IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Lack of regulation on the energy efficiency in Serbia in terms of the assessment of the impact of thermal bridges

To cite this article: Raji Aleksandar *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **410** 012077

Lack of regulation on the energy efficiency in Serbia in terms of the assessment of the impact of thermal bridges

Rajčić Aleksandar[1], Đukanović Ljiljana[1], Radivojević Ana[1*]

[1] University of Belgrade, Faculty of Architecture, Belgrade, Serbia

Email: ana@arh.bg.ac.rs

Abstract. As one of the aspects of sustainable architecture, the energy efficiency of buildings has largely come to life and has found its practical application in modern construction practice. Active action towards the achievement of the adequate energy performance of buildings implies the creation of appropriate regulations, providing basic guidelines for securing energy efficiency in the design and construction of buildings. In that sense, with a dozen years of delay in relation to the introduction of the EPBD, Serbia has adopted its legal regulations regarding energy efficiency in buildings, being in force since 2012. Respecting the basic guidelines of the original directive, the regulations in Serbia were the subject of major changes in relation to the previous ones, making a major shift in the boundaries of the relevant parameters and the basic methodology of calculating the energy performance of buildings. However, in practice, it has been shown that some of the factors that are important for the design and energy behaviour of the buildings have been treated inadequately. This particularly refers to the problem of thermal bridges, whose impact on the overall energy performance of the buildings is too simplified. Consequently, depending on the complexity of the building, the prescribed calculation methodology often yields significantly fewer energy needs than they actually are. By taking the view that the influence of thermal bridges, regardless of their type and character, is treated as an arbitrary magnification of surface transmission loss in the function of magnifying the surface of the thermal envelope, the real impact of both linear and point heat losses is neglected. While the issue of an adequate calculation of linear losses is directly related to the way of designing the building, that is, to the conception of details, the question of the impact of point losses is a consequence of the structure of thermal envelope elements. The paper presents two types of critical cases of thermal bridges: the treatment of linear thermal bridges for which research has shown that their influence can significantly exceed those envisaged by the current rulebook, and the influence of point heat bridges, as seen in the specific case of ventilated façades in which this problem is present.

1. Introduction

The notion of sustainable architecture considers the problem of reduction of energy consumption of buildings as one of the main concerns of the nowadays building practice. In an effort to reduce the energy consumption necessary for the operation of buildings, as well as to reduce the consequential emissions of carbon dioxide, Europe has adopted the concept of energy efficiency in buildings defined by the postulates of the European Commission's Directive of the same name [1]. The adoption of the Directive has inevitably induced methodological changes regarding the calculation of total energy performance of a building, incorporated into the relevant thermal regulations.

While EU country members have followed the desirable course in adoption and implementation of the EPBD measures, political and economic situation prevented Serbia to follow the same trend. Finally, Serbia has taken the first steps towards the improvement of energy efficiency of buildings by the adoption of the new energy efficiency regulations, enacted in 2011, and in force since 2012 [2,3]. The basic structure of new regulations was in accordance with incentives of the directive. Although late in comparison with EU countries, extensive change of thermal regulations made a significant step forward from the concept of thermal protection to the concept of the overall energy performance of buildings. However, the set change in the treatment of new and existing buildings regarding the design and assessment of energy-efficient buildings was not comprehensive in every aspect and some elements of the directive have been consciously omitted in this primary version. One of the main differences refers to the calculation of energy use of a building which is based only on required thermal energy for heating.

From the point of view of building physics, significant changes were observed in the treatment of transmission heat losses by drastically reducing the limit values of thermal transmittance of elements of the thermal envelope. Another novelty was the appreciation and calculation of the effects of heat gains. These changes could be considered a positive development compared to the previous regulations. On the other hand, it turned out that the proposed treatment of the impacts of thermal bridges on total heat transfer is too simplified and as such it directly influences the calculation of energy needs, in this case, the energy need for heating, which is often underestimated. Having this in mind, this paper strives to stress the importance of an adequate treatment of thermal bridges in the calculation procedures of their impact, both on energy performance and comfort of a building. Therefore, a comparison would be made between the results of thermal bridge effects, calculated in both ways – by using the simplified method prescribed by the current Serbian thermal regulations, and by more accurate calculation based on mathematical modelling that relies on postulates of relevant standards, using original *T-Studio* software [4]. The problem would be analyzed in the case of the most critical liner thermal bridges that are present in the Serbian building practice, as well as in the case of ventilated facades that in which the problem of point heat bridges is present.

2. Thermal bridges – assessment of impact

2.1. Types of thermal bridges and general principles in assessing their impact

Additional heat losses in the thermal envelope of architectural buildings are manifested through linear and point thermal bridges. Linear thermal bridges, which are the most common type of thermal bridges in buildings, arise in the interaction of the elements of a thermal envelope as a consequence of their mutual geometric relationships, as well as due to the change in the structure of the assembly. By their geometric nature, they are called two-dimensional thermal bridges as they are a consequence of the geometric relationship of surface elements whose intersection occurs in one line and every case of such interactive connections needs to be analyzed. On the other hand, point thermal bridges, which are by their geometric nature three-dimensional, refer to a singular point in the envelope as a result of an intersection between two walls and a floor or a local fixing system.

In general, additional heat transfer through a linear or point thermal bridge is definied by a linear thermal transmission ψ $[\frac{W}{mK}]$ (1) and, a point thermal transmission χ $[\frac{W}{mK}]$ (2), expressed as a function of the relevant coefficient of thermal coupling (L^{2D} or L^{3D}), thermal transmitance of the element U $[\frac{W}{m^2 \cdot K}]$, its area (A) and length of a joint l [m].

$$\psi = L^{2D} - \sum(U \cdot l) \quad (1)$$

$$\chi = L^{3D} - \sum(U \cdot A) - \sum(\psi \cdot l) \quad (2)$$

In the case of point thermal bridges, if they are repeated in the level of the coupling element, an additional heat loss is expressed as a correction of the U-value of the plane element, ΔU $[\frac{W}{m^2 \cdot K}]$, taking into account the number of breaks per sq.m of area containing point thermal bridges (n), and a point thermal transmission of breakthrough, $\chi\ [\frac{W}{K}]$ (3).

$$\Delta U = \sum (n \cdot x) \qquad (3)$$

Depending on the particular type of a thermal bridge, its value varies, and it could be estimated in several ways, having a different degree of accuracy [5]:

- using mathematical modelling which relies on detailed calculation according to the standard EN ISO 10211: 2007 [6],
- using a catalogue of predetermined values for different types of thermal bridges with fixed, referenced values of the coefficient, in accordance with a relevant standard EN ISO 14683:2007 [7],
- using a catalogue of different types of thermal bridges with parametric values,
- by adopting a unique value of the thermal bridge influence, regardless of the particular case.

It should be mentioned that European countries do not have identical approach regarding the calculation procedures of thermal bridges in energy calculations. This refers even for EU member countries, in spite of the set goal of the energy calculation and compliance procedures [8].

In a situation when a significant linear or point thermal bridge cannot be avoided at the design stage nor after construction or rehabilitation, it is necessary to include its impact in the assessment of additional heat losses in calculating the thermal load or the energy demand. It is also desirable to estimate the risk of condensation and the development of the mould which arises due to the lower surface temperature on the inner side of the element that is under the influence of the thermal bridge [9].

To better understand the impact of thermal bridges on the level of heat loss, classification based on the estimated value of the transmission coefficient can be carried out in order to avoid or improve certain details that cause a significant loss of energy. In this respect, in the case of linear thermal transmission, values less than $0.1[\frac{W}{mK}]$ can be considered negligible, while those less than $0.25[\frac{W}{mK}]$ are considered to be low [10].

Regarding the risk of surface condensation, it could be estimated on the basis of the calculation of the temperature factor f_{Rsi} which is used in the assessment of the risk of surface condensation or the development of the mould on the interior surfaces. Under stationary conditions it is calculated as (4):

$$f_{R_{si}} = (T_{si} - T_e)/(T_i - T_e) \qquad (4)$$

where T_{si} is the internal surface temperature, T_i is the temperature of the inner environment, and T_e is the temperature of the outer environment. The temperature factor f_{Rsi} depends on one hand on the structure of the elements of thermal envelope, ie their thermal characteristics, and on other on the relative humidity of the inner space. In order to prevent the formation of the mould, it is necessary to fulfil the condition that each point on the inner surface has a temperature, that is, a temperature factor greater than or equal to the critical one. It could be assumed that when the f_{Rsi} is higher or equal 0.8, there is no risk of surface condensation [9, 10].

2.2. *Calculation method and assumption of impact of thermal bridges in Serbian regulations*

Calculation of building physics within the framework of regulations in Serbia is based on the methods defined in standard EN ISO 13790:2008 [11] and other derived standards. Regarding the calculation of the heat transfer coefficient, a simplified method was accepted. Accordingly, the overall transmission heat transfer coefficient, $H_T\ [\frac{W}{K}]$ is calculated as follows (5):

$$H_T = \sum_i \left(F_x \cdot U_j \cdot A_j\right) + H_{TB} \qquad (5)$$

where $U_j\ [\frac{W}{m^2 \cdot K}]$ refers to thermal transmittance of element i of the thermal envelope, A_j [m^2] represents its area, F_x, [-] is the temperature correction factor which regulates temperature conditions at the other side of the construction element when they differ from those of the external environment and $H_{TB}\ [\frac{W}{mK}]$

is a heat transfer coefficient due to the effect of thermal bridges. The simplification of the calculation method refers to the calculation of the thermal bridge effect which is assumed as (6):

$$H_{TB} = \Delta U_{TB} \cdot A \qquad (6)$$

In the equation, A [m^2] represents an aggregate area of external construction elements (thermal envelope of the building - external dimensions), while the effect of thermal bridges is, in all cases, assumed as (7):

$$\Delta U_{TB} = 0.10 \ \frac{W}{m^2K} \qquad (7)$$

In this way, regardless of the type and character of thermal bridges, their influence is treated as an arbitrary magnification of surface transmission loss in the function of magnifying the surface of the thermal envelope. Consequently, the real impact of both linear and point heat losses is neglected, so, depending on the exact type of a thermal bridge, the real impact could be either overestimated or underestimated.

In addition to the described lack of such a simplified approach, the adopted method of treatment of thermal bridges also ignores their potentially negative effect in terms of the risk of condensation, which could negatively affect a living comfort.

3. The method of calculation of thermal bridges and the consequences in the construction practice

3.1. The problems regarding linear thermal bridges

In order to analyze the accuracy of the calculation methods of the linear thermal bridges impact and to stress the need for its appropriate estimation, in a variety of different types of junctions of elements in a building where linear thermal bridges can occur [6], the typical example of the penetration of the floor structure through the facade wall, as in the case of the formation of a balcony, is selected to be analyzed and presented in figure 1. This type of connection between the elements of the thermal envelope exhibits extremely high values of linear thermal transmission, much higher than 0.5 [$\frac{W}{mK}$], which is considered as a very unfavourable example of a thermal bridge. Schemes of these junctions have been marked as B, and variation marked as B1 would be the subject of further analysis.

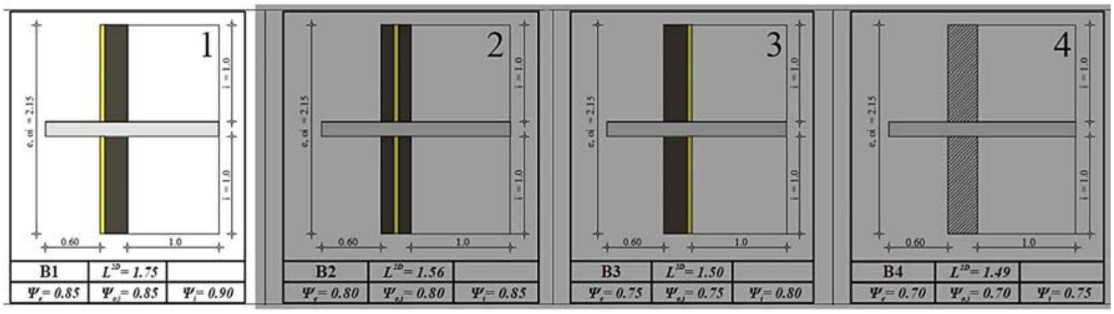

Figure 1. Variations of wall-floor structure junctions creating a balcony

In domestic building practice, the connection between the externally, nowadays insulated façade wall with and the floor structure that continuously penetrates through it is most often an architectural and constructive solution for the formation of balconies, loggias or terraces. The reasons for the presence of this solution are based on the simplicity of performance due to the continuity of the reinforcement, the conditions imposed by seismic regulations, as well as the economic logic of minimizing costs in the construction phase, excluding from consideration the costs of heating during exploitation.

For the purpose of assessment of linear thermal bridge impact, a teoretical model of a junction has been created, in accordance with the postulates of the standard EN ISO 14683:2007 [6]. The idea was to compare the predefined values for linear transmission given in the catalogue of the standard with those that are calculated by numerical modelling according to the EN ISO 10211:2007 using the original T-Studio software [4], in order to confirm or disprove the fixed values given in the catalogue.

Geometrical characteristics of investigated junction are set in accordance with EN ISO 14683, so the internal length of the wall sections are 1m, the length of the floor structure is 1m, and the length of the segment of the balcony is 0.6m. Four basic types of junctions were formed. All of them have a reinforced concrete slab as a floor structure 16, 18, 20, 22 or 24cm thick, while the walls varied as of 20cm reinforced concrete - B1.1, of brick block 20cm - B1.2, brick and 25cm -B1.3 brick 38cm - B1.4. For each subtype of the junction, the performance for different thicknesses of the external thermal insulation varying in thicknesses of 5, 6, 8, 10, 12 and 15 cm was analyzed.

The distribution of the temperature within the change is influenced by the breakdown of the plate, which is manifested by low contact temperatures in the interior, while the presentation of the heat flux shows the intensity in the central zone of detail, that is, in the part of the breakthrough the slab through the facade wall, as shown in figure 2.

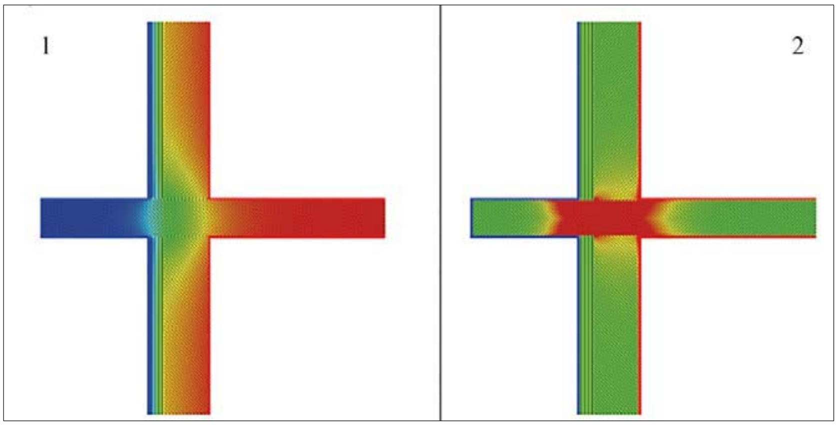

Figure 2. Presentation of temperature (1) and heat flux distribution (2) within the detail B1

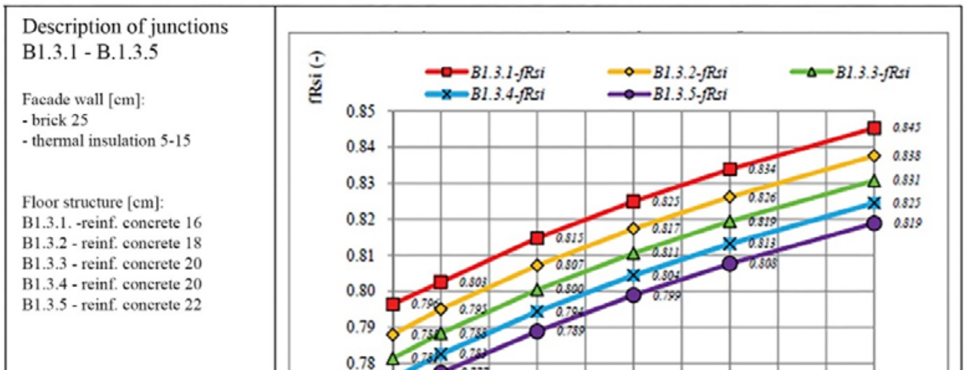

Figure 3. Comparative values of temperature factor f_{Rsi} for variations of a junction B.1.3 (25cm brick façade wall)

On the basis of the input parameters, numerical models of analyzed details were formed, with the aim of calculating the internal and external linear thermal transmission ψ_i and ψ_e, which are compared with the tabular values. For each combination of parameters, values of the temperature factor f_{Rsi}, internal and external linear thermal transmission coefficients were calculated, compared and presented in a relevant graph, here presented for the case of variations of the type of junction B1.3 (figure 3 and figure 4).

The values of the temperature factor f_{Rsi} are inversely proportional to the values of the coefficients of the linear heat transfer ψ. The temperature factor is inversely proportional to the thickness of the floor structure, and is directly proportional to the thickness of the wall thermal insulation, with almost linear growth trend. For analyzed junctions, in almost all of the analyzed cases, the range of f_{Rsi} represent boundary values in terms of the risk of condensation.

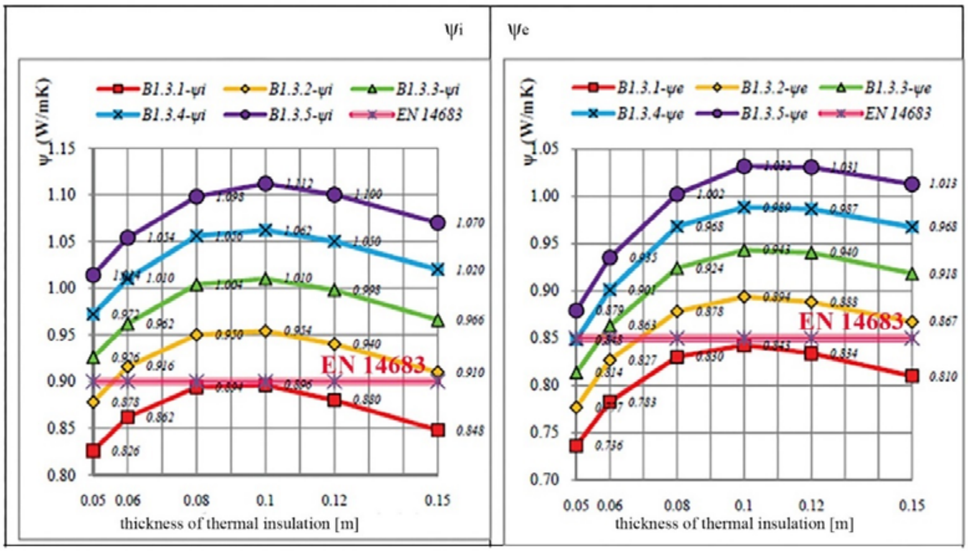

Figure 4. Comparative values of internal ψ_i and external ψ_e linear thermal transmission for variations of a junction B.1.3 (25cm brick façade wall)

The general conclusions for the analyzed junctions (subtypes) in detail B1 are:

- Tabular values can be accepted only in cases where the brick facade is 25cm thick or larger, regardless of the thickness of the thermal insulation.
- In the case when the facade is made of reinforced concrete, the table values cannot be accepted, due to a large miscalculation in relation to the calculated values.
- With the increase in the thickness of the balcony slab, the value of coefficients increases.
- The thickness of the massive layer of the wall and the thickness of the external thermal insulation of the wall are in a complex dependence.
- With the increase in the thickness of the base layer of the wall, the lower values of the coefficients are obtained.

It is characteristic that, regardless of the greater or lesser coherence between tabulated and calculated values of linear thermal transmission, in the case of this type of junction, thermal bridge effect is always significant and hence requires a thorough treatment. This implies the need for correction of such a detail which could be performed in two ways: through the creation of a thermal insulating envelope all around the balcony slab, or by breaking the thermal bridge using special types of connectors.

The first type of improvement refers to the intervention in a form of thermal insulation of the balcony slab from its upper and lower side, with additional thermal insulation of thickness 5, 4, 3 and 2cm. The problem has been analyzed in the least convinenient case of the B1 type of junction, i.e in the case of the reinforced concrete concrete wall. In all of the analyzed case, floor structure has been assumed as a 16cm thick reinforced concrete slab. Improved subtypes of the junction have additional mark „+" in their nomenclature.

In relation to the previous case, where the temperature drop was clearly reflected as a result of the uninsulated breakthrough of the panel through the facade wall, the intervention in this detail results in an evener temperature distribution, as well as in more adequate contact temperatures in the interior. The intensity of the heat flux in the penetration zone of the balcony panel through the facade wall significantly decreases compared to the previous, non-insulated detail.

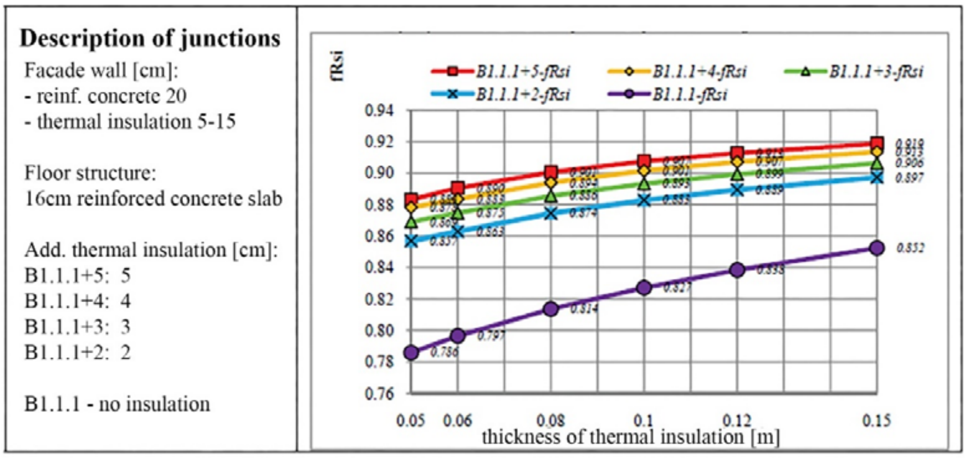

Figure 5. Comparative values of temperature factor f_{Rsi} for variations of an improved junction B.1.1 (20cm reinforced concrete façade wall)

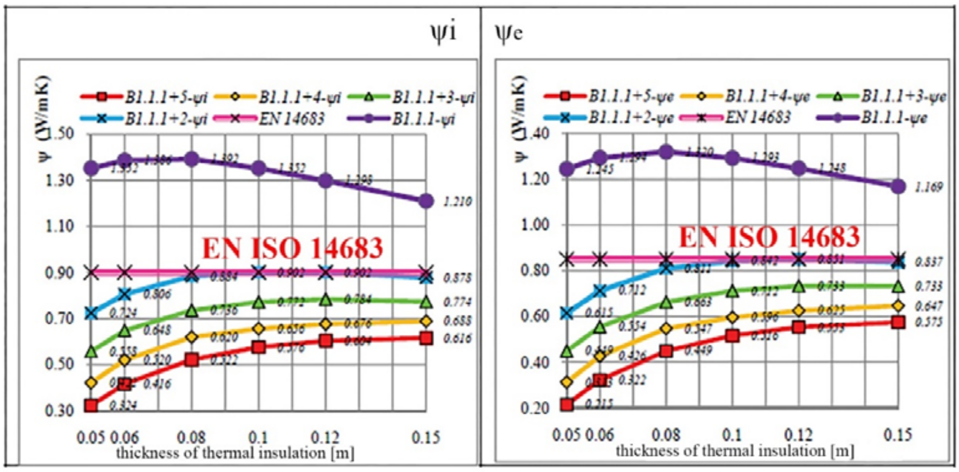

Figure 6. Comparative values of internal ψ_i and external ψ_e linear thermal transmission for variations of an improved junction B.1.1 (20cm reinforced concrete façade wall)

The temperature factor and the contact temperature are directly proportional to the thickness of the additional thermal insulation, as well as the thickness of the facade thermal insulation and the temperature factor values are above the level that indicates the risk of condensation. The effect of the "dressing" of the balcony plate is best seen by the fact that the temperature factor for the junction of the thickest, 15cm insulated facade wall with a non-insulated balcony slab is lower than in the case of details with the lowest facade thermal insulation of 5 cm, but with additional thermal insulation of the balcony slab of only 2 cm.

The conducted analysis showed that:

- Additional thermal insulation of the balcony panel significantly influences the reduction of the values of ψi and ψe, i.e reduction of linear heat losses.

- Only with the additional thermal insulation of the balcony panel, the ψi and ψe values for the reinforced concrete facade wall coincide or are lower in relation to the tabulated data in EN ISO 14683.
- The values of the coefficients ψi and ψe are inversely proportional to the thickness of the additional thermal insulation.

Therefore, it could be conluded that the additional insulation of the balcony slab is a design procedure that is recommended in cases where this can be done consistently and without negative design and functional consequences.

The second way of improvement of the critical junction refers to the use of the special type of connectors that enable the breaking of the thermal bridge. From the point of view of building physics and energy use, this solution could be considered as the most appropriate, since a very high linear thermal bridge that is present in such detail is reduced with a series of point thermal bridges. Depending on the manufacturer, concrete type of connection, dimensions and quantity of reinforcement, manufacturers declare the values of the coefficient ψ in the range from 0.2 $[\frac{W}{mK}]$ to 0.41 $[\frac{W}{mK}]$, which is significantly lower compared to the values of EN ISO 14683 for detail B, and which refers to a continuous thermal bridge and has values ranging from 0.85 $[\frac{W}{mK}]$ to 0.90 $[\frac{W}{mK}]$. In relation to the temperature factor fRsi, manufacturers declare values from 0.85 to 0.90, which means that no surface condensation will occur. However, this solution is less profitable in economic terms, and there are potential problems related to seismic effects.

Having in mind new regulations regarding the problem of energy efficiency of buildings, it turned out that, in practice, designers and builders became aware that the most critical details, such as the penetration of slabs through the facade wall, although not adequately treated in the calculation procedure, nevertheless still produce harmful effects during the use phase of a building. Due to the low contact temperatures, the damage is manifested in the form of creation of a mould. Therefore, it is required to use different technical solutions that will correct the situation within the limits of the minimum burden on the budget. In this sense, the solution to the problem with the use of "combs" is not profitable, and there is also seismic confusion, so they are not used in Serbia. However, the "dressing" of the balcony slab with thermal insulation is applied to a large extent. This is the solution that could be practised in the case of energy renovation of existing buildings as well. The dilemma that exists, in this case, concerns the necessary minimum thickness of the thermal insulation. Also, due to fire safety, the choice of particular insulation material should be taken into account, especially from the bottom side of the floor structure.

3.2. The problems regarding point thermal bridges

As in the case of liner thermal bridges, the impact of point thermal bridges on the increase in thermal losses is not precisely defined by the current thermal regulations in Serbia. In today's design and construction, it is often envisaged to use ventilated facades where the use of facade claddings is solved by the punctate carrying systems, while at the contact points occur thermal bridges of the same name. Although their impact, based on the thermal and geometric characteristics of the connectors themselves, may be approximately calculated with the appropriate standard in the form of correction to the thermal transmittance [12], this approach is not obligatory in the national regulation of Serbia. However, the need for additional verification of the impact of thermal bridges is increasingly occurring in practice, given that a number of investors are foreign companies that often set additional requirements in relation to the required energy efficiency of buildings that are in accordance with the regulations of the countries from which they come.

A recently conducted analysis, stimulated by this need, was carried out in order to reconsider the possibility and justification of the replacement of the originally planned system of individual fasteners for carrying the facade cladding, with the system of punctate fixed linear carriers (figure 7). It has been shown that the choice of the façade fixing system can contribute to a varying extent in the increase in thermal losses, which was confirmed by some other similar research [13]. Verification was performed by calculating and comparing the correction value of the basic thermal transmission, due to the application of the particular hanging system, based on the presence of point thermal bridges originating from mechanical fasteners.

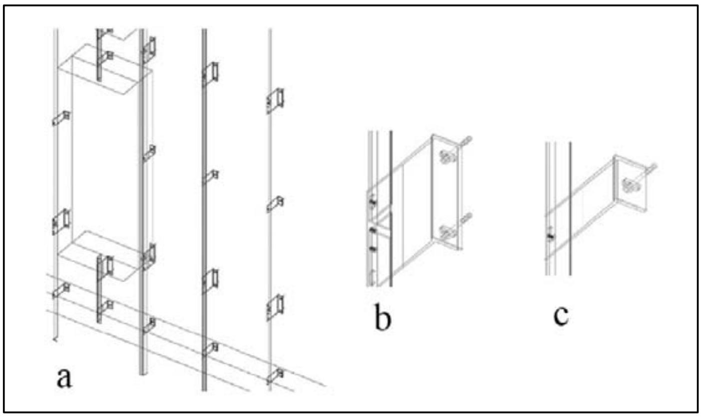

Figure 7. Distribution of elements of the façade fixing system (a) and detail of large (b) and small (b) brackets

An originally planned system of individual fasteners resulted with the additional heat loss of $0.077[\frac{W}{m^2 \cdot K}]$ that represented the target value in relation to which the other results were compared. Alternative façade fixing system consists of two types of metal brackets, in a form of a L profile, primary - larger and secondary – smaller which is half the size. They are fixed to the reinforced concrete wall structure with anchors and that carry vertical metal profiles of the system (horizontal elements are not presented and analyzed). In an effort to determine thermal characteristics of the system, it was analyzed in several possible versions. The brackets were assumed as an aluminium profile, 5 or 7 mm thick, or as a stainless steel profile, 5 or 4 mm thick. It was assumed that a contact of a metal bracket with the concrete wall was interrupted with an adequate thermal bridge reduction pad, which could be 3,4,5,6,10 or 20mm thick. Three types of such separation materials were investigated. Depending on the thickness of the separation material and their own thickness, it was assumed that brackets were fixed to the wall by inox anchors of different diameters - 12mm for 3 or 4mm thick pads, 16mm for 5, 6, or 10mm thick pads, and 20mm for 20mm thick pad. A smaller bracket was always possible to fix with an anchor diameter of 10mm. Elements of the system that cause additional thermal bridges are metal brackets and anchors, and their effects, individual and combined, were analyzed. As an example, results of the combined impact of brackets and anchors with respect to different types of separation materials for two types of brackets (5mm thick aluminium and inox profiles) are presented in figure 8.

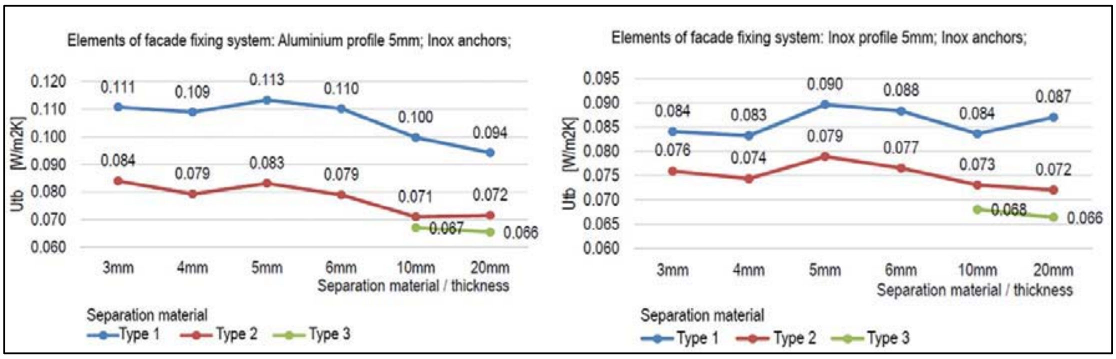

Figure 8. Graphs of total thermal bridges of the façade fixing system: with 5mm Aluminium profiles (left) and with 5mm inox profiles (right)

The limit values of the estimated influence of thermal bridges with respect to the selected mounting system, and the thickness of the bracket (aluminium or stainless steel), and regardless of the specific type of material of the separation are shown in Table 1. Minimum and maximum values for each type of the analyzed bracket is compared with the target value, that is, with a value defined by Serbian regulations.

Table 1. Limit values of the estimated thermal values of different type of analyzed brackets

	Target value	Type of the bracket								Serbian regulations
		7mm Al profile		5mm Al profile		5mm inox profile		4mm inox profile		
		min	max	min	max	min	max	min	max	
ΔU_{TB} $[\frac{W}{m^2 \cdot K}]$	0.077	0.069	0.116	0.066	0.113	0.066	0.090	0.067	0.086	0.10

The obtained results show a wide range of results, as those that are in accordance with the set limits of the originally foreseen system of carrying facade linings, as well as those that are better or worse. Although the differences with respect to the target value are not too great, the analysis shows that there is justification for carefully considering and selecting a concrete system for carrying facade linings. Since the Serbian regulations in the field of thermal protection of the overall impact of thermal bridges (both linear and dotted) are approximated by a value of $0.1[\frac{W}{m^2 \cdot K}]$, it becomes apparent that when applying ventilated facades or hanging facade linings this value can only be stimulated by the influence of point thermal bridges of such systems.

4. Concluding remarks

The conducted analysis have confirmed that thermal bridges, either linear or point, can not be neglected, nor uniformly simplified. Awareness of their real impact on overall heat losses could help and direct decision-making of architects and constructors in terms of designing a volumetry of the building, and structural and architectural details towards the solutions that would result with more efficient buildings regarding their energy performance.

Based on this, it can be concluded that the approximation of thermal bridge influences applied in the current thermal regulations in Serbia in a number of situations gives inaccurate results that can be significantly less than the actual thermal losses of a building. Therefore, the issue of a more adequate calculation of thermal bridge impacts is one of the items that inevitably requires correction in future revisions of regulations.

References

[1] 2003 Directive 2002/91/ec of the European parliament and of the council of 16 December 2002 on the energy performance of buildings *Offic. J. Europ. Comm.* **L1** 65-71
[2] 2011 Rulebook on energy efficiency of buildings *Službeni glasnik RS* **61**
[3] 2012 Rulebook on the conditions, contents and manner of issuing certificates of energy performance of buildings *Službeni glasnik RS* **69**
[4] Rajčić A 2011-2017 *Software T-Studio*
[5] Capozzoli A, Gorrino Aand Corrado V 2013 A building thermal bridges sensitivity analysis *Appl. Energ.* **107** 229-243
[6] EN ISO 14683:2007 Thermal bridges in building construction – linear thermal transmittance – simplified methods and default values
[7] EN ISO 10211:2007 Thermal bridges in building construction – heat flows and surface temperatures – detailed calculations
[8] Kuusk K, Kurnitski J and Kalamees T 2017 Calculation and compliance procedures of thermal

bridges in energy calculations in various European countries *Energ. Proced.* **132** 27-32
[9] Rajčić A 2011 *Methods for Design and Simulation of Thermal Bridges in Architectural Buildings* (unpublished PhD Th.) (Belgrade: Faculty of Architecture University of Belgrade)
[10] Wouters P, Schietecat J and Standaert P 2003 Practical guide for the hygrothermal evaluation of thermal bridges *Project document Eurokobra*
[11] EN ISO 13790: 2008 Energy Performance of Buildings – Calculation of Energy use for Space Heating and Cooling
[12] EN ISO 6946:2007 Building components and building elements – Thermal resistance and thermal transmittance - Calculation method
[13] Theodosiou T, Tsikaloudaki K and Bikas D 2017 Analysis of the Thermal Bridging Effect on Ventilated Facades *Proc. Envir. Sci.* **38** 397-404