Hidden Flaws of Energy Efficient Refurbishment of Buildings in Brutalist Architectural Style

Tijana Zisic*, Aleksandar Rajcic and Dejan Vasovic

Department of Architectural Technologies, Faculty of Architecture, University of Belgrade
Bulevar kralja Aleksandra 73/II, Belgrade 11000, Serbia

* Correspondence: tijana.zisic@arh.bg.ac.rs
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Abstract: The paper presents energy efficient refurbishment practices in Serbia, highlighting the problems of applying the standard improvement measures for energy saving on buildings of a specific era and style. The focus is on the brutalist buildings in Belgrade that are not protected as such, nor is their façade or project in general — even though they are considered to be examples of good practice by architects today. Form and geometry of these objects themselves arise many challenges in terms of thermal insulation of facade walls. The most problematic are cold bridges (parts of the primary concrete construction that are also seen on the exterior), which will bring the issue into the interior — by accelerating the phenomenon of condensation and dew points along the line of connection of two planes with different temperatures. The chosen subject of research is the object of Elementary school Ratko Mitrovic, New Belgrade (block 38), which is a brutalist building from the 1970s, designed by architect Petar Petrovic — that has not undergone any changes since its first day (can still be seen in its original state today). The specific school was chosen because it is also a subject of an ongoing project of energy efficient refurbishments for schools in Serbia — where the hidden flaws of using the standard improvement measures for energy saving can be calculated and the weaknesses of the project can be targeted — questioning whether these proposals are to be considered improvements of the existing state.

Key words: brutalism, energy efficiency, architectural refurbishment, refurbishment challenges

1. Introduction

In order to achieve the expected results for environmental protection and energy efficiency in newly built facilities, as well as in projects of energy efficient refurbishments of existing buildings — the Serbian government adopted norms - which follow world agreements, strategies, and laws on energy saving and increasing measures for efficient systems and building in general.

By harmonizing the national with the EU legislation, the objectives of Directive 2012/27/EU [1] were adopted, which forced the national government to introduce favorable principles of energy efficiency, through the renovation of Serbian building fund [2]. The first step in adopting this type of measures, regulations, recommendations or laws - is the systematization of the existing built fund in Serbia — after which the categories of facilities are established by typology, age, style of construction and possible expected level of energy efficient refurbishment. The problem in Serbia is the lack of regulations for buildings that are not under protection but are recognized by architects as important points in the urban tissue. Such buildings are often inadequately rehabilitated and renovated, according to the principles that would be used in modern buildings.

The topic of this paper is the energy rehabilitation of public buildings designed in brutalist architectural style, which are not under protection but are considered to be witnesses of a certain period of time and the specific method of construction and design. In Belgrade, there are numerous samples of brutalism, especially public buildings that are waiting to be renovated/refurbished. Some examples are (see Fig. 1).

Cinema of Yugoslavia by Mihajlo Mitrovic, EP New Belgrade, New Belgrade Town hall designed by Stojan Maksimovic and Branislav Jovin, Belgrade Institute of Urban planning designed by Branislav Jovin.

The subject of this research paper is Elementary school Ratko Mitrovic in block 38, New Belgrade. A specific case, because unlike other examples of brutalism, there is an architectural project in the making for energy efficient refurbishment for this concrete building.

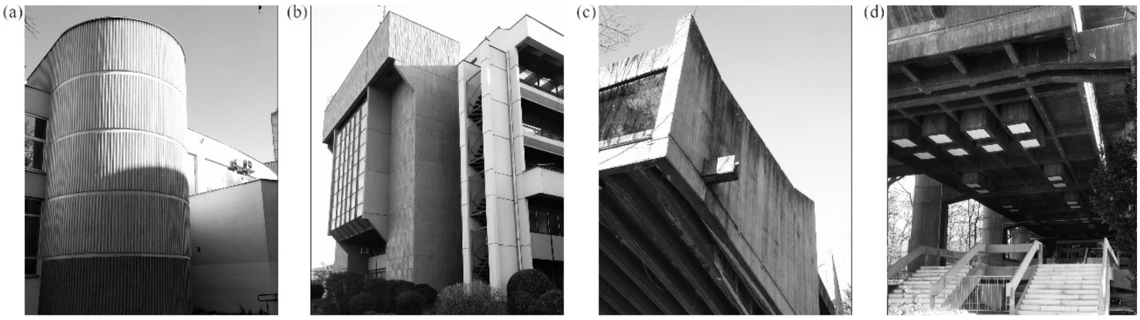


Fig. 1. (a) Cinema of Yugoslavia (source: Dejan Vasovic); (b) EP New Belgrade (source: Dejan Vasovic); (c) New Belgrade Town hall (source: Dejan Vasovic); (d) Institute of Urban planning (source: Dejan Vasovic).

2. Elementary School Ratko Mitrovic

Elementary school Ratko Mitrovic is a building in brutalist manner, designed by the recognized Serbian architect from the previous century — Petar Petrovic, who was awarded the October Award for this project in 1972. Although the school building is a unique representation of design, specific technology in architectural language and construction of the 1970s — it is not protected as such, nor does it fall under the protection of the wider context — the central zone of New Belgrade.

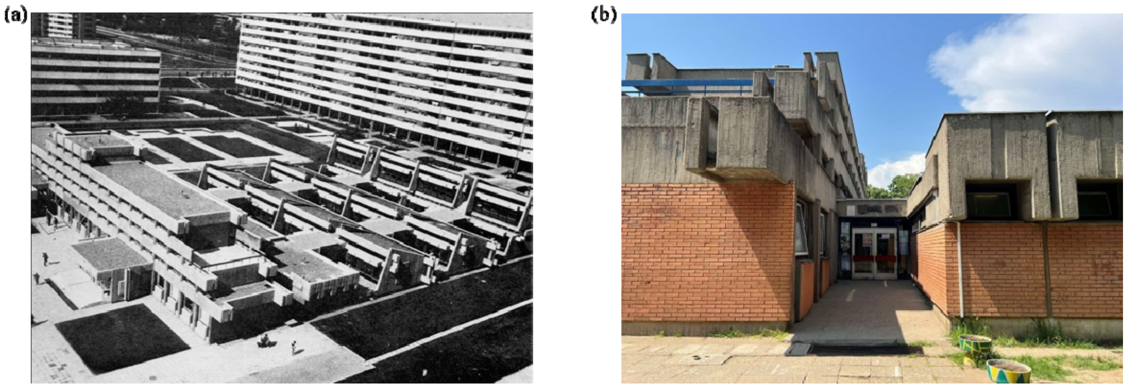


Fig. 2. (a) Archive photograph of the Ratko Mitrovic school in 1972. (source: Historical Archive of Belgrade); (b) Concrete details on the façade of the object today (source: Branislav Zisic).

2.1. Design and function

The functional programming of the school is based on the concept of communication strips from which students access the classrooms (left and right). All classroom spaces are oriented towards the atriums on the south side (each classroom has its own exit and its own enclosed open space). Additional windows have been designed on the opposite wall, just under the ceiling (higher than children's perspective) — which prevent visual communication with the adjacent atrium (in a row), however supply some more natural light to the students using the room. Atrium spaces, in addition to the function of lighting the classrooms, enable students to stay outdoors during the pauses between classes. Moreover, they improve the air quality in the classrooms and enable natural cross ventilation (with the windows on the opposite wall).

In the entrance hall, which unites all horizontal communications on the ground floor, there is also a vertical communication point that leads users to the first floor of the building, with cabinets designed by the same principles, only without open atrium spaces. One of the corridors that start from the hall also supplies the administrative premises on the ground floor, and leads to the gym with locker rooms and toilets.

The triple gauge of the building determines three independent structural units, which are mutually dilated.

2.2. Construction

The floors of the building are done on a reinforced concrete structure (slab), with a layer of 2cm thick mineral wool, protected with kraft paper, 3cm cement screed and cladding - which differs in relation to the purpose of the room: linoleum, natural stone, carpet, ceramic tiles or oak parquet. Two layers of bitumen have been included for hydro isolation.

Ceilings were finished by adding gypsum boards (in classrooms) and pine folded boards (in corridors). Façade walls, pillars and buildings, wreaths and parapets are in natural concrete, which was poured in planed carpentry formwork with accentuated joints. The architectural-urban concept of the building excludes any subsequent processing of concrete [3].

In order to achieve thermal protection of the building, all facade walls are designed on the principle of a sandwich with an insert of 3cm thick thermal insulation. In the project documentation, there is also a calculation of the achieved sound protection on the walls, which amounts to 52 DB and which is the result of the weight of the installed concrete and thermal insert. In this way, the thermal protection of the following coefficient was achieved:

$$U = 3 \times 0.285 = 0.858\ kcal/hm^2{}^\circ C = 0.99785\ W/m^2{\cdot}K\ [8]$$

The parapets of the classrooms, the front walls of the atrium, the accent walls of the hallways on the first floor, the front walls of the connecting tract — have a facade brick cladding with recessed joints in an ornamental style. Special plastic in these places prevented the standard installation of thermal insulation, therefore it was planned to be installed under the roof structure - at the height of the ceiling layers, with a steam dam under the insulation.

With the exception of the front door, all glass surfaces are double glazed — “thermopane” glass. The windows of the gym are glazed with plexiglass, which, in addition to obtaining a tonal effect, also solves the problem of breakage.

2.3. Condition of the building

The building of Elementary school Ratko Mitrovic has never undergone any changes in architecture, construction or interior throughout all the years it has been working. It is still in its original shape from the first day.

The school building, at the time it was built, met all the spatial criteria, as well as the norms concerning the comfort of students and employees. In relation to the laws that are in force today in the Republic of Serbia, the coefficients of thermal permeability are not satisfied at several points of penetration, and energy efficient refurbishment is proposed.

3. Proposed Improvement Measures

As the form of the building itself represents the biggest challenge in the renovation, we have divided the proposed energy efficient refurbishment measures and interventions (given by the local architectural office) into several categories in relation to the positions of the works on the building.

3.1. Doors and windows

Replacing all existing steel windows and doors on the building with aluminum ones that correspond in appearance to the previously found carpentry in appearance. Aluminum profiles, with triple glazing, achieve a coefficient of thermal transmittance of up to 1.1 W/m^2·K, which is in line with the Rulebook [4].

This phase is considered the most important — it brings the least problems and challenges in terms of disturbing the existing appearance of the building, although it has the biggest influence on the future energy class of the refurbished building.

3.2. Roof

It is possible to improve the original concrete roof structure by adding a vapour, ventilation layer, thermal insulation, waterproofing and a new tin roofing on the outside, which is treated with energy-saving paint, while the interior gets a suspended plasterboard ceiling. This increases the coefficient of thermal transmittance up to 0.184 W/m^2·K on the hip roofs of the building (above the classrooms).

The main arising problem is the phenomenon of condensation and dew points, especially around the specific concrete gutters, that limit us because of their geometry and position.

3.3. Floors

School floors can be improved by removing all existing layers down to a concrete structure - over which waterproofing, thermal insulation, PE foil, cement screed and cast polyurethane flooring (for classrooms) would then be laid. In this way, up to 0.327 W/m^2·K is obtained for the coefficient of thermal transmittance. However, the time needed to perform such works is questionable and is it realistic to predict this kind of activity on the school building - which is being renovated for the duration of summer holidays (two months).

3.4. Façade walls

Considering that this is a building where the preservation of the facade is an important task, the only possible way of improvement of the existing façade walls with adding thermal insulation is in the interior. The challenge is the fact that the users are children – all used materials must be strong and resistant to mechanical influences, and non-toxic. Also, the selected insulation material should not be too thick, so as not to take away too much cubic capacity of classroom air.

These requirements can be met by providing mineral thermal insulation boards - 8cm Multipor [5] on the inside of the facade walls. Now the conditions of thermal comfort are met, but there is an almost certain possibility of condensation on the thermal bridges, which is shown in the calculations in the next chapter. Another drawback of this option is the fact that electrical and heating installations ought to be translated (since they are placed on the interior side of façade walls), which requests moving 50 years old piping and cables, or designing completely new systems for the whole school.

3.5. Additional systems

Condensation problems could be remedied by installing ventilation systems, such as air recuperation elements [6], which have a CO_2 sensor - based on which signal they are activated. This would improve air quality in classrooms, allow artificial ventilation in months when it is not possible to rely on cross-ventilation (opening opposite windows in the classroom), and allow constant air circulation in problematic places of thermal bridges — to prevent condensation.

Additionally, photovoltaic cells can be provided on the roof of the classrooms, considering that the lowest part of the roof is oriented to the southwest. The collected energy would be used for the functioning of ventilation systems needed for the air to circulate inside the classrooms and cool/heat the thermal bridges from the inside.

3.6. Energy efficient refurbishment project conclusion

The biggest improvement in energy savings is brought by the first stage - replacement of windows and doors with systems with better characteristics in terms of thermal conductivity, due to the current situation - large losses in ventilation (leaks).

By applying all 5 proposed categories of improvement, the architectural office that created the project for energy efficient refurbishment of Ratko Mitrović Elementary School confirms the C energy class (Qh.an = 60.22 kWh/·m^2) for this building [7].

Although the requirements from the Rulebook are met, the comfort and health of the space users (children) is more important than the energy savings we managed to calculate. If there is a mistake in calculation or the proposed improvement measures, the results will only be visible after the reopening of the school, and while using the space.

4. Definition of Detail and Calculation Methodology

For this type of energy efficient refurbishment, and on objects of this era and architectural style — it is necessary to design detail-specific solutions. The greatest obstacles arise on the contact of two surfaces of different temperatures – which leads to condensation and dew points in the interior. These problems are to be calculated and solved in the building documentation.

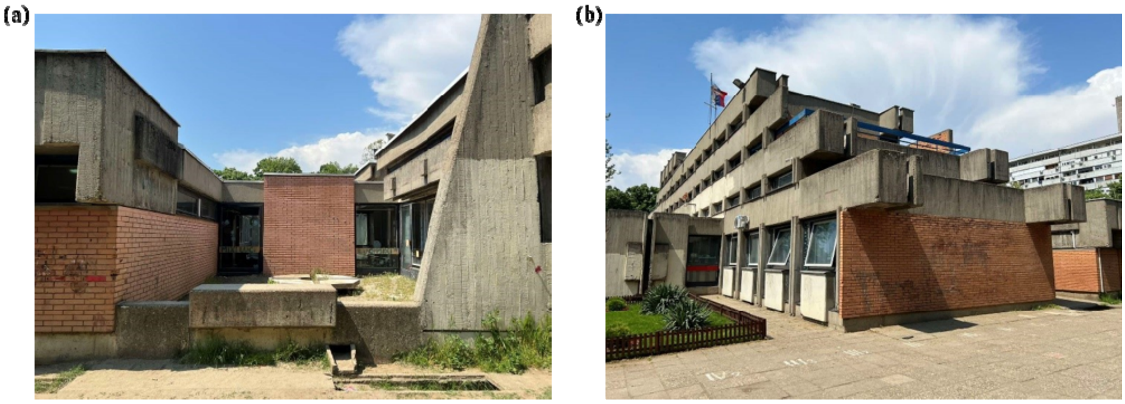


Fig. 3. (a) and (b) façade and atrium view of the Elementary school Ratko Mitrovic (source: Branislav Zisic).

The school building has many characteristic concrete details, as a result of the brutalist manner. These details include specific brickworks and untreated béton brut on the façade walls, which are to be protected and kept in their original state. This situation prevents us from insulating the whole areas of walls from the outside, and leaves us with the interior insulating option – which results in every meander of the structure forming a cold bridge.

On the illustrations below, see Fig. 4, there is an isometric view of a partition wall in the interior, between the two classrooms — that then continues to form the barrier between the two atriums in the exterior (forming a cold bridge). Also seen below — a concrete accent gutter is set to be improved by adding thermal insulation inside of it, and onto the existing concrete roof — which leads to jet another contact of problematic surfaces (in terms of temperature).

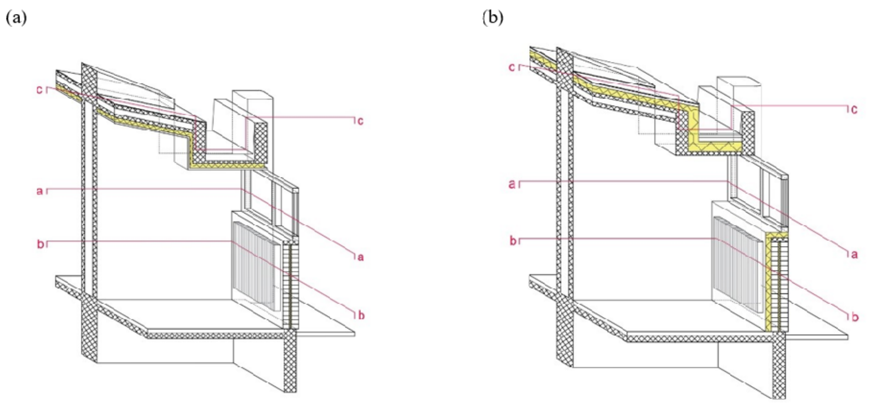


Fig. 4. (a) isometric view of the existing state of the object with marked sections specific for calculation; (b) isometric view of the isolated structure (after all of the listed improvements) with marked sections specific for calculation.

4.1. Calculation parameters

These are the parameters used in the calculation below, showing information for Belgrade:

- Outdoor design temperature in winter for Belgrade Te = –12 ° C
- Internal design temperature for schools in winter for Belgrade Ti = + 20 ° C
- Thermal conductivity of materials according to The Rulebook on the Energy Efficiency in Buildings [4]
- Used: TStudio software [8] (invoice according to Finity Difference Element method). Calculation in accordance with EN ISO 10211-1 and 2.
- Facade wall composition: inside, brick 12cm + thermal insulation 3cm + brick 12cm, outside
- Composition of walls between classrooms: brick 7.5cm + reinforced concrete wall structure 15cm + brick 7.5cm. The concrete part of the wall protrudes beyond the outer façade plane at least 50 cm
- Roof composition: inside, planking 3cm + insulation 3cm + reinforced concrete structure 6+10+6cm + sheet metal roofing, outside.

4.2. Calculation methodology

In relation to the geometric and material properties of architectural detail — the calculation is done by the FDE (or FEM) temperature method at specific points of detail. It is of interest to calculate the temperatures on the interior surfaces — potentially the lowest, which will occur at the inner corners (contact of walls, or walls and windows).

These temperatures are lower if there is an increased heat flow caused by an unfavorable case or inadequate design. In this case it is the penetration of the inner concrete wall through the facade wall, without interruption of the thermal bridge. Thus calculated (contact) temperature, is entered in the following calculus: [4]

$$fRsi = (Tsi - Te) / (Ti - Te),$$

where:

- fRsi — is the temperature factor
- Tsi — is surface internal temperature
- Te — is temperature of the external environment
- Ti — is temperature of the internal environment
- T1 / T2 — is the lowest temperature at the point which is marked on the graphs below

The calculated value of fRsi is compared with the values given in the graph below (Fig. 5.), which shows the relationship between the temperature factor and the percentage of relative humidity at which condensation occurs [9].

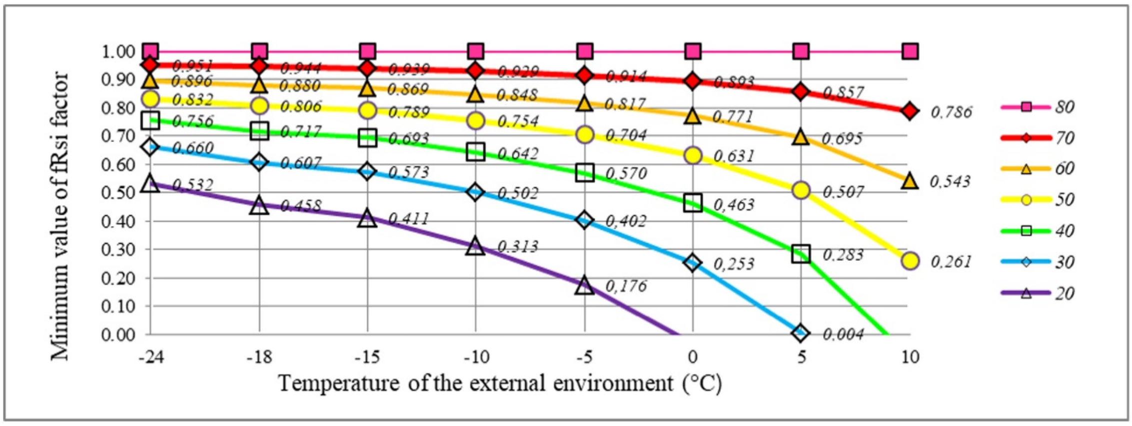
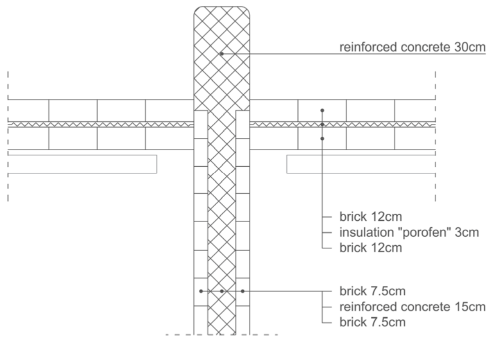
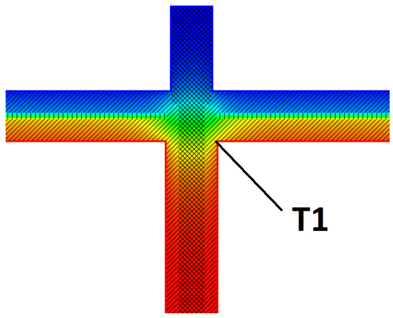


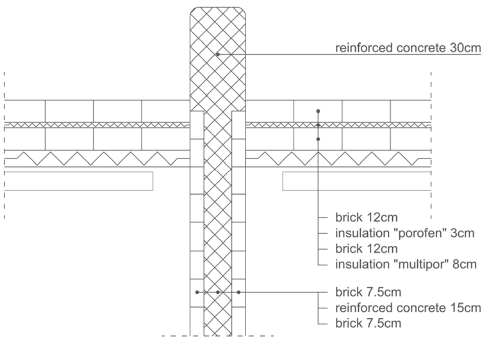
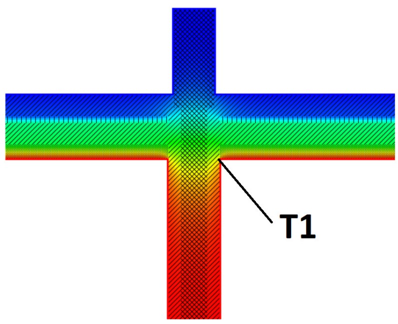
Fig. 5. Graphic view of the relationship of fRsi factor and the temperature of the external environment.

4.3. Results and discussion

In school interiors, the usual relative humidity is about 50%. This means that if the relative humidity is lower, the risk of condensation increases on critical surfaces (corners).

Details D1.1 and D1.2 show that the influence of the penetration of the partition concrete wall on the increased heat flow in the parapet zone is significant. After the intervention, the coating on the inside with 8 cm Multipor plates improved slightly in terms of the intensity of the thermal bridge, but worsened in terms of temperature factor.

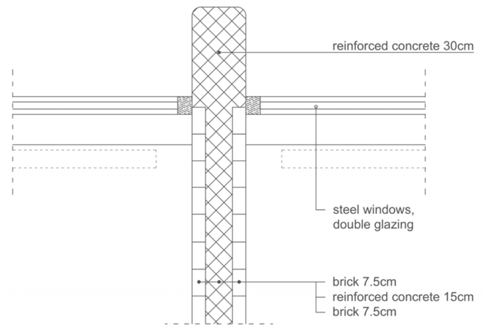
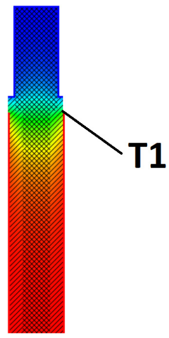
Detail	Architectural drawing	Temperature field
D1.1: Horizontal section a-a existing state		
Results	Lowest contact temperature Linear thermal bridge (loss) Temperature factor Condensation at relevant humidity of interior air	T1 = +12.7 °C Ψ = 0.996 W/m·K fRsi = 0.772 φ = 50%

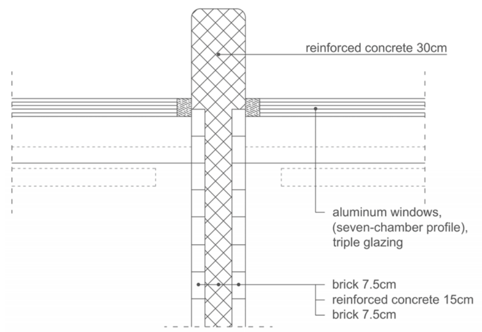
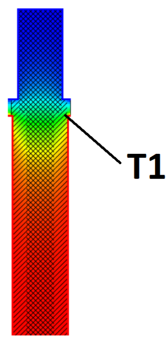
Detail	Architectural drawing	Temperature field
D1.2: horizontal section a-a state after the energy efficient refurbishment		

Results	Lowest contact temperature Linear thermal bridge (loss) Temperature factor Condensation at relevant humidity of interior air	T1 = +11.9 °C Ψ = 0.685 W/m·K fRsi = 0.747 φ = 48%

In details D2.1 and D2.2, at linear joints of the window with the wall (which continues to exist outside, without a thermal break), it is quite certain that condensation occurs. In the current state (detail D2.1), in reality, this danger is partially mitigated by the "old" windows, which do not seal well, and this unfavorable effect of infiltration in terms of heat loss, in this case, is positive in terms of drying.

In the future (detail D2.2), after the intervention, the new windows will have good sealing, low infiltration, and since the conditions for condensation have not improved significantly (from 25% to 30%), it is certain that condensation will occur on the connection of the window frame to the wall, so a worse situation is expected than in the current state.

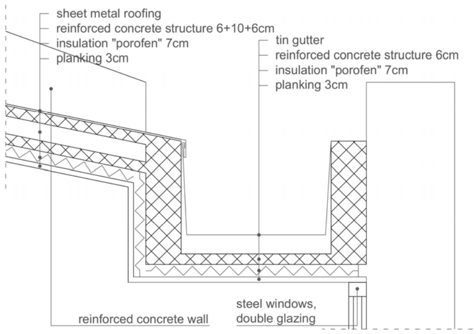
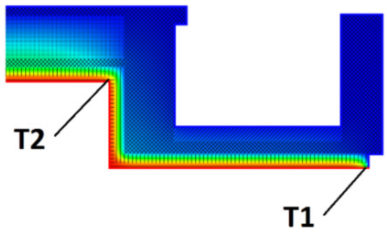
Detail	Architectural drawing	Temperature field
D2.1: horizontal section b-b existing state		
Results	Lowest contact temperature Linear thermal bridge (loss) Temperature factor Condensation at relevant humidity of interior air	T1 = +2.6 °C Ψ = 1.33 W/m·K fRsi = 0.46 φ = 25%

Detail	Architectural drawing	Temperature field
D2.2: horizontal section b-b state after the energy efficient refurbishment		
Results	Lowest contact temperature Linear thermal bridge (loss) Temperature factor Condensation at relevant humidity of interior air	T1 = +5.3 °C Ψ = 1.32 W/mK fRsi = 0.54 φ = 30%

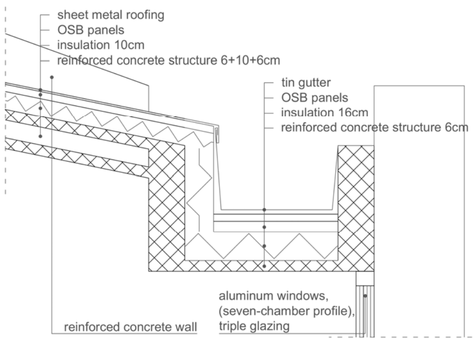
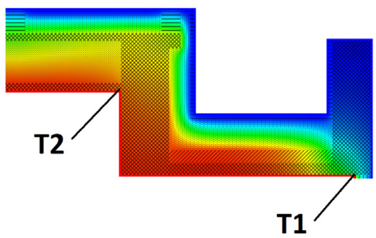
In details D3.1 and D3.2, which refer to the connection of the concrete beam with the concrete gutter and the concrete hollow roof ceiling, it can be seen that in the existing state (D3.1), in which the thermal insulation is located on the inside of the roof construction, within the ceiling layers, the critical temperature occurs at the joint with the window, and it is certain that condensation will occur.

In relation to the intervention (D3.2), in which the ceiling lining with internal thermal insulation was completely demolished and external thermal insulation was installed, the general situation regarding heat losses has improved, but at the critical point (T1), the situation has worsened and there is a dramatic danger of condensation due to thermally uninsulated concrete facade beam (which is uninsulated due to the preservation of the visual identity of the facade).

<table>
<tr><th>Detail</th><th>Architectural drawing</th><th colspan="2">Temperature field</th></tr>
<tr><td>D3.1:
vertical
section c-c

existing state</td><td>
</td><td colspan="2">
</td></tr>
<tr><td>Results</td><td>Lowest contact temperature
Linear thermal bridge (loss)
Temperature factor
Condensation at relevant humidity of interior air</td><td>T2 = +15.5 °C
Ψ = 0.59 W/mK
fRsi = 0.86
φ = 60%</td><td>T1 = +6.2 °C
Ψ = 0.59 W/m·K
fRsi = 0.569
φ = 37%</td></tr>
</table>

<table>
<tr><th>Detail</th><th>Architectural drawing</th><th colspan="2">Temperature field</th></tr>
<tr><td>D3.2:
vertical
section c-c

state after the energy efficient refurbishment</td><td>
</td><td colspan="2">
</td></tr>
<tr><td>Results</td><td>Lowest contact temperature
Linear thermal bridge (loss)
Temperature factor
Condensation at relevant humidity of interior air</td><td>T2 = +17.3 °C
Ψ = 0.813 W/m·K
fRsi = 0.916
φ = 78%</td><td>T1 = 0.1 °C
Ψ = 0.813 W/mK fRsi = 0.378
φ = 20%</td></tr>
</table>

At point T2, there is no danger of condensation in the current state or in the future state.

5. Concluding remarks

The conducted analysis has confirmed that linear thermal bridges, can not be neglected, nor uniformly designed in sense of thermal insulation of brutalist objects. Moreover, there are questions arising about the financial and humane aspects of the energy efficient refurbishment works on these buildings.

If it takes too much time for the investment to recoup, and while doing so there are side effects that affect the comfort of users (children in this case): less space and air in the classrooms, condensation and dew points, worse air quality — is it really an improvement we are talking about?

Based on the facts above, there should be a more detailed Rulebook with guides about these specific renovations, and steps that are allowed and justified for taking while designing projects for renovation of brutalist objects, with the significance of these buildings in mind.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, T.Z., A.R. and D.V.; methodology, A.R and T.Z.; software, A.R.; data analysis, T.Z. and A.R.; validation, T.Z. and A.R.; writing—original draft preparation, T.Z.; writing—review and editing, T.Z, A.R. and D.V.; visualization, T.Z. and A.R.; supervision, A.R. and D.V.; all authors had approved the final version.

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