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ENERGY EFFICIENT REFURBISHMENT OF MUNICIPAL PUBLIC BUILDINGS IN BELGRADE, SERBIA

Abstract

The paper presents the methodological approach for improvement of energy performance of public buildings in the process of partial refurbishment, having in mind the constrains that are originating from existing technological, material and stylistic characteristics. Being the carriers of wider social and historical connotations, these buildings are often under the certain level of protection as the parts of the cultural heritage making the process of improvement a complex one. For this reason, an improvement path algorithm has been defined and consequently tested on two representative cases investigating the boundaries, possibilities and outcomes of the energy refurbishment procedures.

Keywords: refurbishment, methodology, energy efficiency

ЕНЕРГЕТСКА ОБНОВА ЈАВНИХ ЗГРАДА - ГРАДСКИХ ОПШТИНА У БЕОГРАДУ, СРБИЈИ

Сажетак

Овај рад представља методолошки приступ унапређењу енергетских перформанси јавних зграда у процесу парцијалне обнове, узимајући у обзир ограничења условљена постојећим технолошким, материјалним и стилским карактеристикама зграде. Као носиоци ширих друштвених и историјских конотација, ови објекти су често под одређеним степеном заштите као културна добра, што процес њихове обнове чини веома комплексним. Из овог разлога, дефинисан је сет корака унапређења, који је потом тестиран на два репрезентативна случаја испитујући границе, могућности и исходе процеса енергетске санације објеката.

Кључне ријечи: обнова, методологија, енергетска ефикасност

1. INTRODUCTION

Existing public buildings are representing a specific portion of the building fund marked by high diversity in typological, structural and material characteristics as defined by the design principles and available technology of the time of construction. Many of these structures were not purposely designed for the function they now serve and have undergone various alterations and modifications which have largely changed their original state.

As they provide socially significant services, these buildings are frequently visited by the general public which presents a potential for a strategically different approach in the process of refurbishment - introducing not only the functional and technological elements into design process but also educational and demonstration ones. In that sense, these building represent a role-model for the people to see and other buildings to be like.

Starting from these considerations, process of refurbishment requires the specific case-sensitive approach, especially with the aim of improving the overall energy performance. Even more so when the considered building is under a certain level of heritage protection, which municipality buildings often are. Such an approach has previously been taken by researchers when considering energy efficient refurbishment of housing building stock built before 1919. in Serbia [1] and even considering of the most prominent public buildings in Belgrade from the aspect of energy refurbishment and constraints when buildings are under cultural heritage protection [2]. This paper, however, considers the constraints and possibilities in energy refurbishment process of a specific section of public buildings, that are the city municipality buildings, and offers findings gathered from conducting this process on two such buildings in Belgrade.

2. REFURBISHMENT METHODOLOGY

Methodology is developed in several main steps: initial investigation of the existing state, identification of individual improvement measures suitable for the specific case, formulation of improvement packages in accordance to the design conditions given by the institute for the protection of architectural heritage, valorization of different variants and production of design documentation. These main steps can be further divided into smaller steps in the following order:

- Data collection: architectural and other technical building data, on the basis of archival material, is collected and analyzed. Then, "In situ" research of building envelope's characteristics is performed by conducting an energy audit procedure. The thermal characteristics of the envelope are also determined by the method of thermal imaging of the building to see where the greatest energy losses are;
- Model formulation: a digital thermal model of the building is made by using Rhinoceros[1] 3D modeling software. The geometry of the building is divided into thermal zones, clearly distinguishing which zones and areas are heated, and which are not heated - such as basements, archives and technical rooms. Thermo-physical properties of the building are defined - structure of the envelope, parameters for natural ventilation, etc. The simple calculation of building physics is done in the program "KnaufTerm2 Pro"[2], which is a software package, intended for calculating the energy performance of buildings in accordance with applicable legislation in the Republic of Serbia, simulated for typical climatic conditions of Belgrade. The same model can be used for more complex, dynamic calculations, but they are not used, because they are not required by the current legislation.
- Assessment of possible energy efficiency and architectural measures in the scope of local construction practices, materials, financial feasibility and professional experience. Proposed measures need to take into account restrictions arising from the type, purpose and architectural characteristics of the building in terms of the need to preserve the existing condition and its architectural characteristics.
- Scenario definition: improvement scenarios were defined in three levels by incorporating energy efficiency measures in succession, starting from the same methodology that was used in previous research [3]. The first improvement scenario implies the improvement of the building for one energy class, for such is the obligation prescribed by the Rulebook on Conditions, Content and Method of Issuing Energy Performance Certificates [4] when refurbishing an existing building. The second level of improvement involves improvement of all thermal envelope elements to meet the standards (Umax) prescribed by the Rulebook

[1] Rhinoceros https://www.rhino3d.com/
[2] Knauf Insulation: http://knaufinsulation.rs

on Energy Efficiency in Buildings [5] and the third level of improvement includes maximal feasible improvement of the thermal envelope. Since this paper is based on real-life project, some modifications to this improvement methodology had to be made, in accordance to project task and existing situation. In first improvement, the most needed interventions and those easiest to carry out are implemented. In second improvement, parts of the thermal envelope that are difficult to access and/or have very small surface area and/or minimal impact on building's performance were not improved due to the cost of such works would outweigh the benefits. In all three improvement scenarios, individual elements of the thermal envelope have their thermal characteristics improved just to the point prescribed by the Rulebook [5] and not more. There is also a fourth improvement scenario which would be redesign - a total functional, structural and aesthetic overhaul of the building making it better suited for use in present time. This scenario however is not part of this paper.

- Simulation, calculation and valorization: determining the best scenario based on the analysis of energy required annually for heating, primary energy and total CO_2 emissions. When calculating the required energy, only the energy required for heating in the defined heating period, through the methodology of heating degree days (HDD) was taken into account, in accordance with the Serbia's Rulebook on energy efficiency of buildings [5]. The energy needed for lighting was not the topic of this study, or the energy needed to cool the building during the summer months, but as the proposed measures improve its thermal characteristics, it is assumed that the ratio of energy needed for cooling would be proportional to space heating, with minor changes due to higher solar gains.

Described methodology has been used in real case scenarios and has been finalized in the form of technical documentation required for the execution of the Energy refurbishment procedure of two Belgrade city's municipality buildings.

3. CASE STUDY

The case study consists of two buildings - Palilula municipality building and Zemun municipality building, which make a good basis for comparison on account their many similarities. Apart from the climate they share, both being located in Belgrade, Serbia, they are both public buildings, serving the same function of administrative, city municipality buildings. Although one was built at the end of nineteenth and the other in the middle of the twentieth century, they are made out of the same materials with very similar construction techniques and are roughly the same size. Both buildings have had multiple interventions during their exploitation in terms of their geometry and function - additional spaces have been added, attic spaces turned into offices, windows changed etc. They only differ in facade design as Zemun municipality building's street facade is treated in typical neo-classic style (See Figure 3) while Palilula municipality building, as an example of Belgrade's modern movement, has somewhat reduced ornamental expression (See 0).

3.1. PALILULA MUNICIPALITY BUILDING

3.1.1. Existing condition of the building

The building of the City Municipality of Palilula was built as an endowment according to the project made in 1938. After the abolition of the endowment in 1954, the building was nationalized and later turned into an administrative building. After the Second World War, an intervention was made in the form of adaptation of the attic into a useful office space, i.e. upgrades on the flat terraces of the courtyard, also in the form of office space.

The building has a basement, ground level and six floors, with its dominant axis being northeast - southwest, i.e. the courtyard part to the southeast. The yard part is uneven in relation to the street part and it has the same number of floors.

The building is built in a massive structural system with load-bearing masonry walls of various thicknesses and various brick formats, so that in the composition we find walls 51 cm, 38 cm and 25 cm thick, going from the basement level to the upper floors.

In the period after the Second World War, the building was upgraded with the addition of reinforced concrete slabs above the 6th floor (6th floor of the courtyard), above which a sloping wooden roof covered with sheet metal was constructed.

The street facade is characterized by relatively reduced facade plastic in the form of vertical grooves in the zones between the window openings and stone decorative slats around the windows and terraces in the central part of the facade canvas, i.e. distinctive texture made of artificial stone in the ground floor area. (See 0)

The existing windows are mostly made of PVC profiles and were installed in the early 2000s. During the exploitation, changes were made to the shape of the windows as well as their dimensions, so the current state is partially different from the original one. Although the existing PVC windows are in relatively good condition, they are, given their age, characterized by inadequate thermal characteristics, keeping in mind the current standards.

The building is supplied with thermal energy through a district heating system from the Public Utility Company of the Belgrade Power Plant using a radiator heating system. The radiator network is indented as not insulated within the thermal envelope of the building.

Cooling is performed by individual units of the "split" type of different capacities and ages (conditions) with the installation of outdoor units directly on the facade. Ventilation is natural through window openings. Sun protection is realized by internal curtains of the Venetian type, i.e. canvas curtains.

Figure 1. *Thermal imaging and photograph of the street facade of the building of the City Municipality of Palilula. The image clearly shows heat losses in horizontal reinforced concrete cerclages as well as beams over windows. No vertical reinforced concrete elements are observed*

3.1.2. Improvement measures

Improvement measures are grouped in three improvement packages presented on 0. The first level of improvement is achieved by:

- Replacing existing PVC windows with new ones, with six-chamber PVC profiles with triple glazing filled with argon and low-emission coating. The geometrical characteristics of the newly planned windows (size and composition/division) are the same as existing ones, but the newly planned windows are characterized by a better heat transfer coefficient of U = 1.5 W/m^2K.

The second level of improvement involves the following architectural interventions:

- Thermal insulation of the courtyard facade was performed by placing a thermal insulation layer of 12 cm of stone wool over the existing facade.
- Thermal insulation of the courtyard facade overhangs was performed by placing a layer of stone wool 15 cm thick and a final layer of cement mortar.
- Thermal insulation of mezzanine structures towards the attic space was performed by installing a layer of 15 cm stone wool with the addition of appropriate protective layers (steam dams, protective foils) in accordance with the requirements of building physics.
- The thermal insulation on the part of flat roof was planned. A 20 cm layer of stone wool on the underside and finished with plasterboard on the appropriate substructure.

For the third level of improving the performance of the building, the following additional interventions have been proposed:

- Thermal insulation of the street facade was performed by installing a thermal insulation layer of 12 cm of stone wool. The street façade is characterized by relatively reduced façade plastic, and the intervention removed all layers up to the load-bearing layer of the wall and reworked the façade in accordance with the existing condition in terms of material and geometric characteristics. Work on this facade would require a long-term disruption of pedestrian traffic since the walkway in front of the building is very small so therefore this intervention is not included in the second scenario.

- Thermal insulation of pitched roof above the attic office space was performed by adding a thermal insulation layer of 22 cm of stone wool between the existing rafters. This roof already had 12cm of thermal insulation and works on the inside of the roof would require eviction of offices and demolition of existing finishes so it was therefore not part of second improvement strategy.

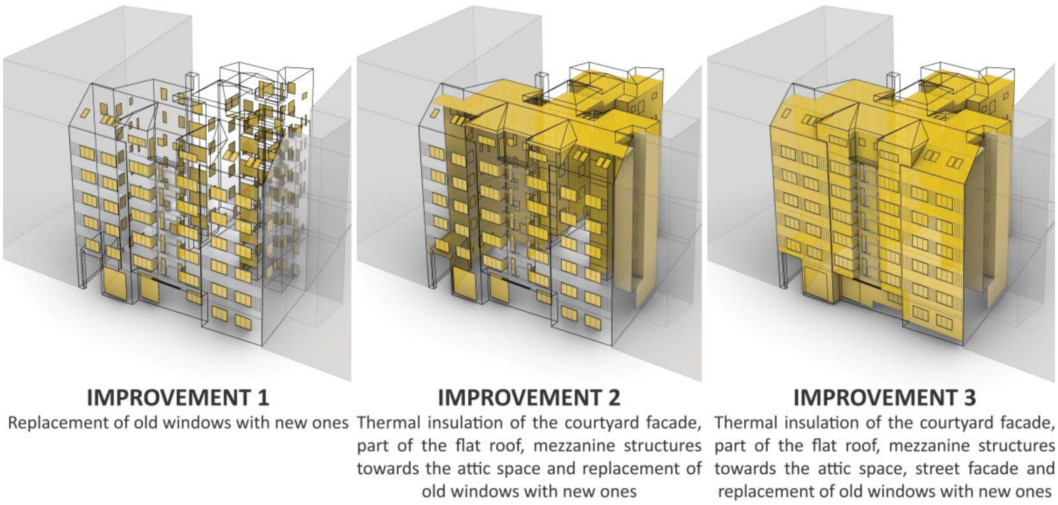

Figure 2. *Illustration presenting elements of the Palilula municipality building's thermal envelope intervened upon in first, second and third level of improvement (from left to right)*

3.2. ZEMUN MUNICIPALITY BUILDING

3.2.1. Existing condition of the building

The subject of the energy efficiency study is the building of the City Municipality of Zemun in Magistratski trg No. 1. The building of the seat of the City Municipality of Zemun, in its original form, was built in 1886. and has undergone significant changes and additions to this day. The thermal envelope of the building is very heterogeneous as a result of a number of interventions carried out since the construction of the building, which changed the volume, appearance and constructive material characteristics. Today, this building is part of a protected historical urban area and all interventions on the building's facade need to comply with the conditions issued by the Institute for the Protection of Cultural Monuments of the City of Belgrade.

The building is built in a massive structural system with load-bearing solid brick walls of various formats and thicknesses. The basement walls in the old part are built of bricks of the old format 14/29/7, with a total thickness of 80 cm. On the added part, the walls are built with a new brick format 12/25/6.5 with the total thickness of 60 cm. The walls of the ground floor in the old part are also built of old bricks and treated with a layer of decorative plastic in the form of artificial stone on the outside with a total thickness of 60 cm, while the new part has a total width of 50 cm. The walls of the first floor have a total width of 50 cm, and 40 cm in the new part. Second floor walls (completely rebuilt after the Second World War) were built using a new brick format, 40 cm wide on both parts. The attic walls are 25 cm wide brick walls with a 8 cm thick gypsum layer added on the inside, leaving the layer of air 20-25 cm wide in between the gypsum and masonry wall.

The available project documentation cannot determine the existence of reinforced concrete elements, as well as thermal imaging conducted during the energy audit, except in the extended part of the building. (see Figure 3)

The roof construction of the attic is wooden with a profiled tile cover. By adapting the attic, a new wooden structure was added in the form of rafters on the underside of the existing structure and a layer of plasterboards was placed towards the attic space. In the zone between the rafters, a layer of 10 cm thick insulation was placed.

Windows were changed in the 90's with the installation of PVC profile windows. Historically, several interventions have been performed at the position of the window, which have changed the type and structure of the window. The existing roof windows were installed during the last reconstruction and do not have the appropriate thermal characteristics by today's standards. (see Figure 3) The facility is supplied with thermal energy through a district heating system from the Public Utility Company of the Belgrade Power Plant using a radiator heating system.

Cooling is performed by individual units of the split type. Ventilation is natural, through window openings. Sun protection is via internal curtains of the Venetian type and external blinds on the roof windows on the south and southwest side of the building.

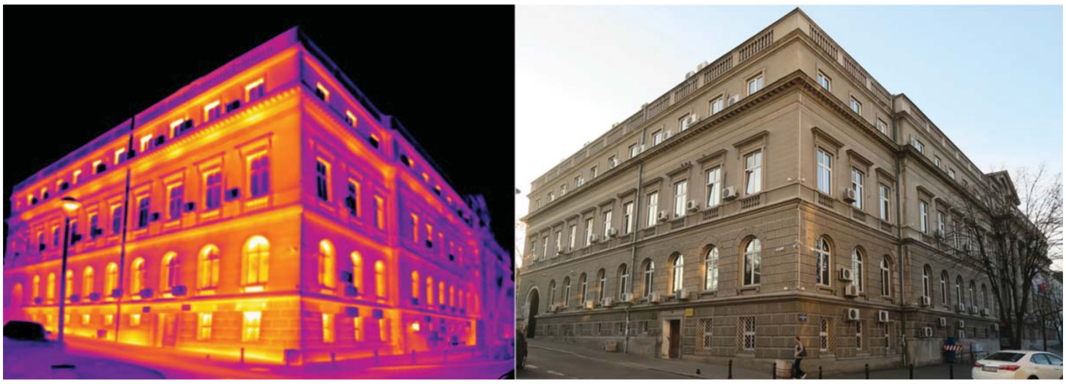

Figure 3. *Thermal imaging and photograph of the street facade of the building of the City Municipality of Zemun. Heat losses are evident in the area where concrete beams are - over windows and in the area of window openings*

3.2.2. Improvement measures

Improvement measures are grouped in three improvement packages presented on Figure 4. The first level of improvement is achieved by:

- Replacing existing PVC windows with new wooden ones, according to the conditions obtained from the Institute for the Protection of Cultural Monuments of the City of Belgrade. The newly planned solid wood windows are glazed with thermopane glass with geometric characteristics (sash division and decorative moldings) matching the original windows, according to the available information on the original windows. Newly planned windows are characterized by a heat transfer coefficient of 1.5W/m^{2}K, in accordance with the Rulebook [5]. The dismantling of the existing as well as the installation of new windows is planned on the inside of the building, so as to reduce the risk of damage to the facade, that would require additional work.
- Replacing existing roof windows with the same type windows with better thermal performance. Disassembly and reassembly are planned from the inside with all the necessary cladding according to the type of cover. Glazing is with laminated inner and tempered outer glass Uw = 1.5W/m^{2}K.

The second level of improvement involves applying additional architectural interventions in the form of:

- Thermal insulation of the courtyard facade by placing a 10 cm thick stone wool layer over the existing facade.
- Thermal insulation of the courtyard facade overhangs by placing a layer of stone wool 20 cm thick and a final layer of cement mortar on the rabbit net.
- Thermal insulation of slabs towards the attic space was done by installing a layer of 20 cm stone wool with appropriate protective layers (steam dams, protective foils) in accordance with the requirements of building physics.
- Thermal insulation of pitched roof above the attic office space was performed by adding a thermal insulation layer of 24 cm of stone wool between the existing rafters.

The third level of improving the performance of the building was done by adding proposed intervention:

- Insulating the street facade was by installing a thermal insulation layer of 10 cm of stone wool on the inside of the facade wall, due to the limitations issued by the Institute for the Protection of Cultural Monuments of the City of Belgrade.

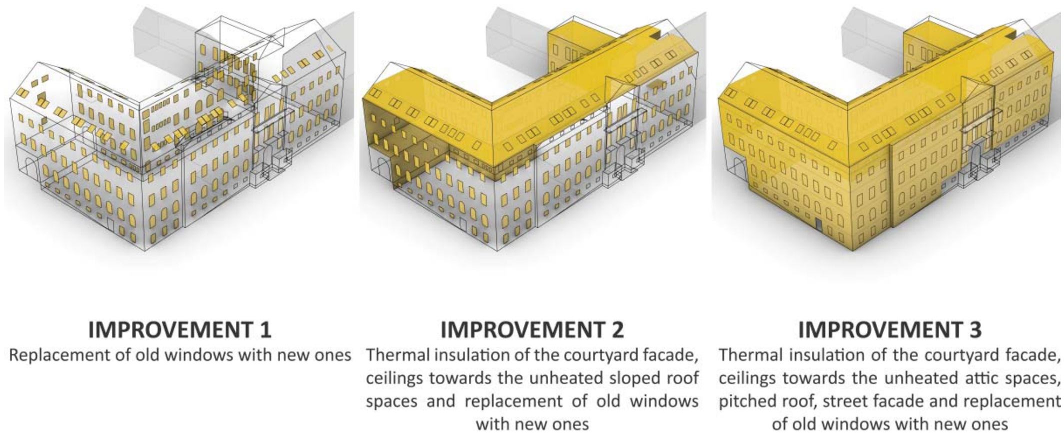

Figure 4. *Illustration presenting elements of the Zemun municipality building's thermal envelope intervened upon in first, second and third level of improvement (from left to right)*

4. RESULTS AND DISCUSSION

Calculations show that reviewed buildings can be substantially improved from the aspect of energy efficiency and even get to energy class "C", prescribed by the regulations as a mandatory level of energy performance of newly built facilities. (See Figure 5)

Removing the old windows and adding new, geometrically and stylistically identical but with better thermal characteristics has a surprisingly different effect on the building's energy consumption. This change has had little effect on Palilula's building performance and a much greater change in Zemun municipality building's energy consumption in the first improvement package. (see Figure 6) This can be explained by worse performing existing windows in Zemun, with greater ventilation losses and with the predominant window orientation. In Zemun, most of the windows face east or west, while Palilula municipality has most of the windows with south orientation. With higher solar gains to start with, better performing windows have not had such a great impact considering only energy needed for heating is calculated.

Since the new windows in Zemun municipality's building were installed in the openings where the original windows, equipped with Esslinger blinds used to be, there is a difference in height, which was solved by installing a "blind" overhead light.

Thicker outer walls, greater volume and a more compact form of Zemun municipality building make it more energy efficient then Palilula municipality building to start with (see Figure 5). Since thicker walls have a better U value, the impact of adding thermal insulation on them has less of an effect on the entire building's energy performance, as can be seen on Figure 5 for second improvement strategy.

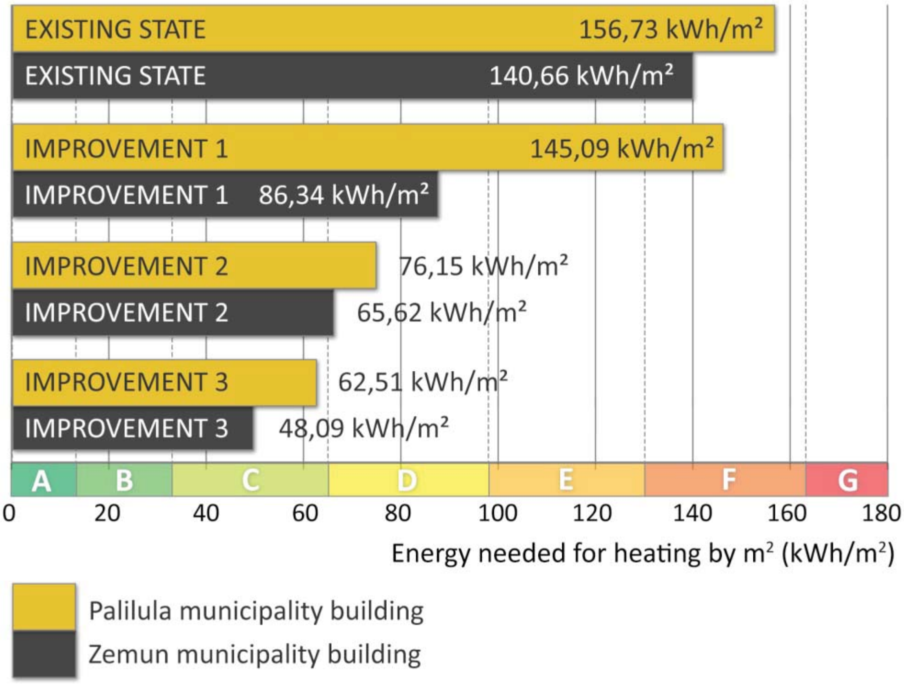

Figure 5. *Comparison of energy needed for heating Palilula and Zemun municipality buildings during winter months per square meter in existing state, first, second and third level of improvement (from top to bottom); CO_2 emission and primary energy are linear to this function*

Adding thermal insulation to the street facade, in the third improvement strategy, although difficult, is necessary for existent building to reach a "C" energy rating. In Palilula's municipality building it was sought to preserve the visual style of the building, so after adding a 12 cm thermal insulation to the facade, all existing facade features and stylistic elements are planned to be made again using cement mortar. In Zemun municipality building however, building's facade cannot be intervened upon by the conditions given by the Institute for the Protection of Cultural Monuments of the City of Belgrade. Therefore, thermal insulation has to be added from the inside of the building. Such intervention is not usually looked upon favourably by investors because it requires construction work done from the inside of the building, meaning the offices need to be moved elsewhere until the work is complete. Also, such action reduces the inside volume of the building which can be view by the occupants as a bad thing, but since these old buildings usually have large rooms with high ceilings it can be also considered as a good thing because the reduction of the heated volume further decreases building's energy needs. Also, these buildings were not built for electrical and communication systems they are now required to have. Adding insulation on the inside of the facade walls allows for major installation overhaul - it presents the space and the opportunity to install all the needed electrical, heating/cooling, internet and communication infrastructure a modern administrative building needs.

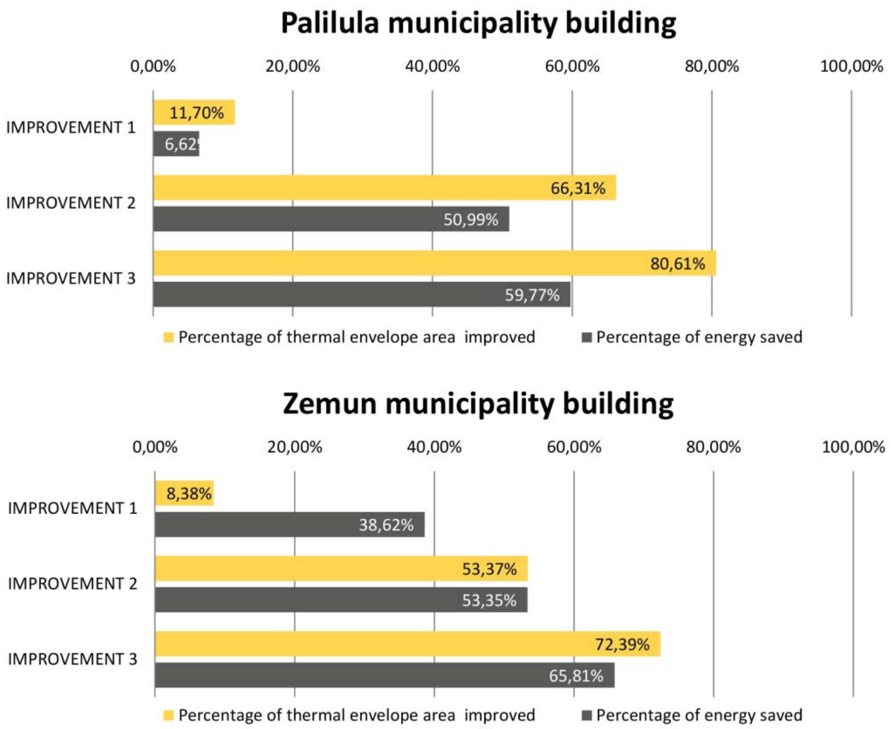

Figure 6. *Diagram comparing the percentage of Palilula and Zemun municipality building's thermal envelope area intervened upon in first, second and third level of improvement with the percentage of energy saved for heating (percentage of CO_2 emission reduction and primary energy reduction are the same)*

Every building has it's "weak spot" from the point of energy efficiency, as can be clearly seen in Figure 6, and improving that part of the thermal envelope brings the best building performance for the minimal intervention. But, as can also be seen in Figure 6, the wider the scope of the intervention - the more measures are taken, the less efficient those measures become. So, at one point, improving existing building's thermal performance by taking simple architectural measures becomes redundant. Therefore, we think the best refurbishment strategy for existing public buildings is a fourth improvement scenario which would be redesign - a total overhaul of the building making it better suited for use in present time. Such an approach would take into account functional, structural and aesthetic aspects of the building, as well as the energy aspect, thus creating a building from a different time well suited for this one.

5. CONCLUSION

Existing public buildings, especially municipality buildings, are an important part of a city's building fund. They are representatives of the values of a society that built them and historical monuments testifying to the design principles, construction techniques, materials and available technology of the time of their construction. Many of these buildings were not originally designed for the function they now serve and are ill equipped to meet the conditions the contemporary way of life requires of them. Therefore, these buildings need to be upgraded to meet our demands in terms of comfort and performance.

Using two public municipality buildings in Belgrade, Serbia as a case study, this paper proves that existing public buildings can be refurbished by using simple architectural measures to the level of user comfort and energy efficiency required from the newly built facilities, regardless of the level of protection they are under. These simple measures consist of adding a layer of thermal insulation to the elements of the building's thermal envelope - walls, ceilings, flat or pitched roofs etc. both from the outside and inside of the building or changing the window opening with new ones having better thermal characteristics.

However, since many existing public buildings require more than just simple measures to meet the demands of contemporary society, attention needs to shift from the concept of refurbishment to the concept of redesign - a total functional, structural and aesthetic overhaul of the building razing it to the level of functional needs and aesthetics of the 21st century.

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