NUMERICAL INVESTIGATION OF THE EFFECT OF INSULATION ON HEAT TRANSFER OF THERMAL BRIDGES WITH DIFFERENT TYPES

by

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In the present study, the effects of different types thermal bridges formed by beams for floor-wall junctions in reinforced concrete structures, with and without balconies, and the optimum configuration of the insulation layers to avoid heat loss were investigated as numerically. Both insulation between the walls and internal insulation was selected for floor-wall junctions and internal insulation was used for floor-wall junctions with balcony. Fluent package program was used to solve the temperature domain numerically. Results showed that high heat transfer rates were obtained in the region of thermal bridges for all building models. It was also obviously obtained that heat transfer rate decreased with making insulation on the beam surfaces.

Key words: *thermal bridge, insulation, fluent, numerical heat transfer*

Introduction

Thermal bridges as parts of the building envelope have a major effect on the thermal performance, *i. e.* increased heat loss in the winter and heat gain in the summer; reduced interior surface temperature, thus, increased risk of condensation and mold growth in the wintertime [1]. They drastically act to reduce the building envelope thermal resistance (R-value) and hence increase the transmission loads and accordingly jeopardize the beneficial use of thermal insulation [2].

There are many investigations into thermal behavior of thermal bridges. Larbi [3] developed statistical models of the thermal transmittance of 2-D thermal bridges. Modeling approach is used to accurately evaluate the effect of thermal bridge on energy performance of buildings. Firstly intersections of walls were modeled by using Sisley software program and then these models were reduced and integrated with computer program called Clim 2000 [4]. Gao *et al.* [5] tried to develop low order three dimensional heat transfer model to calculate the dynamic responses of temperatures and heat flows within thermal bridges. Modeling of dynamic components of 2-D heat transfer was investigated with thermal bridges for building by Salgon and Neven [6]. When 3-D heat transmission and thermal mass components were not taken into consideration, occurring serious errors were emphasized on evaluating thermal performance of whole building. Results of both experimental and multi-dimensional thermal analy-

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sis programs were used at evaluations [7]. Dilmac *et al.* [8] a new method developed for calculation of the parameters cited in ISO 9164 for floor/beam-wall intersections. The results obtained by the proposed method for typical floor with beam sections were compared with the results obtained by the methods stated in EN 832/EN 13789/EN ISO 14683 and the results obtained from 2-D analysis. Effect of thermal bridge was investigated for corner points which were built with walls. Thermal camera and finite volume method were used [9]. Asdrubali *et al.* [10]. offered a methodology to apply a quantitative analysis as simple thermographic searches and analytical processing for some types of thermal bridges. Karabulut [11] and Karabulut *et al*.[12] informed about thermal bridges and investigated effects of different geometries, ambient temperature, insulation thickness on thermal bridges formed by beams and also compared inner and outer surface temperature and heat flux variations. Multidimensional dynamic models were set up to predict the thermal performances of thermal bridges using a frequency response method by Mao and Johannesson [13]. Heat transfer along thermal bridges within the programs was intended to calculate in dynamic conditions by considering building inertia by Martin *et al*. [14]. An integral approach was developed to calculate effect of thermal bridges on the corner points of multilayer walls [15].

This study describes a numerical analysis of thermal bridging for floor-wall junctions in buildings using the computational fluid dynamics (CFD) software package FLUENT to investigate the thermal properties of various intersections of walls with floors and balconies, and study the effects of different insulation configurations. The temperature distributions and heat fluxes were calculated to analyze the effects of thermal bridging between the beams and walls. Thermal bridge models analyzed in this study can be useful for architects, civil engineers, residents of the building and insulation material workers who should be more attention in application because thermal bridges have an important effect on building heat losses and energy performance. At the same time, the analysis of the thermal bridges' impact aims to shed light on the potential for energy renovation measures to be applied in older buildings.

Models and numerical method

Configuration of the walls was modeled on the basis of the standard building envelope applicable to apartments in TURKEY. As shown in fig. 1, the thickness of the various thermal insulation layers was fixed at 5 cm, and the insulation was applied to the interior and to the cavity between walls of floor-wall junctions in a number of different configurations. Wall structures vary with climate in Turkey. In warm climates, bricks and concrete bricks are only covered with thin plaster layer while in cold climates sandwich walls are used. The sandwich wall consists of an insulation layer in the middle of the two brick layers and two plaster layers on the inside and outside surfaces. Ceilings are made of a plaster layer on bottom, reinforced concrete, and insulation on top. The thickness and thermal properties of component materials are shown in tab. 1.

Table 1. Features of materials [16]

Construction materials	Thermal conductivity [$Wm^{-1}K^{-1}$]	Thickness [m]
Concrete	2.1	0.3
Thermal insulation material	0.026	0.05
Brick wall	0.45	0.085
Inner plaster	0.87	0.015
Outer plaster	1.4	0.025

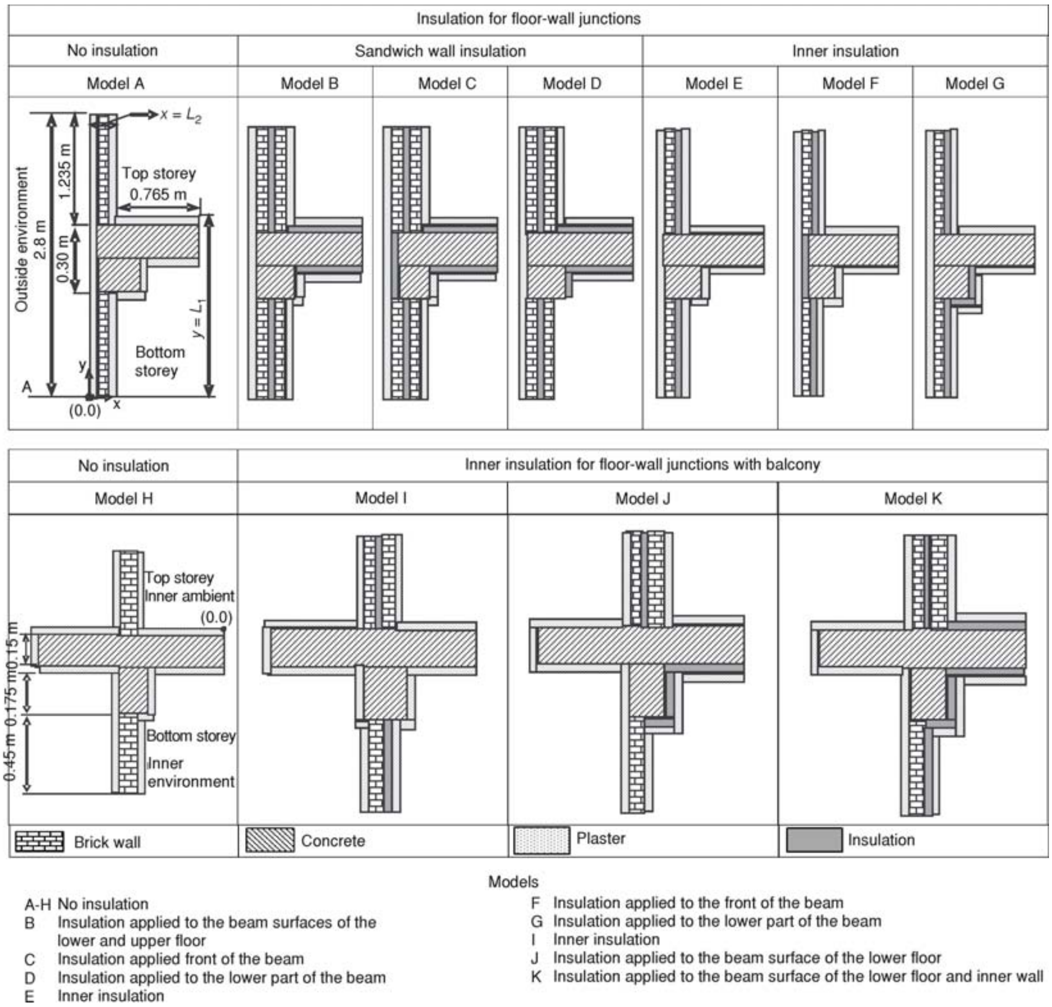

Figure 1. Wall configurations

The finite volume method (ANSYS-FLUENT program) was used for calculations. Finite volume 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 to the problem. This method uses a technique which is based on the control volume for transforming heat flow equations into algebraic equations which can be solved numerically. In other words, this technique is based on the principle of taking the heat flow equations integration in each control volume. This integration result provides equations which characterize each control volume which occurs. A quadrilateral grid was used for simulation with a total of 8000 to 9000 elements.

Inside floor surface ($y = L_1$):

$$h_{\text{in}}(T_{y=L_1} - T_{\text{in}}) = k_{\text{in}} \left.\frac{\partial T}{\partial y}\right|_{y=L_1} \tag{1}$$

Inside wall surface ($x = L_2$):

$$h_{\text{in}}(T_{x=L_2} - T_{\text{in}}) = k_n \left.\frac{\partial T}{\partial x}\right|_{x=L_2} \tag{2}$$

where h_{in} is the inside surface heat transfer coefficient and T_{in} – the inside ambient temperature.

Outside surface ($x = 0$):

$$k_1 \left.\frac{\partial T}{\partial x}\right|_{x=0} = h_{\text{o}}(T_{\text{o}} - T_{x=0}) \tag{3}$$

where h_{o} is the outside surface heat transfer coefficient, T_{o} – the outside environment temperature. For analysis, outside environment temperature and heat transfer coefficient were assumed as –20 ºC and 25 W/m^{2}K; inside environment temperature and heat transfer coefficient were assumed as 20 ºC and 8 W/m^{2}K, respectively [17].

Results and discussion

Table 2 shows the temperature distributions obtained at the inner surfaces with no insulation, exterior insulation, and interior insulation using an analytical approach and two dimensional numerical approach (finite difference method) [18] as well as the numerical results from the CFD analysis. The three datasets were in good agreement.

Table 2. Comparison of analytical, 2-D numerical [18] and FLUENT results for different wall models

Surface temperatures [K]					
Models	Analytical	Fluent	Surface	2-D numerical [18]	Fluent
Without insulation	282.220	282.300	A	291.400	291.300
Externally insulation	281.350	281.400	B	287.000	286.870
Internally insulation	281.420	281.540			

The temperatures at the outer and inner surfaces of the building, as well as the heat fluxes, are shown for all the models. For plots related to the outer surface with normal floors, the origin is located at the lower side of the floor, and the positive y-axis corresponds to the upward vertical displacement. For plots related to the inner surface, the origin is located at the inner surface of the beam, with the x-axis increasing to the left and the y-axis increasing downward. The origin for the upper floors is located at the inner surface of the upper floor beam, with the x-axis increasing to the left and the y-axis increasing upward. For plots related to the inner surface of the upper floor with balcony extensions, the origin is located at the inner surface of the beam of the upper floor, with the x-axis increasing to the left and the y-axis increasing upward.

Figure 2 shows the simulated temperature distributions of the floor-wall junctions. With no insulation (configuration A), the density and strength of the heat flux vectors, particularly at the beam, were large. For configuration B, the insulation was applied to the beam surfaces on both the upper and lower surfaces of the floor and to the cavity between walls, which reduced the heat flux at the beam; however, it did not eliminate the effects of thermal bridging. For configuration C, the insulation was applied between the flooring and the exterior surface, which led to a considerable reduction in the heat flux at the beam section; however, there was a significant heat flux at the lower and upper parts of the insulation due to discontinuities in the insulation. For configuration D, the insulation was applied to the lower part of the beam, which led to

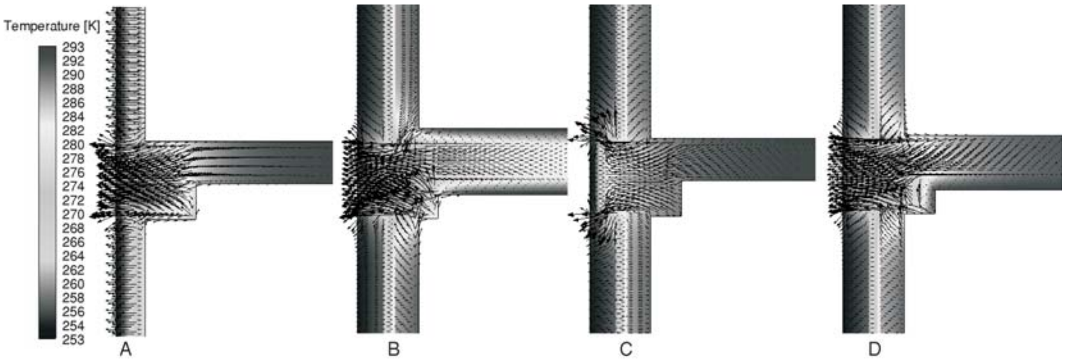

Figure 2. Temperature distributions of the floor-wall junctions with sandwich insulation

an increase in the surface temperature; however, the effects of thermal bridging were still clearly observed.

Figure 3 shows the outer surface temperature and heat flux distributions of the floor-wall junctions with insulation placed at a variety of locations. The temperature reached 260.9 K on the beam with no insulation, and the temperature on the wall was 257.4 K, fig. 3(a). For configurations B and D, the temperatures at the surface of the beam were lower compared to the beam with no insulation. For configuration C, the insulation was applied to the surface of the beam, which reduced the temperature to 253 K; however, as the insulation was not continuous, large changes in temperature were evident at the ends of the insulation. For configuration A, the heat flux at the outer wall surface reached 102.76 W/m^2, whereas it was approximately 16 W/m^2 for configurations B, C, and D, fig. 3(b). From fig. 3(b), a large increase in the heat flux was obtained at the beam section, the form of which was similar to the temperature distributions at the outer surface, showing the effects of thermal bridging. The insulation was applied to the base and ceiling surfaces in configurations B and D, which led to a reduction in the heat flux at the outer surface of the beam; however, the effects of thermal bridging could not be eliminated. For configuration C, the heat flux reached 56 W/m^2 at the lower and upper parts of the insulation applied to the beam.

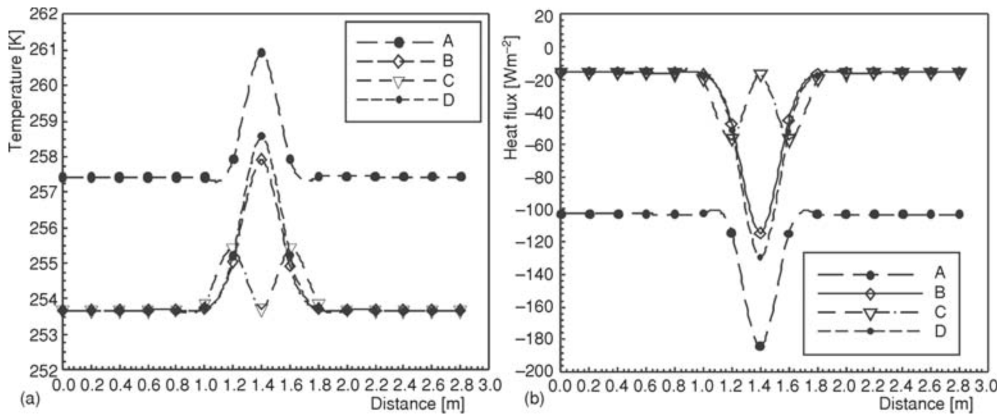

Figure 3. Outer surface temperature and heat flux distributions of the floor-wall junctions with sandwich insulation

As shown in fig. 4(a), the highest temperature on the inside surface of the beam was observed for configuration C, where the front of the beam was also insulated. For configuration A, the lowest temperature was 276 K at the corner, where the effects of thermal bridging were most pronounced. Although the highest corner temperature was obtained for configuration C, where the front of the beam was insulated, the lowest temperature was obtained for configuration D because the temperature was reduced due to the insulation applied to the lower surface of the beam.

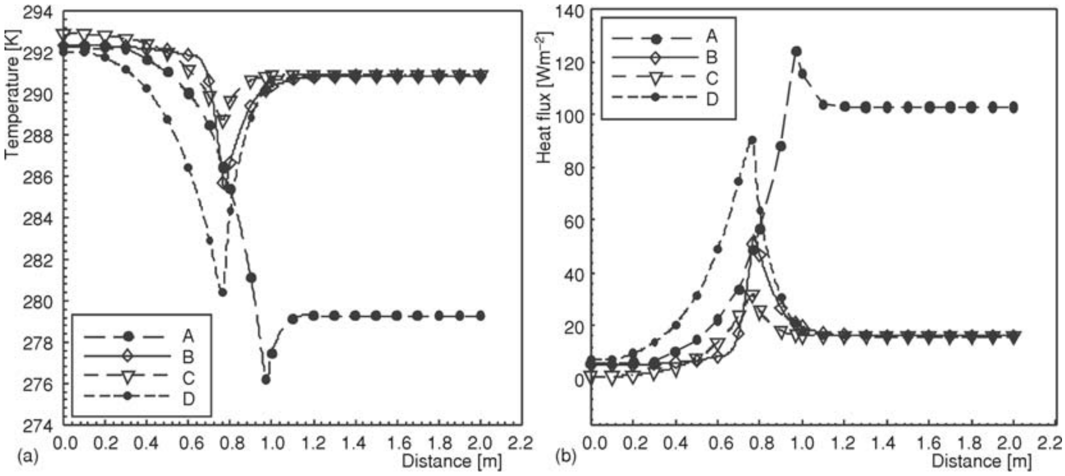

Figure 4. Inner surface temperature and heat flux distributions of the floor-wall junctions with sandwich insulation

When compared with configuration A, fig. 4(b), the insulated cavity between walls reduced the heat flux by 86%. When the heat flux at the surface of the beam was examined, the largest heat flux reduction (72%) occurred for configuration C, where the front of the beam was also insulated in addition to the cavity between walls. A reduction of approximately 14% was obtained for configuration B, whereas there was a 60% increase in the heat flux for configuration D, where only the surface of the beam at the lower floor was insulated in addition to the cavity between walls.

This result demonstrates that complete insulation, rather than local insulation, is required to eliminate thermal bridging.

Figure 5 shows the temperature distribution of the floor-wall junctions with internal insulation. Only for configuration E, where internal insulation was applied, was the wall section exposed to a cold environment, despite the increased surface temperature of the wall. The heat flux indicated that the effects of thermal bridging continued along the beam. For configuration F, the insulation was applied to the front of the beam in addition to the inner insulation, which led to an increase in the temperature of the beam, as well as a reduction in the heat flux. However, the effects of thermal bridging were evident from the large localized heat flux at the outer surface. For configuration G, the surface temperature of the lower floor beam and wall increased, and the heat flux at the beam area was large.

Figure 6 shows the simulated outside surface temperature and heat flux distributions with different configurations of interior insulation. The lateral heat flux was reduced close to the beam due to the insulation applied to the inner walls, which led to a reduction in the surface tem-

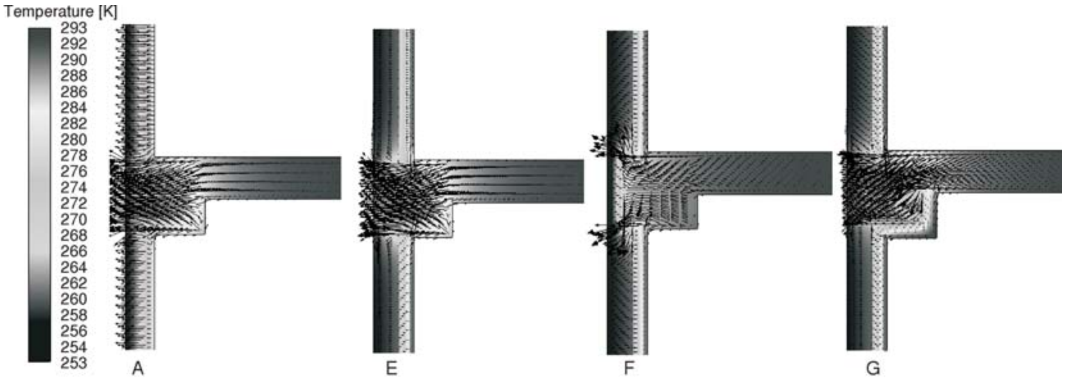

Figure 5. The temperature distribution of the floor-wall junctions with internal insulation

perature at the beam for configuration E, fig. 6(a). For configuration G, the insulation at the surface of the beam at the lower floor led to a reduction in the surface temperature of the beam. However, the lowest beam surface temperature of 254 K was obtained for configuration F. As shown in fig. 6(b), the heat flux for configuration F was reduced by 75% compared with configuration A. The reduction in temperature at the beam was 44% and 60% for configurations E and G, respectively. The heat flux at the wall surface was reduced by 84% for both configurations E and G compared with configuration A. For configuration F, there was a 79% local increase in the heat flux due to the discontinuity in the insulation.

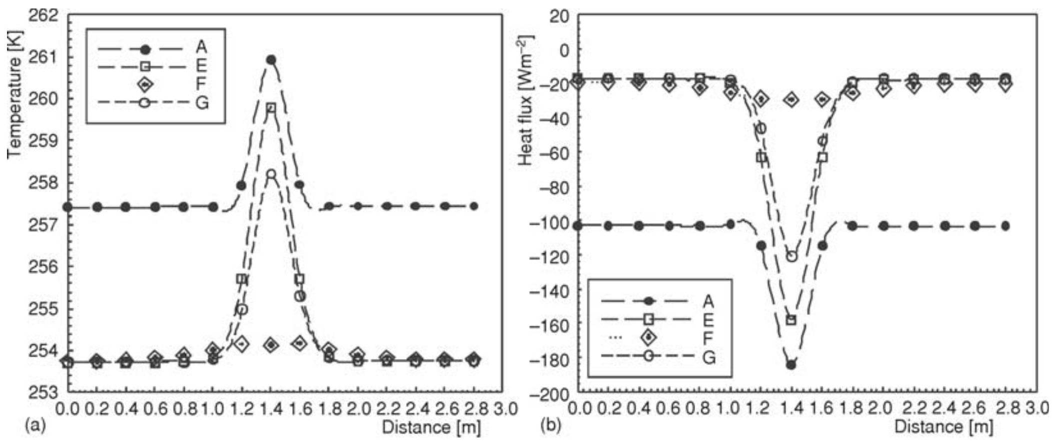

Figure 6. Outer surface temperature and heat flux distributions of the floor-wall junctions with internal insulation

From fig. 7(a), the surface temperature was reduced in the direction along the surface of the lower beam towards the outer environment. For configuration E, a reduction in the lateral heat flux to the beam due to the inner insulation led to a reduction in the beam temperature relative to configuration A. For this reason, a lower beam surface temperature was obtained for configuration E, and the temperature at the first corner point towards the outer environment was also reduced. For configuration F, the exterior insulation of the front of the beam led to a higher surface temperature compared with configuration G. In contrast, for configuration G, where the

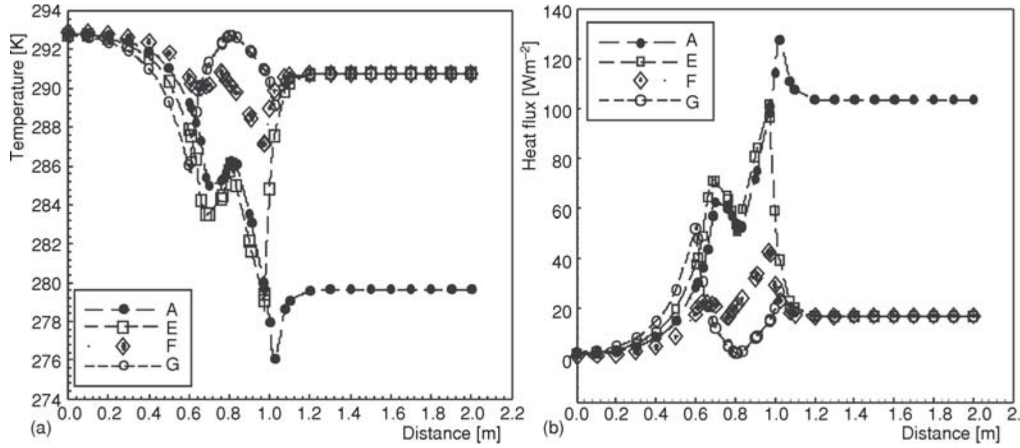

Figure 7. Inner surface temperature and heat flux distributions of the floor-wall junctions with internal insulation

beam surface was insulated internally, a considerably larger beam surface temperature was obtained compared with the other configurations (A, E, and F).

For configuration A, fig. 7(b), the heat flux at the second corner point towards the outer environment was a maximum, and was lower at the wall surface. For configuration E, the heat flux was lower at the same corner point due to the insulation. For configurations F and G, lower heat fluxes were observed due to the application of insulation in such a way as to reduce the effects of thermal bridging.

Figure 8 shows the temperature distribution of the thermal bridges formed by beams with floor-wall junctions and balconies. For configuration H (no insulation), the heat flux was large at the wall and the beam. For configuration I, the heat flux was lower at the wall as a result of the insulation, and it decreased at the beam due to the reduced lateral heat flux. For configuration J, the insulation was applied to the beam surface of the lower floor, which led to a reduction in the heat lost from this part to the beam. However, the heat flux from the surface of the beam of the upper floor increased, as shown in the temperature distribution plots.

For configuration K, the heat flux was reduced considerably compared with configuration H. However, the heat flux from the insulated upper cavity between walls was evident in the temperature distribution.

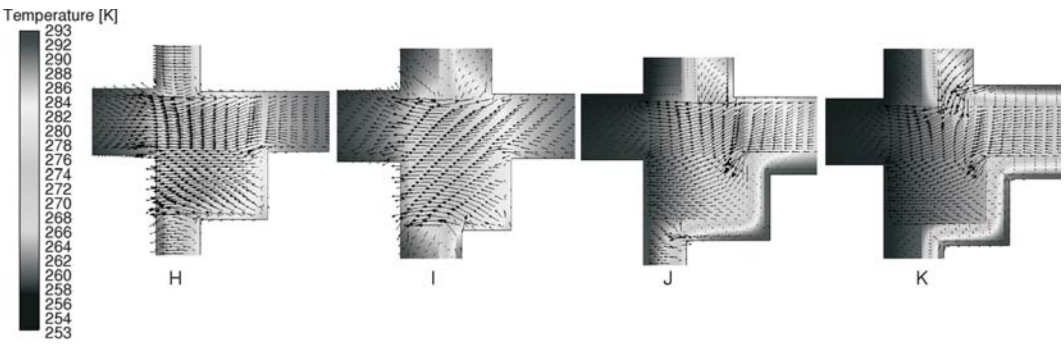

Figure 8. Temperature distribution of the thermal bridges formed by beams with floor-wall junctions and balconies

Figure 9 shows the temperature and heat flux distributions for the floor-wall junctions with balconies. The temperature was reduced from the internal environment toward the exterior environment at the surface of the upper floor, and was a minimum at the corner, where the effects of thermal bridging were most significant. For configurations J and K, insulation was applied to the lower floor surfaces, which led to a reduction in the heat flux into the beam section, and a lower surface temperature was observed at the upper floor surface compared with configurations H and I. As shown in fig. 9, the surface temperature of the beam for configuration I was lower than that for configuration H. Whereas the largest local heat flux at the beam surface was observed for configuration J at the corner, the largest overall heat flux was observed for configuration H. Thus, the insulation should be applied in such a way that the beam and wall surface are completely covered in order to prevent loss of heat to the beam. At the surface of the wall, the heat flux was reduced by 87% through the use of an insulated cavity between walls (I, J and K).

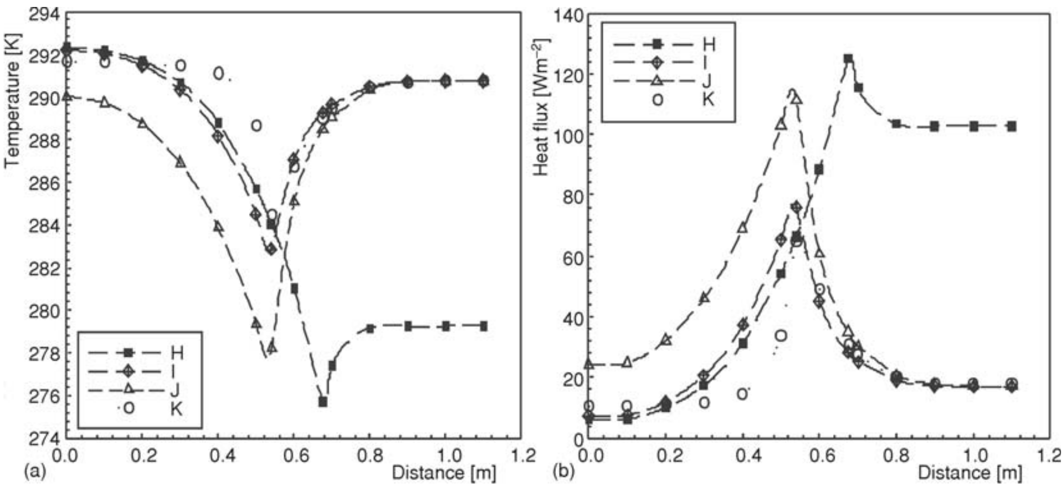

Figure 9. Inner surface temperature and heat flux distributions of the thermal bridges formed by beams with floor-wall junctions and balconies

The field measurements using infrared thermography shows thermal bridges of each part of actual existing buildings [19]. The infrared camera used in this research is a Therma-CAM S 65 from FLIR SYSTEMS, and the software is ThermaCAM Researcher 2001 (from FLIR). The camera has the ability to make both thermal and visual images, with real-time 14-bit digital output and auto focus. Measurements were made for outer wall and beam of different buildings [19]. As can be seen from fig. 10, temperature distributions are determined to be high in beam, column and wall junctions when compared with wall region for non-insulated building. The reason is that reinforced concrete structure is a highly conductive material whose thermal conductivity is more than 4 times higher than brick wall material. Because heat always flows through the easiest path from the heated space to the outside (the path with least resistance), thermal bridges are the cause of important heat loss. As it may be seen from the figures, when the insulation is applied on the external wall and beam surface, the temperature of the outer surfaces decreases and the continuous layer of insulation reduce thermal bridge effect by saving energy and improving comfort conditions.

Figure 10. Heat losses for a sample building; (a) typical floor-wall junctions, (b) floor-wall junctions with balcony

Conclusions

Thermal bridging in junctions between walls and floors in buildings was investigated using the software package ANSYS Fluent. The temperature distributions and heat fluxes were calculated for a range of different geometries, with various configurations of 5-cm-thick insulation layers. The aim was to investigate the effects of different types thermal bridges formed by beams for floor-wall junctions in reinforced concrete structures, with and without balconies, on the thermal performance of buildings, and to determine the optimum configuration of the insulation layers to avoid heat loss.

The heat flux at the outer surface of the beam was approximately 91% larger without insulation on the flooring than with insulation. The floor with a balcony was insulated in a variety of ways; we found that the surface temperature of the upper floor beam for configuration J was lower than for configurations I and H. Insulation should be applied to the entirety of the surface of the beam on the lower floor. Configuration J exhibited the lowest beam temperature, leading to the lowest surface temperature of the upper floor. Although insulation applied to the upper surface of the beam resulted in an increase in the surface temperature of the beam for configuration K, it did not completely eliminate the heat loss, and the discontinuity in the insulation led to thermal bridging.

Nomenclature

h – heat transfer coefficient, [$Wm^{-2}K^{-1}$]
k – thermal conductivity, [$Wm^{-1}K^{-1}$]
L_1 – wall height, [m]
L_2 – wall thickness, [m]
T – temperature, [K]
x – co-ordinate along wall thickness, [m]
y – co-ordinate along wall height, [m]

Subscripts

in – inside

o – outside
n – inner wall layer
l – outer wall layer

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