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Numerical Investigation of Heat Transfer for Thermal Bridges Taking into Consideration Location of Thermal Insulation with Different Geometries

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Original scientific paper

In the present study, heat transfer structures were investigated for thermal bridges on both intermediate floor beamed wall block and balcony extension intermediate floor beamed wall. Temperature and heat flux contours were obtained for all models in the case of internal and external insulation cases with different insulation thicknesses (S_i = 3 cm, 5 cm and 7 cm). Results showed that high heat transfer rates were obtained in the region of heat bridges for all building models. However the heat transfer rate did not decrease on the heat bridge region in the case of internal insulation. The most appropriate insulation model was the external insulation case and it was also obviously determined that heat transfer rate decreased with increments of insulation thickness.

Numeričko istraživanje prijenosa topline u toplinskim mostovima obzirom na položaj toplinske izolacije različitih geometrija

Izvornoznanstveni članak

U ovom radu istražuje se prijenos topline u toplinskim mostovima postavljenim na podovima međukatova i na balkonskim istakama. Određene su temperature i gustoće toplinskih tokova za sve modele za slučajeve vanjske i unutrašnje izolacije, s različitim debljinama izolacije (S_i = 3 cm, 5 cm i 7 cm). Rezultati istraživanja su pokazali vrlo visoke vrijednosti toplinskih tokova u području toplinskih mostova kod svih ugradbenih modela. Doduše nije došlo do opadanja toplinskog toka u toplinskim mostovima u slučaju postavljanja unutrašnje izolacije. Puno se prikladnijim pokazao model u slučaju postavljanja vanjske izolacije i jasno je određeno da dolazi u tom slučaju do smanjenja toplinskog toka s povećavanjem debljine izolacije.

Keywords
Insulation
Fluent
Thermal bridge

Ključne riječi
Fluent
Izolacija
Toplinski most

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1. Introduction

Thermal bridges are parts of the building envelope where the otherwise uniform thermal resistance is significantly changed (e.g. at structural joints with roofs, floors, ceilings, and other walls, or other building envelope details such as corners, window or door openings), resulting in a multidimensional heat flow [1]. They have a major effect on the thermal performance of the building envelope, significantly increasing winter heat loss and summer heat gain. Different research studies have shown that thermal bridges can significantly reduce the thermal resistance of walls and roof assemblies. With data from test rooms, one-dimensional heat flow assumption causes an underestimated value of the total heat loss coefficient, about 10-40 % for certain building envelope [2].

There are many investigations into thermal behavior of thermal bridges. One of the earliest thoroughly investigates the effect of the position and dimension of an insulating layer on the inside surface temperature and the difference between the measured and calculated values by 1D analysis [3]. Larbi [4] developed statistical models of the thermal transmittance of 2D thermal bridges. Gao [5] tried to develop a low order three dimensional heat transfer model for additional losses of thermal bridges. Coupling this technique with a traditional one dimensional model for wall losses, it is possible to reduce a large amount of time simulations. Multidimensional dynamic models were set up to predict the thermal performances of thermal bridges using a frequency response method by Mao [6]. A computer program has been developed to calculate the dynamic responses of temperatures and heat flows within thermal bridges. Modeling of dynamic

Symbols/Oznake

h	- heat transfer coefficient, W/(m²·K) - koeficjent prijenosa topline
k	- thermal conductivity, W/(m·K) - toplinska provodnost
T	- temperature, K - temperatura
x	- coordinate along wall thickness, m - koordinata u smjeru debljine zida
y	- coordinate along roof width, m - koordinata u smjeru širine krova
L	- wall thickness, m - debljina zida
S	- insulation thickness, m - debljina izolacije

Indeks / Indices

in	- inside - unutrašnji
o	- outside - vanjski
n	- inner wall layer - unutrašnji zidni sloj
l	- outer wall layer - vanjski zidni sloj

components of two dimensional heat transfer was done and investigated with thermal bridges in completion of building by Salgon et. al. [7].

In this study, the significance of insulation and thermal bridges has been emphasized and both the importance of insulation thickness and the sections where thermal bridges are seen have been calculated by using Fluent software program for internal and external insulation cases and for different insulation thicknesses (S_i = 3 cm, 5 cm and 7 cm). Temperature contours, heat flux, local temperatures and external heat flux distributions have been calculated for both intermediate floor beamed wall block and balcony extension intermediate floor beamed wall.

2. Model and numerical method

The two major types of walls subject to analysis and generally found in buildings are as follow: layer beamed wall block and balcony extension floor beamed wall (Table 1). For intermediate floor beamed block, insulation material at different thicknesses (S_i = 3 cm, 5 cm and 7 cm) is applied from inside and outside. However, outside insulation is applied to wall other model.

For complete analysis, the thickness and thermal properties of component materials are shown in Table 2 and the configuration of the walls were modeled on the basis of the standard building envelope applicable to apartments in TURKEY. The finite volume method (FLUENT program) was used to solve thermal bridge analysis. Finite volumes method is based on the principle of dividing the geometry which will be solved into portions to find a solution for each of these sections and then by uniting these solutions to find a general solution of the problem. This method uses a technique which is based on control volume for transforming heat flow equations, to algebraic equations which can be solved as numerical. In other words this technique is based on the principle of taking heat flow equation integration in each control volume. This integration result provides equations which characterize each control volume coming to the light. A quadrilateral grid was used for simulation with a total of 8000 to 9000 elements (Figure 1).

The study is conducted under the following assumptions: (i) no heat generation (ii) constant thermal properties (iii) perfect thermal contact between layers (iv) constant heat transfer coefficient on the outside and inside surface. The boundary conditions are given as follows,

1. Inside surface (x=L):

$$k_{\mathrm{n}} \left.\frac{\partial T}{\partial x}\right|_{x=L} = h_{\mathrm{in}}(T_{x=L} - T_{\mathrm{in}}), \tag{1}$$

where h_{in} is the inside surface heat transfer coefficient.

2. Outside surface (x=0):

$$k_{1} \left.\frac{\partial T}{\partial x}\right|_{x=0} = h_{\mathrm{o}}(T_{\mathrm{o}} - T_{x=0}), \tag{2}$$

where h_o is the outside surface heat transfer coefficient, T_o is the outside ambient air temperature.

For complete analysis, outside air temperature and heat transfer coefficient were assumed as -10 ºC and 25 W/(m²·K); inside air temperature and heat transfer coefficient were assumed as 22 ºC and 7.7 W/(m²·K) respectively.

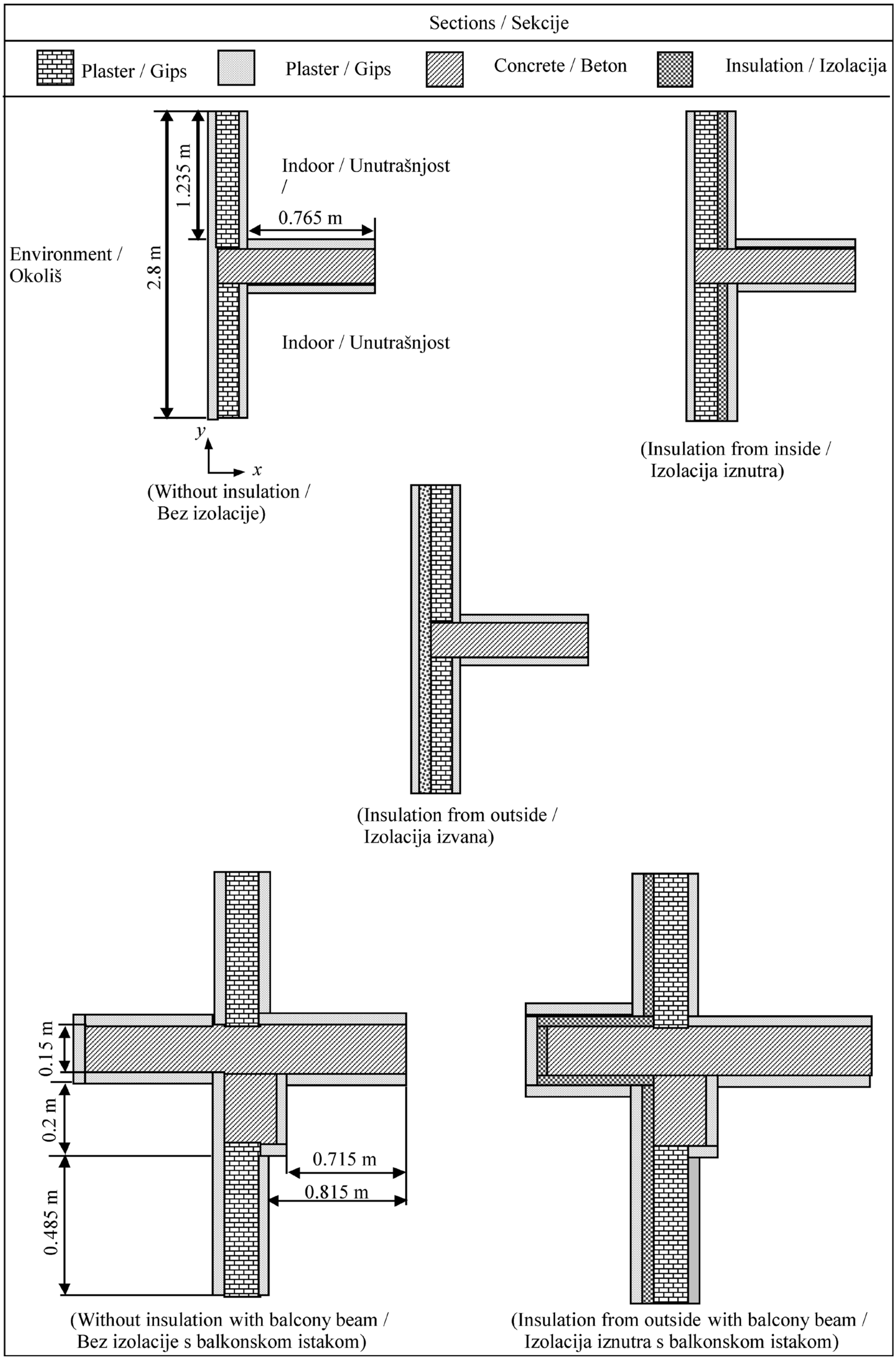


Figure 1. Grid system a) intermediate floor beamed wall block; b) balcony extension intermediate floor beamed wall block
Slika 1. Mreža a) podna stijenka između katova; b) međukatna balkonska istaka

Table 2. Features of Materials [8]

Tablica 2. Svojstva materijala

Material / Materijal	Thermal conductivity / Toplinska provodnost, W/(m·K)	Thickness / Debljina, m
Concrete / Beton	2.1	0.3
Heat Insulation Material / Toplinski izolacijski materijal	0.04	0.03-0.05-0.07
Brick wall / Cigleni zid	0.45	0.1
Inner plaster wall / Unutrašnji gipsani zid	0.87	0.15
Outer plaster wall / Vanjski gipsani zid	0.87	0.25

3. Results

Calculated analytical results for the exterior surfaces of three different plane walls (without insulation, externally insulated, internally insulated) have been compared with the numerical results by the Fluent program for the accuracy of the results. As seen in Figure 2, the analytical and numerical results are compatible.

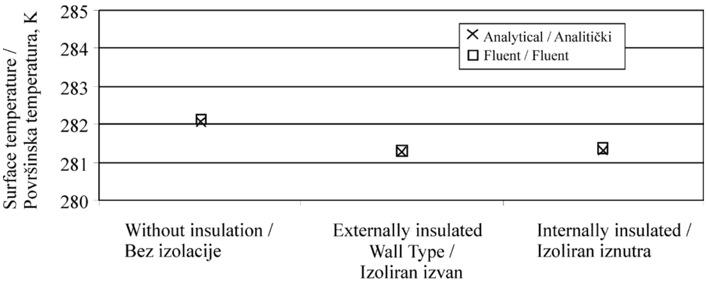


Figure 2. Comparison of analytical and numerical results for three different plane walls

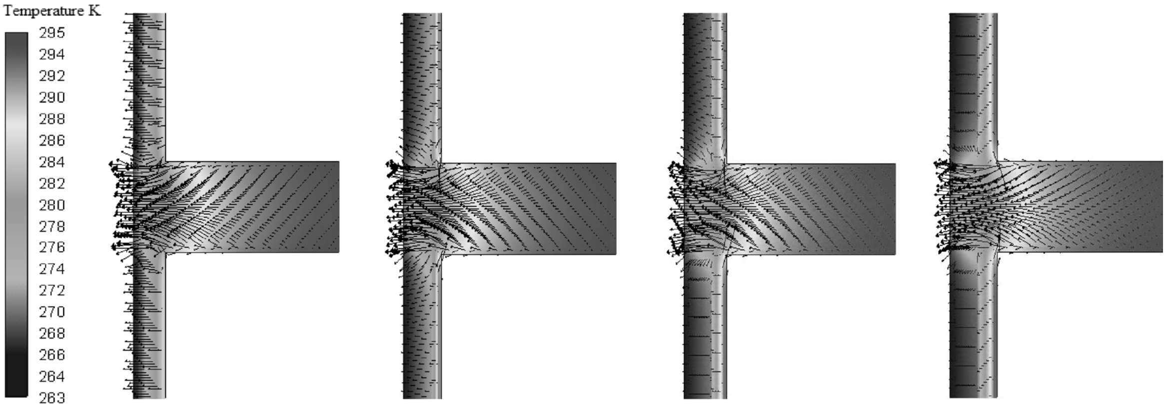
Slika 2. Usporedba analitičkih i numeričkih rezultata za tri različita ravna zida

Temperature distributions and heat flux vectors have been shown for each construction model. In addition to these, variation observed on the wall exterior surface temperatures, interior surface temperatures and heat flux values throughout the surface distance have been graphically presented at different insulation thicknesses. In graphics related to interior surface, zero point starts from the interior surface of the lower floor and the distance increases towards top along "*y*" axis, and increases towards right along "*x*" axis. On the graphics related to the external surface, zero point starts from the bottom along the vertical axis, and it increases towards the top.

Temperature distribution contours and heat flux vectors for the cases of non-insulated wall, 3 cm, 5 cm, 7 cm and internal insulation are shown in Figure 3. In the non-insulated case, heat fluxes are observed to be high in the beam area, and to be less and smaller values on the wall section (Figure 3a). With an increase of insulation thickness, lateral heat fluxes are determined to decrease and especially at 7 cm of insulation thickness; very short heat flux vectors can be seen on the surfaces of the walls. Besides, when the insulated thickness increases, it helps the temperature in the beam cross-section to increase towards the external environment and thus, the effect of the heat bridge is sen to be reduced.

Local temperature distributions and heat flux occurring on the internal and external surfaces of the intermediate floor beamed wall block can be seen in Figure 4. When compared to the non-insulated case, it increases by adding the insulation to the inner surface temperature approximately 8 K (Figure 4a). While the temperature, is stable at every insulation thicknesses till the beam corner point, it reaches the minimum value at the corner point. After this point, the temperature value increases again along the ceiling surface and reaches 294 K. As seen in Figure 4b, even with application of 3 cm insulation material, transfer of heat is reduced to about 65 % when compared with non-insulated case. This ratio increases up to 80 % when insulation thickness is 7cm.

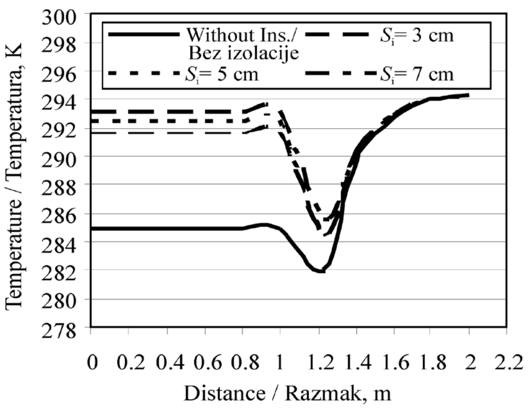
Figure 4c shows temperature variations on external surface where cases of internal insulation are examined (Figure 4c); it has been found that the temperature is stable along the exterior wall surface, while it increases along the exterior surface of 30 cm beam where the effect of the thermal bridge is observed. Here, it is clearly seen that internal insulation is not able to prevent the negative effect of a thermal bridge. High heat transfer rates from internal environment to outside reduce inside surface temperature values. The heat flux variations occurring on the external surface seem to be parallel with temperature variations (Figure 4d). Although the values of heat flux are stable till beam area for all cases, the highest heat flux value is observed at the beam area. Although heat transfer is found to decrease only in the areas of thermal bridge when compared to the non-insulated case, the effect of insulation is not observed in this area.



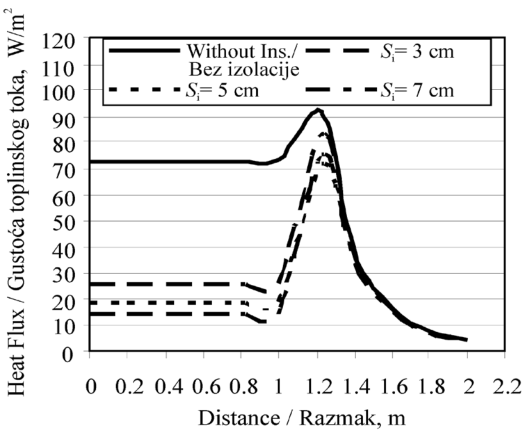
a) Without insulation / Bez izolacije b) S_i=3 cm c) S_i=5 cm d) S_i=7 cm

Figure 3. Temperature contours in the intermediate floor beamed wall block for internal insulation

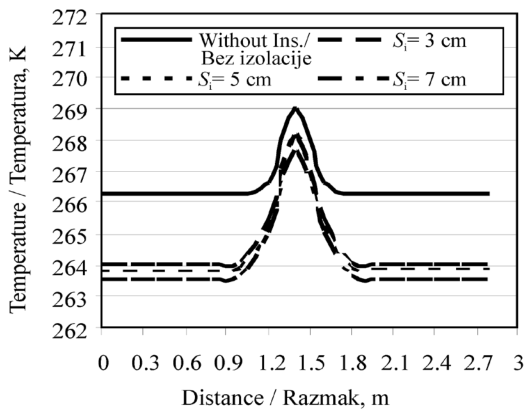
Slika 3. Temperaturno polja na međukatnom podu s unutrašnjim izolacijama



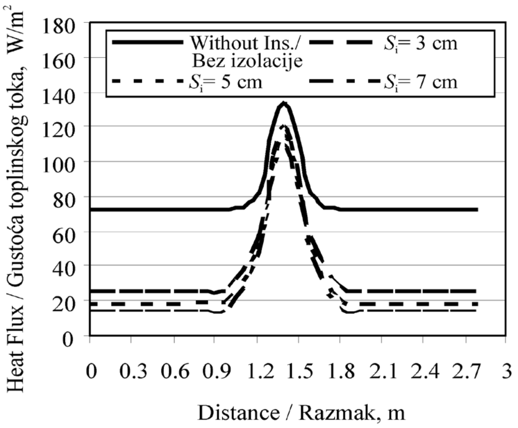
a) Temperature vaiations on the internal surface / Temperaturne varijacije unutrašnje površine



b) Heat flux variations on the internal surface / Varijacije gustoće toplinskog toka na unutrašnjoj površini



a) Temperature variations on the external surface / Temperaturne varijacije vanjske površine



d) Heat flux variations on the external surface / Varijacije gustoće toplinskog toka na vanjskoj površini

Figure 4. Temperature and heat flux variations on the internal and external surface of the intermediate floor beamed wall block for internal insulation

Slika 4. Varijacije temperatura i gustoća toplinskih tokova na unutrašnjoj i vanjskoj površini međukatnog poda izoliranim iznutra

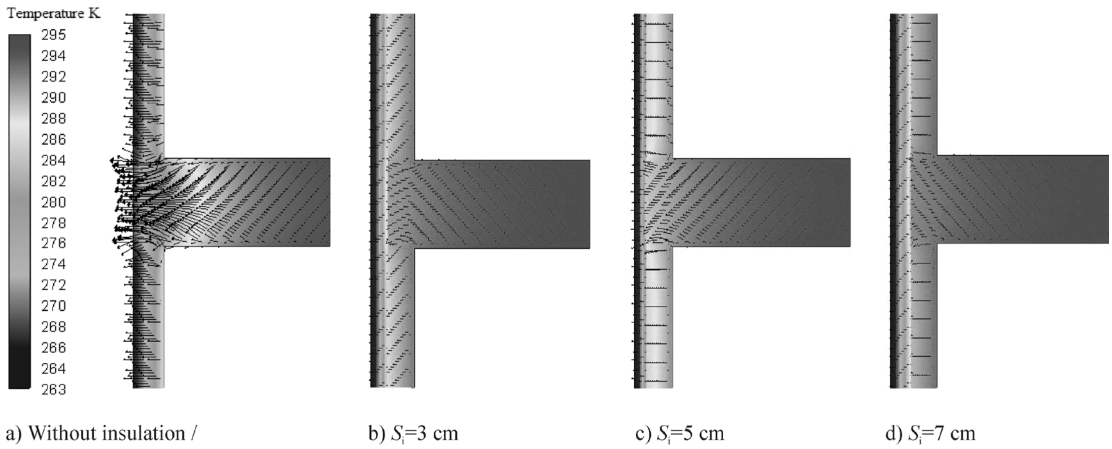
Temperature distribution on the intermediate floor beamed wall block is shown in Figure 5, for cases of non-insulated wall and 3 cm, 5 cm and 7 cm external insulation. As seen from Figure 5 wall temperatures increase by applying the insulation and energy storage has been provided at the wall and beam areas. Furthermore, heat flux vectors are not seen along the whole exterior surface, and the effect of the thermal bridge is observed to disappear completely in the case of S_i= 7 cm.

In Figure 6, local temperature and heat flux variations occurring on the internal and external surfaces of the intermediate floor beamed wall block are displayed. In Figure 6a, while the temperature on the internal surface in the non-insulated case is 285 K, it decreases until approximately 282 K at the wall-beam joint point. The corner point where the wall and the beam are joined is the point of the internal surface where the lowest temperature value is measured. These areas are efficient thermal bridges and there are two-dimensional heat flux effects to be seen at these sections. A temperature increment start at the ceiling surface, beginning from 20 cm away from the corner point, and this temperature increases up to 294 K. The wall temperature is seen to increase 9 K with insulation. Besides, insulation prevents temperature decrease at corner points where thermal bridges arise.

Local heat flux variations occurring on the internal surface of the externally insulated internal intermediate floor beamed block are seen in Figure 6b. In the non-insulated case, heat fluxes on the wall surface are extremely high. On the corner point where the wall and the beam join, heat fluxes reaches the highest value of 91 W/m^2 and then it decreases along ceiling surface after this point. The reason for this is that the environments housing the top and bottom surfaces of the thermal bridge share the same temperature value. In the case of external insulation, heat flux values from the surface are found to decrease. At the corner point, heat flux value decreases to approximately 13 W/m^2 in case of 7 cm external insulation and this situation continues along the ceiling surface. This decrement for the heat flux causes the temperature to increase at the corner point and accordingly, to impact on a thermal bridge decrease while the surface temperature increase. Since the thickness where the heat is stored is less in the case of internal insulation when compared to external insulation, heat transferred through the wall surface is also a little lower. Therefore, surface temperature of the interior wall is a bit higher than the situation observed in the case of external insulation. Heat flux rate decreases by increments of thickness of insulation. This decrement shows its effect also at the beam area.

The local temperature variations occurring on the exterior surface is shown in Figure 6c. As a result of the reduction gained on the heat flux from inside, exterior surface temperatures are seen to decrease when the insulation thickness is increased. A homogeneous temperature distribution has been obtained on the surface, temperature fluctuations and thermal stress resulting from the heat bridge has completely disappeared. This situation can also be seen in the heat flux variation graphic (Figure 6d). 7 cm insulation is the case in which external surface heat flux and temperature reach their lowest values.

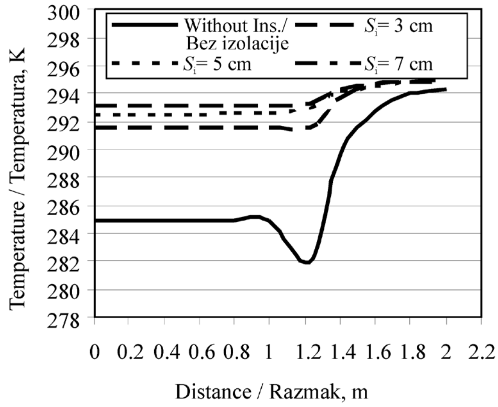
In Figure 7, temperature distributions for cases of non-insulated wall and 3 cm, 5 cm and 7 cm external insulation on balcony extension intermediate floor beamed wall block are given. Heat fluxes are seen to reach high values on the balcony extension in the non-insulated cases. As a result, inner surface temperatures remain at lower values. When insulations with different thicknesses are applied on the external wall, the amount of the heat fluxes decreases and the temperature of the internal surfaces increases in parallel with the increase insulation thickness. As seen in the temperature distribution, heat storage ability is increased due to insulation and its thickness.



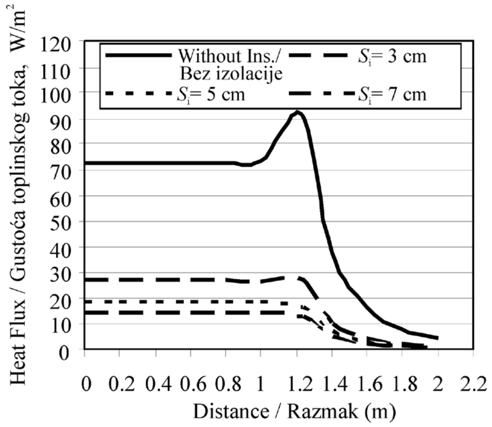
a) Without insulation / Bez izolacije b) S_i=3 cm c) S_i=5 cm d) S_i=7 cm

Figure 5. Temperature contours in the intermediate floor beamed wall block for external insulation

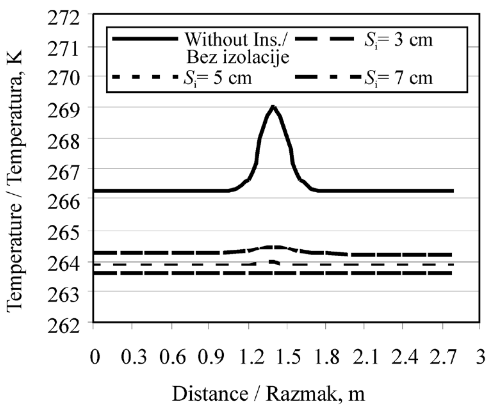
Slika 5. Temperature međukatnog poda s vanjskom izolacijom



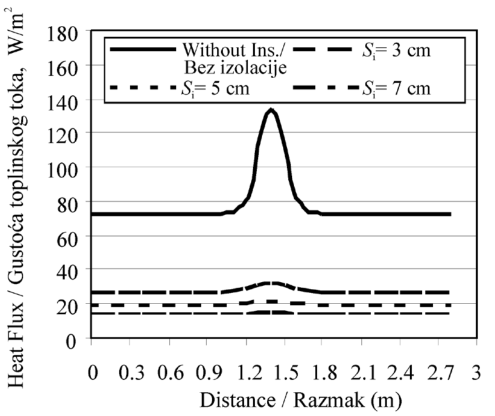
a) Temperature vaiations on the internal surface /
Temperaturne varijacije unutrašnje površine



b) Heat flux variations on the internal surface /
Varijacije gustoće toplinskog toka na unutrašnjoj površini



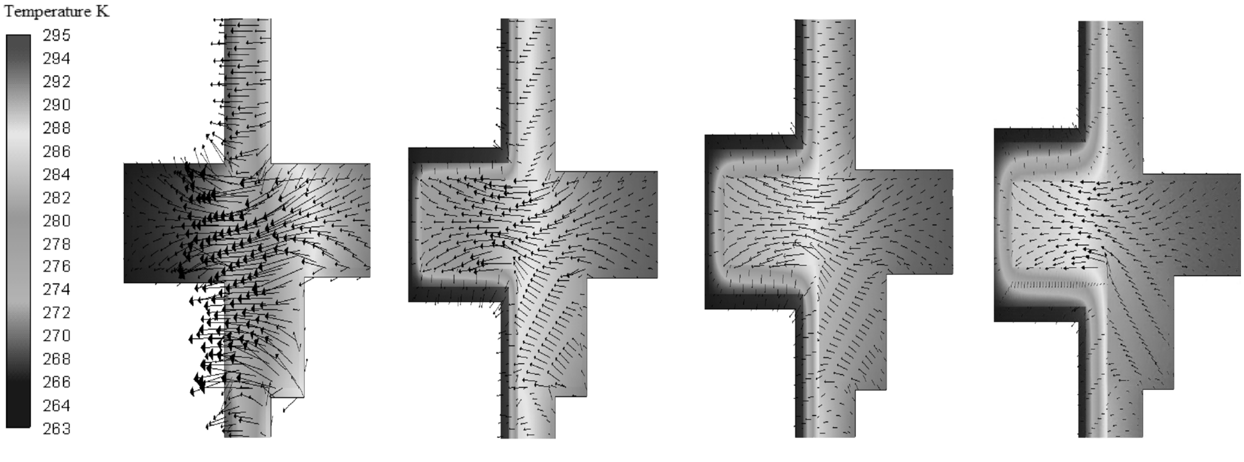
a) Temperature variations on the external surface /
Temperaturne varijacije vanjske površine



d) Heat flux variations on the external surface /
Varijacije gustoće toplinskog toka na vanjskoj površini

Figure 6. Temperature and heat flux variations on the internal and external surface of the intermediate floor beamed wall block under external insulation

Slika 6. Varijacije temperatura i gustoća toplinskih tokova na unutrašnjoj i vanjskoj površini međukatnog poda izoliranim izvana



a) Without insulation / Bez izolacije b) S_i=3 cm c) S_i=5 cm d) S_i=7 cm

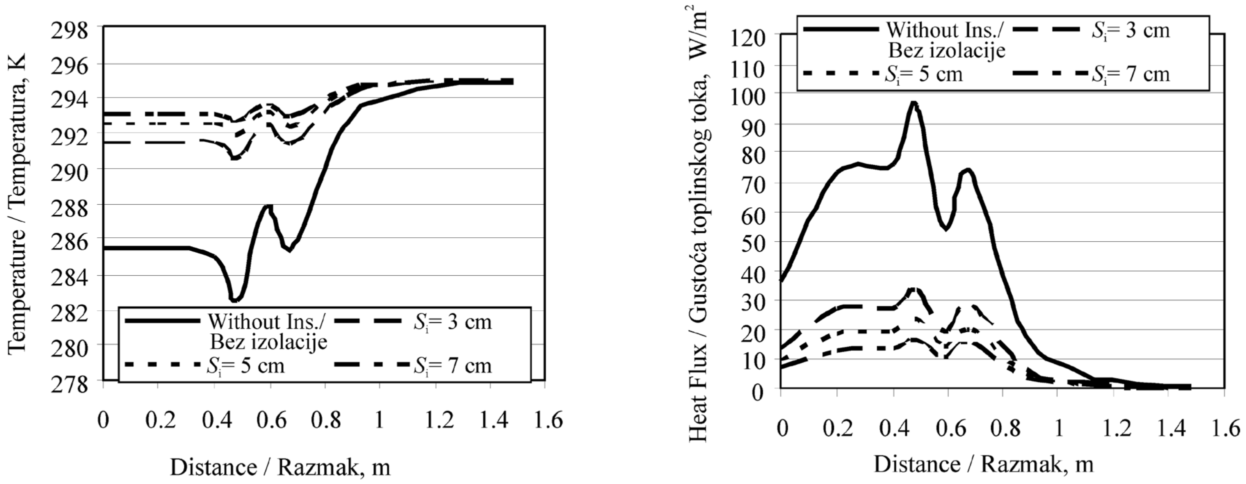
Figure 7. Temperature contours in the balcony extension intermediate floor beamed wall block

Slika 7. Temperature balkonske istake

When internal surface temperatures are analyzed, it is seen that the temperature decreases at the corner from internal surface to external surface, when compared to the wall surface, and at the corner towards internal environment, the temperature reaches 285 K value and has the same temperature as the wall (Figure 8a).

When heat flux variation occurring on the internal surface is analyzed, it is seen that the heat flux increases from the internal surface of the wall towards upside, and at the corner towards exterior wall, the flux reaches its highest value with 96 W/m^2 (Figure 8b). This value decreases at the corner towards inner environment and increases again at the second corner which is towards the external environment.

walls, reinforced concrete components transfer more heat from inside to outside. Thus, the temperature of the wall in the reinforced concrete component-wall intersection is higher than the temperature of the reinforced concrete component, at the area closer to the interior surface, and heat transfer occurs from the wall to the reinforced concrete component. On the other hand, at the area where intersection is closer to the exterior surface, temperature of the reinforced concrete component is higher than temperature of the wall, and heat transfer is observed from the reinforced concrete component towards the wall. Therefore, the heat transfer, which is one-dimensional (vertical to the planes composed by the wall surfaces) outside the reinforced concrete component



a) Temperature variations / Varijacije temperature

a) Heat flux variations / Varijacije gustoće toplinskog toka

Figure 8. Temperature and heat flux variations on the internal surface of the balcony extension intermediate floor beamed wall block for external insulation

Slika 8. Varijacije temperatura i gustoća toplinskih tokova na unutrašnjoj balkonskoj istaci s vanjskom izolacijom

4. Conclusion

Thermal bridges are the restricted areas having U-values (heat loss) substantially higher than the average U-value of the building (heat loss through transfer). The extra heat losses occurring in these areas cause;

- Increase in fuel consumption,
- Sectional increases in heat flux and decrease in the internal surface temperatures,
- Sweating or mould on these sections and lack of thermal comfort needed for a healthy and productive environment.

At the regions where reinforced concrete components and walls are joined; since the thermal conductivity of reinforced concrete components is much higher than the walls, reinforced concrete components transfer more heat

and its close proximity, becomes two-dimensional around the reinforced concrete component. If constant heat insulation cannot be provided at the sections where heat bridges are found, a two-dimensional transfer would become more significant. Extra heat losses and low inner surface temperatures are inevitable, and there is also a high possibility to see sweating and moulds. In this study, the significance of insulation and thermal bridges has been emphasized and both the importance of insulation thickness and the sections where heat bridges are seen have been calculated by use of Fluent packaged software for internal and external insulation cases and for different insulation thicknesses. Temperature contours, heat flux, point temperature and external heat flux distributions have been calculated for both layer beamed wall block and balcony extension intermediate floor beamed wall.

The significance of the insulation thickness has been emphasized, but economic analysis has not been included in the study. Therefore, it has been agreed that optimum values of insulation thickness should be found for each external temperature range. In addition, it has come to the conclusion that the insulation should be applied from outside and it should be applied continuously by covering the wall along the exterior surface up to the bottom of the balcony, in order to remove the effect of thermal bridge in both cases of middle layer beamed wall block and balcony extension.

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