SER4SC

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES
CONFERENCE PROCEEDINGS

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Contents

Introduction

1st Session

2nd Session

3rd Session

4th Session

5th Session

6th Session

Partial interventions on the facades in the process of energy renovation of residential buildings - examples from the Serbian construction practice

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Abstract

Energy rehabilitation of facades of residential buildings is a process aiming to improve housing comfort and save operational energy. In the case of multi-family housing in Serbia, this procedure often involves partial interventions on the facade, which are mainly due to limited investments and lack of consensus at the building level to implement a comprehensive rehabilitation process.

There are currently several approaches, such as: 1) replacement of facade joinery as a measure taken by tenants most often individually, without synchronization at the building level; 2) thermal insulation of the facade as a technologically more complex measure in which, in certain cases, due to the lack of agreement between all users of the building, certain façade zones remain uninsulated; 3) in rare cases, repair of leaking of flat roofs, with integrated complete or partial thermal insulation.

The paper analyses several situations arising as a result of partial interventions for which, in accordance with EN 10211, a numerical simulation was performed using the T-Studio software. It has been found that the problems caused by a partial insulation of the facade or a partial replacement of facade joinery lead to the occurrence of thermal bridges and increase of the heat flow in certain areas of structures with a reduction in internal contact temperature, which increases the risk of condensation, with consequences in the form of development of mould and of microorganisms, which leads to reduction of life comfort and possible specific diseases of the user. Such negative phenomena occur both, in the apartments whose owners did not participate in the process of energy rehabilitation of facades, and in the contact zones of energy rehabilitated apartments, which, in this way, lose their invested assets and the expected effects of energy savings.

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Keywords: energy renovation; partial interventions; façade envelope; thermal bridges;

1.Introduction

One of the major concerns of the today's society refers to the reduction of energy consumption that can be seen as a vital component of a holistic understanding of sustainability. In such efforts, buildings are recognized as the largest consumers of energy of a society. Hence, increasing their energy efficiency as a way to reduce the need for energy has become an imperative. Following the concept of energy

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performances of buildings which is the basis of modern regulations in the field of thermal protection of buildings [1], Serbia has taken the first steps towards improving energy efficiency of buildings by the adoption of the new energy efficiency regulations, enacted in 2011 [2, 3]. With the new set of regulations, for the first time in Serbia, the issue of energy savings is equally set in front of the newly designed buildings, as well as the existing ones.

Typical structures of the thermal envelope of existing residential buildings in Serbia have thermal properties that are far below those required by modern legislation [4,5]. At the same time, the share of the windows and façade walls in the energy balance is dominant in such buildings. Having this in mind, in the process of energy rehabilitation of multifamily, i.e. collective housing in Serbia, there are several approaches that are present in the practice:

- replacement of facade joinery as a measure taken by the tenants most often individually, i.e. without synchronization at the building level;
- thermal insulation of the façade, which is a technologically more complex measure; consequently, in certain cases, due to the lack of agreement between all users of the building, certain façade zones remain uninsulated;
- in some specific cases that include a problem of leaking of a flat roof - repair of the leaking roofs is integrated with complete or partial thermal insulation.

Such interventions are a result of mainly restrictive and limited investments, combined with a lack of consensus at the building level to implement a comprehensive rehabilitation process. Although, in general, consciousness of tenants regarding the energy efficiency leads towards the success in energy savings [6], since, in the present case, the efforts are usually made by individual tenants, they result with partial interventions on a building envelope. Therefore, the positive effects of the improvement measures might be questioned.

With respect to the mentioned aspects, the paper analyses some cases arising as a result of partial interventions, in the first place those that refer to window replacement and thermal improvement of façade walls as the elements of thermal envelope that most often undergo the energy improvement measures. Selected situations were the subject of a numerical simulation that was performed using the original T-Studio software [7], conducted in accordance with EN 10211 [8]. This software package is designed for two-dimensional calculation of heat balance, using calculation procedure which is based on the finite difference method (FDM).

Nomenclature

Symbols

f_{Rsi}	temperature factor
T	temperature [ºC]

Greek symbols

λ	thermal conductivity [W/mK]
φ	relative humidity [%]

Subscripts

i	internal
e	external
si	surface internal
se	surface external

2.Description and potential side-effects of partial energy improvement measures

2.1. *Window replacement*

Replacement of facade joinery is a measure that is most cost-effective in terms of saving energy and increasing the comfort in the interior (thermal, acoustic, visual) [5, 9]. This measure is mainly the result of an individual approach and the willingness and financial ability of each of the tenants. Consequently, we are facing a diversity regarding the colour, material, window geometry (division, dimensions) of the facade joinery on existing buildings that shows deviation from the original look. This is especially noticeable and emphasized at the building level in the process of self-initiative, unplanned and unsynchronized glazing process of the loggias and terraces.

It can be said that this phenomenon is that much present that the attention is no longer focused on the consequences (primarily visual), i.e. on the resulting changes of the character of the architectural object and the character of such changes that are permanent or long-lasting. Besides, such changes follow the pattern of the chaotic installation of air-conditioners on the facades. On the other hand, it is often that such interventions are not followed by the simultaneous thermal insulation of the façade walls. Therefore, such contact between the improved, well insulated window and the uninsulated or poorly insulated façade wall represents a thermal bridge that brings a high risk potential for appearance of condensation [10].

2.2. Thermal insulation of façade walls

Thermal insulation of the facade is another frequent measure of energy renovation of the building, but which is technologically more demanding than the replacement of joinery because it requires work from the outside, i.e. the use of the scaffolding.

In addition, the facade wall is in visual sense and by its shape, a more expressive component, and in most cases, its surface area is larger or significantly larger than that of the windows. Therefore, it is logical that in the process of energy rehabilitation the façade is viewed integrally, both from the design and from the energy aspect. However, in a situation when tenants are those who finance the energy renovation of a multifamily building, deviation from a comprehensive facade treatment can be caused by various reasons such as:

- some tenants have no financial opportunity to participate in renovating the facade, and other tenants do not want to compensate this cost, or
- in some cases, certain tenants are *a priori* against any intervention and do not allow any work on the respective facade parts.

Consequently, there are situations with unexpected "architectural results", as shown on the Figure 1.

Fig. 1. Effects of partial thermal insulation of façade walls – example of a multifamily building from Belgrade

From the technological point of view, partially processed facades bring new, unexpected problems, the solution of which is borne by the extra costs that are most often manifested through sheet metal work to cover the horizontal outflows of thermal insulation, in order to protect them against penetration of atmospheric water and the potential peel off of thermal insulation.

From the energy point of view, there are various new problems, and some of them will be indicated in this paper. The described absence of comprehensive intervention causes the occurrence of thermal bridges and the increase of the heat flow in certain areas of structures, resulting with a reduction in internal contact temperature and the increment of the risk of condensation. Consequently, development of mould and microorganisms might be expected, which leads to the reduction of a living comfort and possible specific diseases of the user. These negative phenomena are certainly expected in those flats whose occupants (owners) did not allow or did not participate in the process of energy rehabilitation of facades, but can be also manifested in neighbouring flats, particularly those above or below the respective.

3.Definition of model and research methodology

3.1. Geometric and material properties of the analysed wall-floor construction connection

As a model which was investigated in this paper, the connection between a 25cm thick solid brick wall and a 20cm reinforced concrete slab was chosen. The wall has 2cm thick mortar render on both sides. The floor construction of the analysed model is a 20cm reinforced concrete slab, plastered on the bottom side with 2cm thick mortar render, and with a 2cm thick parquet floor, placed over the 5cm thick reinforced cement screed. The assumed measure of energy improvement of the facade wall was carried out by adding the layer of thermal insulation and a thin façade rendering as a finishing layer. Thermal properties of assumed structures and elements are given in the Table 1.

Effects of the partial thermal improvement of the façade wall were analysed on two typical models:

- Model 1- simple junction of the façade wall and the floor construction, and
- Model 2 - junction of the façade wall and the floor construction in the contact zone with a facade opening (window) (Figure 2).

Research of the character of the contact at the junction of the wall and the floor structure was analysed through several different scenarios regarding the manner and extent of energy optimization of the wall.

Table 1. Thermal conductivity of the assumed layers of the modelled wall - floor connection

type of structure		layer	λ [W/mK]	thickness [cm]
Façade wall	existing/original layers	internal plaster	0.85	2
		solid brick	0.63	25
		external rendering	0.85	2
	additional layers (optional)	*thermal insulation*	*0.04*	*10*
		facade rendering	*0.85*	*1*
Floor construction		plaster	0.85	2
		reinforced concrete slab	2.5	20
		reinforced cement screed	2.33	4
		parquet	0.20	2

3.2. Climate data relevant for the calculation

Presence of thermal bridges could be manifested by the formation of condensation on the analysed contact between the insulated and uninsulated parts of the building fabric. Since this manifestation is potentially possible in the winter period, for the purpose of this study the appropriate climatic data which are in accordance with applicable regulations were set [2]. The external design temperature is defined as -12°C (corresponding to climatic characteristics of Belgrade) with simultaneous relative humidity of 90%. For interior design conditions it is assumed that the temperature of the indoor air was + 20°C, while the humidity varied.

Although the regulation stipulates that relative humidity of the interior space is 50%, the paper analyzed the cases in which internal relative humidity is higher (55, 60, 65, or 70%). Such situation is realistic and often happens in the winter due to the inappropriate use of the space. Excess moisture in the living space which is confirmed by the recent study of thermal comfort during the winter in Belgrade residential buildings is, in the first place, a result of a habit of drying laundry on heating devices, higher cooking frequency or higher occupant density, but without the proper ventilation of the space [11]. Thus, for some time relative humidity could rise to 80% and more.

3.3. The method of calculating the impact of the thermal bridge

The impact of the thermal bridge is calculated on the basis of the risk of surface condensation .The potential risk is traced on 4 characteristic points of the wall-floor connection, marked on the Figure 2. The interior surface temperatures for these points were calculated and compared with the dew point temperature for the given project conditions (temperature and relative humidity in the room):

- T1 - on the wall, 5cm before the connection to the ceiling;
- T2 - on the ceiling, 5cm before the connection to the wall;
- T3 - on the wall, 5cm before the connection to the floor; and
- T4 - on the floor, 5cm before the connection to the wall;

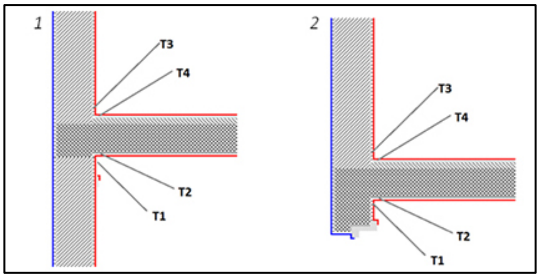


Fig. 2. Characteristic points on the wall-floor connection – Model 1 (left) and Model 2 (right)

On the basis of the calculated temperatures, the temperature factor f_{Rsi} is calculated, through which the risk of condensation is assessed. Temperature factor at the steady state condition can be expressed by the formula as:

$$f_{Rsi} = \frac{T_{si} - T_{se}}{T_i - T_e} \tag{1}$$

where :

- T_{si} is surface internal temperature,
- T_{se} is surface external temperature,
- T_i is the temperature of the internal environment, and
- T_e is the temperature of the external environment

Temperature factor f_{Rsi} depends only on the structure itself. Once calculated for certain values of T_i and T_e, it can be used to calculate the surface temperature under different conditions, using the formula:

$$T_{si} = T_e + f_{Rsi} \cdot (T_i - T_e) \tag{2}$$

In order to prevent the formation of mould, it is necessary to fulfil the condition that every point on the inner surface has a temperature or temperature factor greater than or equal to the critical. [12] This condition therefore depends on the external temperature, the internal air temperature, and the relative humidity of the indoor air.

Correlation of these parameters can be expressed as:

$$f_{Rsi} \geq \frac{\left((0.0125 \cdot \varphi)^{0.1247} \cdot (109.8 - T_i) - 109.8 - T_e\right)}{T_i - T_e} \tag{3}$$

where

- φ is relative humidity of indoor air [%],
- T_i is internal air temperature [°C], and
- T_e is external air temperature [°C].

In order to prevent the condensation risk and the growth of the mould, it is necessary to fulfill the condition that each point on the inner surface of the wall has a temperature or the temperature factor that is greater than or equal to the critical - under the explained climatic conditions (T_i=+20°C and T_e= -12°C) [12]. The temperature factor f_{Rsi} is determined for different combinations of the internal design temperature and different values of the relative humidity. (Table 2).

Table 2. Boundary values of the temperature factor for different values of relative humidity

φ [%]	50	55	60	65	70	75	80
$f_{Rsi, min}$	0.77	0.81	0.86	0.89	0.93	0.97	1

Therefore, the calculated values of f_{Rsi} obtained for the characteristic points of the analysed models should be higher than the boundary values, in which case there is no risk of condensation on the critical places of the connected structures. All calculations of relevant thermal characteristics of the analyzed cases of energy optimization were carried out using the original software package T-Studio [7].

4.Results and discussion

As already explained, two typical models were created (simple junction of the façade wall and the floor construction, and junction of the façade wall and the floor construction in the contact zone with a facade opening) and for each of them, different cases of partial interventions on the façade wall are investigated. Analyzed cases correspond to actual situations in which energy improvement was partially realized, and was not applied either in the upper apartment, or in an apartment below the observed one.

In the case of the Model 1, the following situations were analysed:

- Case 1 (original state – no intervention): a connection between the uninsulated facade wall and the floor construction;
- Case 2 (upper flat without intervention): the wall is uninsulated above and isolated below the floor construction;
- Case 3 (lower flat without intervention): the wall is insulated above and uninsulated below the floor construction; thermal insulation overlays the floor construction;
- Case 4 (lower flat without intervention): the wall is insulated above and uninsulated below the floor construction; thermal insulation does not overlay the floor construction;

For all of the analysed cases, internal surface temperatures T1-T4 were calculated with corresponding temperature factors f_{Rsi} for different values of internal relative humidity. These values are presented in the Table 3. Condensation risk is estimated in the table by comparison of the calculated values with the boundary ones for each value of relative humidity and commented as no (does not satisfy the boundary conditions) or yes (satisfies the boundary conditions).

A similar analysis was carried out in the contact zone with a facade opening (window). The following cases were analysed:

- Case 1w (original state – no intervention): a connection of uninsulated façade parapet on the upper floor, uninsulated lintel over the window on the lower floor, with a floor construction
- Case 2w (upper flat without intervention): a connection of uninsulated façade parapet on the upper floor, insulated lintel on the lower floor, with a floor construction
- Case 3w (lower flat without intervention): a connection of insulated façade parapet on the upper floor, uninsulated lintel on the lower floor, with a floor construction; thermal insulation overlays the floor construction;
- Case 4w (lower flat without intervention): a connection of insulated façade parapet on the upper floor, uninsulated lintel on the lower floor, with a floor construction; thermal insulation does not overlay the floor construction;

Condensation risk for the Model 2 is presented in the Table 4, in the same manner as in the case of the previous model.

Table 3. Review of the condensation risk potentials of the Model 1

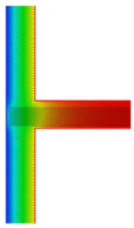
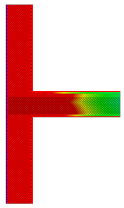
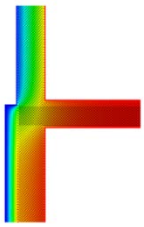
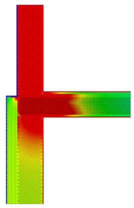
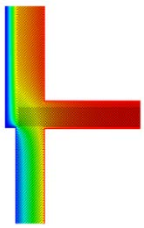
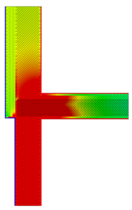
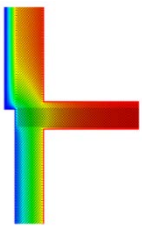
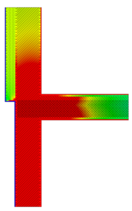
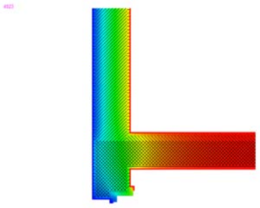
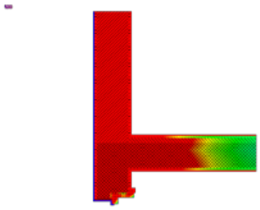
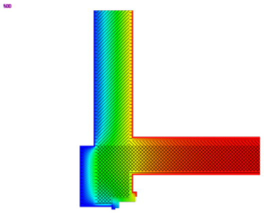
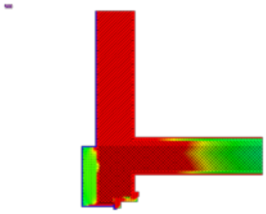
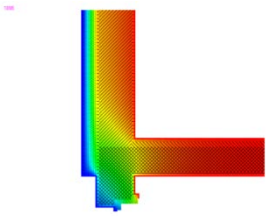
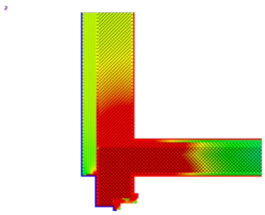
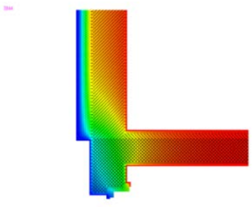
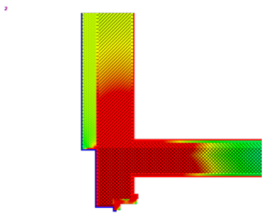
Temperature field	Temperature flux		T_1[°C] f_{Rsi}	T_2[°C] f_{Rsi}	T_3[°C] f_{Rsi}	T_4[°C] f_{Rsi}	φ [%]
Case 1							
			11.08 0.72	11.40 0.73	11.44 0.73	13.30 0.79	
		satisfaction of the boundary conditions	no	no	no	yes	50
			no	no	no	no	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70
Case 2							
			15.80 0.87	15.59 0.86	14.22 0.82	15.93 0.87	
		satisfaction of the boundary conditions	yes	yes	yes	yes	50
			yes	yes	yes	yes	55
			no	no	no	yes	60
			no	no	no	no	65
			no	no	no	no	70
Case 3							
			14.44 0.83	15.16 0.85	16.20 0.88	16.60 0.89	
		satisfaction of the boundary conditions	yes	yes	yes	yes	50
			yes	yes	yes	yes	55
			no	no	yes	yes	60
			no	no	no	yes	65
			no	no	no	no	70
Case 4							
			11.87 0.75	12.35 0.76	13.21 0.79	14.33 0.82	
		satisfaction of the boundary conditions	no	no	yes	yes	50
			no	no	no	yes	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70

Table 4. Review of the condensation risk potentials of the Model 2

Temperature field	Temperature flux		T_1[°C] f_{Rsi}	T_2[°C] f_{Rsi}	T_3[°C] f_{Rsi}	T_4[°C] f_{Rsi}	φ [%]
Case 1w							
			6.38 0.57	9.26 0.66	10.86 0.71	12.44 0.76	
		satisfaction of the boundary conditions	no	no	no	no	50
			no	no	no	no	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70
Case 2w							
			10.29 0.69	12.34 0.76	12.58 0.77	12.98 0.77	
		satisfaction of the boundary conditions	no	no	yes	yes	50
			no	no	no	no	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70
Case 3w							
			9.38 0.67	12.11 0.75	14.81 0.84	15.18 0.85	
		satisfaction of the boundary conditions	no	no	yes	yes	50
			no	no	yes	yes	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70
Caase 4w							
			7.07 0.60	9.99 0.69	12.89 0.78	13.89 0.81	
		satisfaction of the boundary conditions	no	no	yes	yes	50
			no	no	no	yes	55
			no	no	no	no	60
			no	no	no	no	65
			no	no	no	no	70

The conducted analysis shows the following:

- Satisfactory results are obtained for relative air humidity in the interior up to 55%, but in those cases when it has a higher value (60% or more), the risk of condensation exists.
- Proximity to the window, that is, the small length of the wall beneath the floor construction contributes that satisfaction of the boundary conditions is less likely to be achieved in the case of the Model 2.
- In the case of both models, boundary conditions are most frequently satisfied on the position of the point 4, i.e. on the upper side of the floor construction.

5.Conclusion

At the end of the conducted research, in brief, it could be concluded, that in the case of incomplete thermo-insulated facades, owners/tenants who have individually isolated corresponding part of the façade, do not necessarily receive all the expected thermal comfort, largely due to the negative impact of thermal bridges, resulting from the close contact of the uninsulated border positions of the adjacent apartment below or above.

For the complete success and the achievement of the full effects of the undertaken measures of energy improvement in multi - storey buildings, it is necessary to have the synchronous operation of all the tenants, i.e. on all the apartments in the building. Otherwise, there is a real possibility of occurrence of negative effects and construction damages.

This would also mean that, in addition to the expressed need for energy improvement of existing buildings defined through appropriate legislation, the state should support and assist such intentions of the owners and users by measures of financial incentive, but also by adopting appropriate standards and recommendations that would direct them towards the joint action.

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