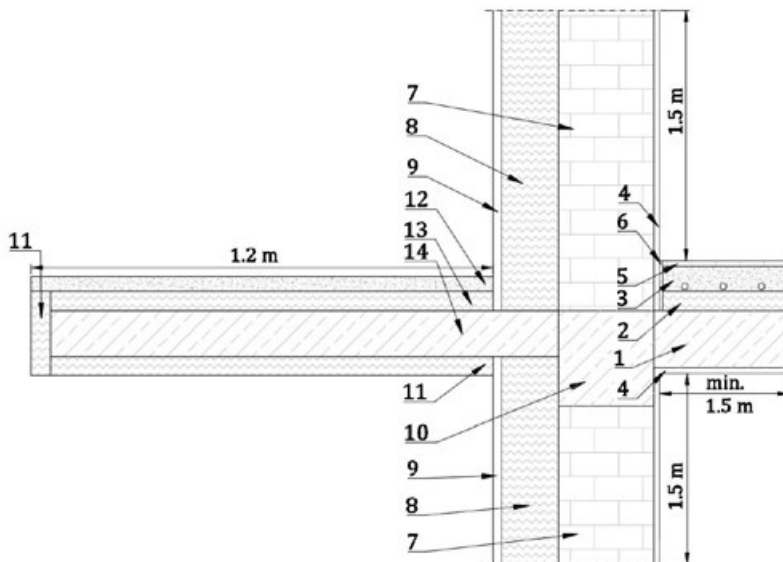
Source: author's own work.

Figure 4. Scheme of thermal bridge III – connection of the external wall with the insulated balcony slab and floor heating plate (markings according to table 1)

Source: author's own work.

Influence of thermal bridges on the thermal efficiency and surface temperature of floor heating system

The results of numerical calculations of heat transfer in the floor heating slab and in the floor heating slab adjacent to the external wall with three analysed thermal bridges, were compared.

It was found that after taking into account the influence of thermal bridges, the thermal efficiency q_i of the floor heating is almost unchanged. The heat flux density q_i after considering the external wall with thermal bridges varies by 1.1-3.5%, depending on the pipe spacing and the thermal resistance of the finishing layer, which corresponds to 0.5-2 W/m². Even consideration the most disadvantageous thermal bridge, i.e. the external wall with the uninsulated balcony slab (bridge II), contributes to a small decrease in the thermal efficiency q_i (figure 5).
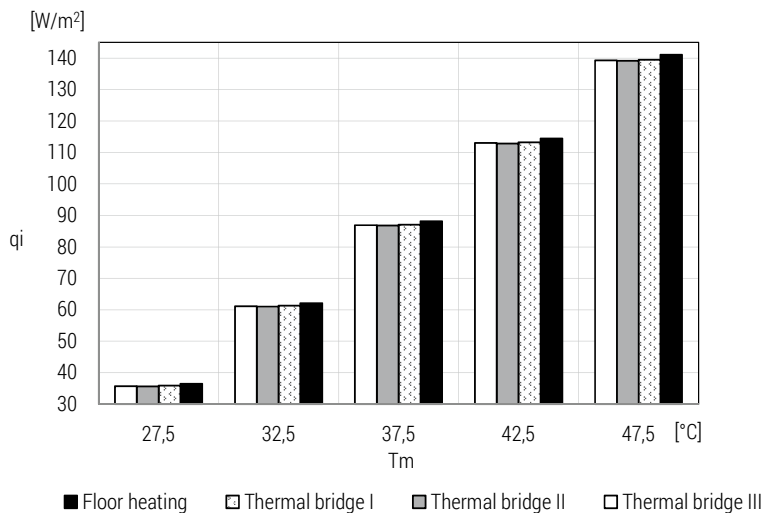

Figure 5. Thermal efficiency q_i of floor heating after considering the influence of thermal bridges for various heat medium temperature T_m (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W; U = 0.25 W/(m²·K); T_a = −20°C)

Source: author's own work.

The average surface temperature $T_{F,m}$ of the floor heating after considering in calculation model the external wall with three analyzed thermal bridges is reduced (figure 6). Differences between the surface temperature of the floor heating plate with and without thermal bridge equal from 0.04 K to 0.15 K, depending on the pipe spacing and the thermal resistance of the finishing layer. Therefore, it was found that the influence of thermal bridges on the surface temperature of the floor heating system is negligibly small.
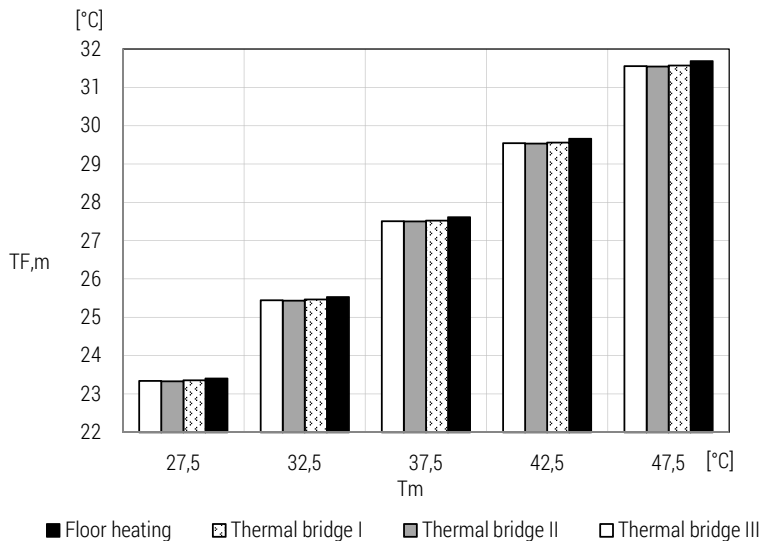
Figure 6. Average surface temperature $T_{F,m}$ of floor heating, after considering the influence of thermal bridges for various heat medium temperature T_m (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W; U = 0.25 W/(m²·K); T_a = −20°C)

Source: author's own work.

On the basis of comparison of the temperature field in the floor heating slab and in the slab adjacent to the external wall, it was found that the presence of three analyzed thermal bridges slightly affects the isothermal distribution. An example of the temperature field in the floor heating plate before and after taking into account the external wall with thermal bridges is presented in figures 7-10. Due to the large size of analyzed building structures, only details are presented, not entire structures.
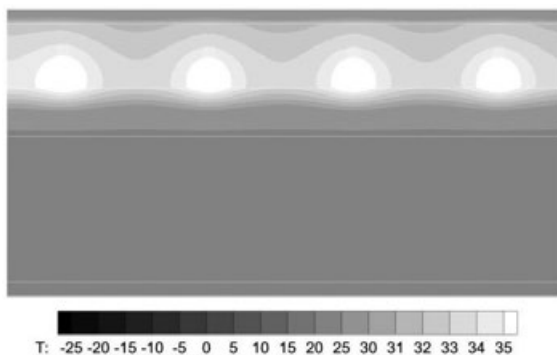

Figure 7. Temperature distribution in floor heating slab (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

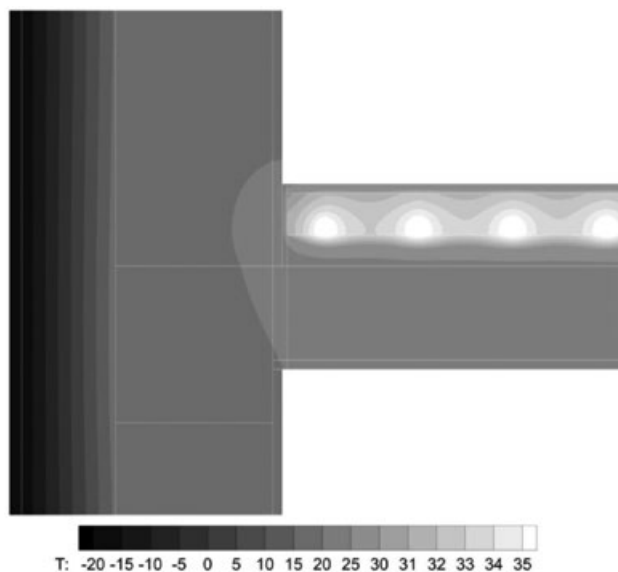**Figure 8.** Temperature distribution in thermal bridge I (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

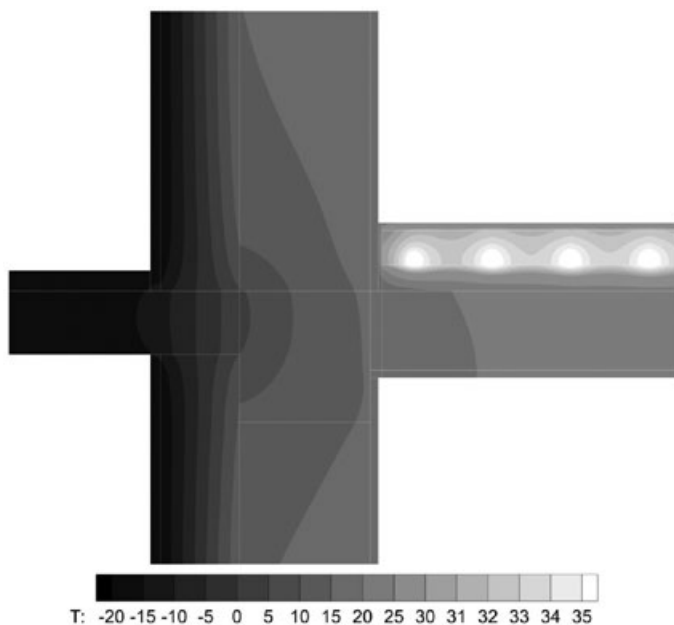**Figure 9.** Temperature distribution in thermal bridge II (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m²·K)/W; T_m = 37.5°C)

Source: author's own work.

It is shown in figures 8-10, that consideration in calculation model the external wall (bridge I), uninsulated (bridge II) and insulated (bridge III) balcony slab affects the reduction of temperature in the area of the first and second pipe located at the external wall, despite the use of the edge insulation of thickness 8 mm. The distribution of isotherms for next pipes almost does not change.
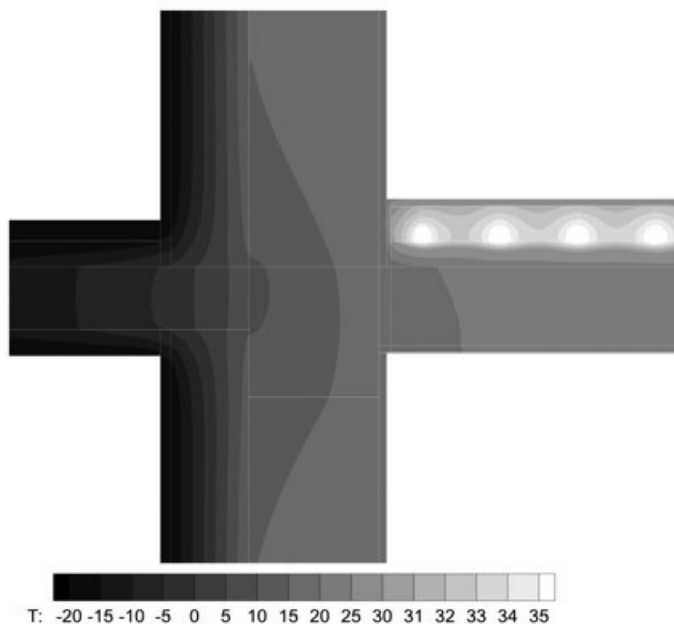

T: -20 -15 -10 -5 0 5 10 15 20 25 30 31 32 33 34 35

Figure 10. Temperature distribution in thermal bridge III (W = 0.15 m; $R_{\lambda,b}$ = 0.1 (m^2·K)/W; T_m = 37.5°C)

Source: author's own work.

After taking into account various values of overall heat transfer coefficient U of the external wall adjacent to the floor heating slab, it was found that the change in the U does not cause a significant change in the thermal efficiency of the floor heating q_i (figure 11).
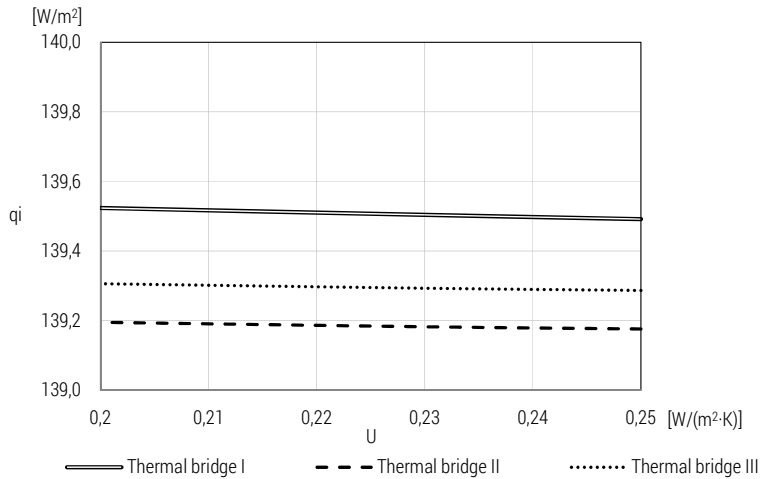
Figure 11. Dependence of thermal efficiency qi of a floor heating on the heat transfer coefficient of the external wall U including the influence of thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m²·K)/W)

Source: author's own work.

Influence of thermal bridges on the heat losses in floor heating system

After considering the floor heating slab interaction with an external wall with three thermal bridges, a decrease in the density of the heat flux emitted to the room below q_e was observed (figure 12). Decrease of q_e value depends on the type of thermal bridge, the pipe spacing, the temperature of the heating medium and the thermal resistance of the finishing layer. The smallest decrease was observed for the thermal bridge I, i.e. the connection of the ceiling with the external wall. For thermal bridge I the value q_e decreases by 1.3 W/m² to 2.4 W/m², which is from 28% to 9% of the heat flux density q_e of the floor heating without considering the influence of thermal bridge. For the II bridge, i.e. the connection of a uninsulated balcony slab with the external wall, the heat flux density q_e decreases by 22–83% which corresponds to 5.6 W/m² to 3.8 W/m². For the III bridge, i.e. the connection of insulated balcony slab with the external wall, the fall is from 19% to 66% (4.6 W/m² to 3.4 W/m²).

The reduction of the floor heating heat losses q_e to the room below, after considering the influence of external wall with thermal bridges, is associated with heat losses through the external wall. Due to the higher temperature difference between the room with the floor heating and the external environment in relation to the temperature difference between the rooms on both sides of the floor heating slab, a more intensive heat exchange appears, which

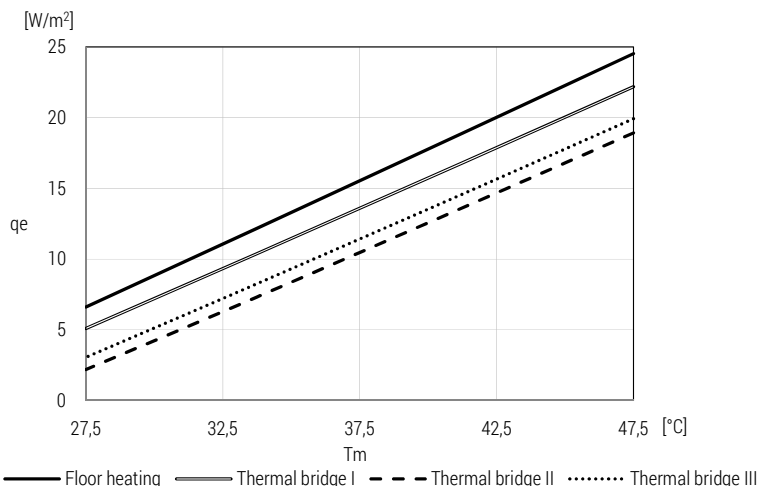results in increased heat losses through the external wall while reducing heat losses to the room below.

Figure 12. Dependence of the heat losses q_e of a floor heating on the heat medium temperature including the influence of thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m$^2\cdot$K)/W)

Source: author's own work.

Analysis of the heat losses q_e for three heat transfer coefficient U of the external wall adjacent to the floor heating slab, indicates that the increase in the U value causes the decrease in q_e by a maximum of 0.5 W/m^2 (figure 13).
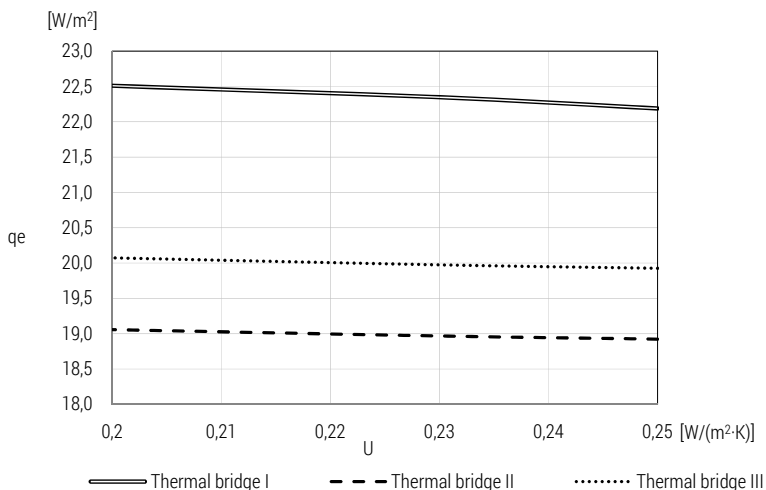

Figure 13. Dependence of floor heating heat losses q_e on the heat transfer coefficient U of the external wall with thermal bridges (W = 0.1 m; $R_{\lambda,b}$ = 0.05 (m$^2\cdot$K)/W)

Source: author's own work.

Conclusions

Consideration in the floor heating calculation model the influence of three types of thermal bridges, i.e. the connection of the external wall with the inter-floor ceiling, the connection of the insulated and uninsulated balcony slab with the external wall, does not significantly affect the calculated thermal efficiency of the floor heating and its average surface temperature. The maximum change in the density of the heat flux emitted from the radiator surface is 3.5% which corresponds to 2 W/m^2, and the maximum temperature change is 0.15 K. The results refer to the external air temperature in the range -20°C–0°C and the overall heat transfer coefficient of external wall U in the range of 0.20-0.25 W/(m^2·K), meeting the current requirements specified in the Technical Conditions (WT, 2013).

Taking into consideration the influence of three types of thermal bridge causes the decrease in heat losses to the room below the floor heating slab by a value of about 1 W/m^2 to 6 W/m^2, which accounts for a 9% to 83% of heat losses of floor heating slab considered separately.

The distribution of isotherms in the three analysed structures adjacent to the floor heating plate indicates the minimal impact of the external wall with thermal bridges on the temperature field inside the floor heating slab. Only in the case of pipes running directly at the external wall, a drop in temperature due to thermal bridges is observed. Therefore, it can be concluded that the 8 mm thick edge insulation layer, recommended by producers of surface heating systems, is sufficient to minimize the impact of the three analysed thermal bridges on the thermal performance of a floor heating.

Acknowledgements

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