Energy Efficiency and Sustainability Potential Analysis of Residential Buildings according to their Architectural, Structural and Thermal Characteristics

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Abstract. Resulting from the devastating earthquake in 1963, the housing stock of the capital city of Skopje was destroyed by 85%. Due to the crucial need for rapid construction of residential buildings in order to provide homes, more than 60% of the existing residential buildings in Skopje were built in the period between the 1963 and 1980. Today, many of these buildings are in the same condition as they were built then, and they do not correspond to current energy efficiency standards. Therefore, there is a need for urgent application of energy saving measures to these buildings. The aim of this paper is to analyse architectural, structural and thermal characteristics of the most common type of the already existing residential buildings in a selected city quarter of Skopje, built after the earthquake which are lacking thermal insulation materials. Based on the documented data, a comparative software analysis of structural elements of the most common type of building was carried out for both the existing condition and the future scenario with improved thermal characteristics. According to the analysis, the analysed buildings have great energy efficiency and sustainability potential. If proper renovation is carried out, it can significantly improve their energy performance and meet criteria for current energy efficiency standards.

1. Introduction
The Municipality of Karpos, which today covers a large part of the former Municipality of Idadija, is known as one of the most recent and attractive municipalities of Skopje, whose housing stock was mostly built in the period between 1965 and 1980 [1]. These residential buildings were built in a similar architectural style, from a reinforced concrete structural system with very poor energy efficiency features. The required heating energy for the settlements is mostly supplied through the BEG - Central distributing heating system [2].

According to the analysed data from the State Statistical Office, as well as the documented data from the State Archive of the City of Skopje, one of the most common types of residential buildings questionable in their energy efficiency features is the so called “Russian” building, built between 1963 and 1965. Most of these buildings were built in the Municipality of Karpos, especially in the city quarter Karpos 3.
Based on the conclusions from the State Statistical Office data and according to the fact that most of the buildings in the quarter were built without thermal insulation [3], there are some issues which might arise such as the following one. What proper procedures should be taken in order to: reduce energy consumption, improve energy efficiency and sustainability of the residential sector of the city and reduce the air pollution? For this purpose, architectural and structural analyses of the existing residential buildings in the selected city quarter were firstly carried out, and then, based on the analysed data, a comparative software analyses of structural elements of the typical “Russian” building for the current existing condition and the future improved scenario, were carried out.

2. Architectural and urban analyses of the selected residential buildings

In the selected quarter, 31 residential buildings were classified as type 1 and type 2 “Russian” buildings and they represent 72% of the total housing stock in the settlement. These buildings are also known as prefabricated residential buildings of the type “Karpos”, which were intensively constructed in 1963, due to the donation project of Russia. These types of buildings were built in the countries of the former Soviet Union, named as “Khrushchyovka”, [4] and were designed as social architecture, which means they were very rational in their construction in terms of height of the buildings, building materials, size of apartments etc. The “Russian” buildings have 4 floors (a ground floor + 3 floors). The adequate urban density of 20% in the quarter is achieved according to their height and floor area. Regarding their position, the buildings have a rectangular shape, a compact volume and their position is such that each building gets enough sun during the day, providing that no building cast a shadow on the adjacent ones.

![Characteristic floor plan of a multi-storey “Karpos” building type: a) type 1; b) type 2, reproduced with the permission of the State Archive, City of Skopje [Basic project, phase Architecture], [The State Committee for Construction and Architecture of the USSR], [Moscow, 1963]](image)

**Figure 1.** Characteristic floor plan of a multi-storey “Karpos” building type: a) type 1; b) type 2, reproduced with the permission of the State Archive, City of Skopje [Basic project, phase Architecture], [The State Committee for Construction and Architecture of the USSR], [Moscow, 1963]
Figure 1 shows the plan of the characteristic floor of the two types of “Russian” buildings, which tells the number, the type and the area of the apartments. Type 1 buildings contain 4 entrances and a total of 56 apartments, 16 of which are studios, 32 are two-bedroom apartments and 8 are three-bedroom apartments. Type 2 buildings have 2 entrances, a total of 24 apartments, 8 of which are studios, 8 are two-bedroom and 8 are three-bedroom apartments.

3. Structural analysis of the selected residential buildings
Use of prefabricated concrete elements for the performance of the structural system of type 1 and type 2 buildings was derived from the need to provide necessary space for housing in the shortest period possible. Massive structural system of supporting concrete walls does not offer the possibility of developing this type of objects vertically, which is why they have no more than four floors. These buildings were very economical in their building materials, architectural design, with optimal windows and small terraces [4]. The outer perimeter of the walls in prefabricated reinforced concrete elements was generally made of 3 layers as can be seen from Figures 2 and 3:
- Exterior coat made of a concrete panel with finishing mortar with a thickness of 6 cm;
- Intermediate layer - thermal insulation from polystyrene with a thickness of 5 cm;
- Interior structural reinforced concrete panel with a thickness of 15 cm. [5]

The external panels are made from prefabricated reinforced concrete elements with a height of 260-270 cm, according to the dimensions of a structural field (260/580cm or 320/580cm). A three-layer panel with profiles and anchors for connecting the panels is produced with the technological integration process, see Figures 2 and 3. The internal structural walls are usually performed as single-layer reinforced concrete panels with a thickness of 12-14 cm. The elements for the slabs are generally performed as single-layer reinforced concrete panels with dimensions corresponding to a structural field, i.e. a constructive module (260-360 cm in width and 260-580 cm in length), see Figures 6 and 7 [5].

4. Basic features of the “Russian” residential buildings in the selected settlement
Results based on the data for the examined buildings obtained from the State archives of the Republic of Macedonia, the department of the city of Skopje and the conducted survey with the tenants and
residents of the buildings in the selected area are shown in Table 1. Two types of buildings, which were analysed, are similar according to their architectural characteristics, especially in their urban position, shape and module dimensions. However, number of apartments and tenants is different. The buildings type 1 contain 56 apartments or 151.2 tenants per building, and there are 18 such buildings in the district. Each of them has a floor area of 745 m². This type of buildings contains 1008 apartments with a total of 2721.6 tenants. The buildings type 2 have 24 apartments or 64.8 tenants per building, and there are 13 buildings of this type. Floor area of each building is 405 m². This type of building contains 312 apartments with a total of 842.4 tenants.

Table 1. Residential building types and their basic data in the studied city quarter.

| Type of building | Building type 1 | Building type 2 |
|------------------|----------------|----------------|
| Description of the building | Russian building | Russian building |
| Year of construction | 1963 – 1965 | 1963 - 1965 |
| Number of buildings | 18 | 13 |
| Number of flats per building | 56 | 24 |
| Number of tenants per building | 151.2 | 64.8 |
| Floor area (m²) | 745 | 405 |
| Number of stories | 4 | 4 |
| Shape of building | Rectangular | Rectangular |
| Type of construction and materials | Prefabricated reinforced concrete structural elements | Prefabricated reinforced concrete structural elements |
| Structural elements | Poor insulation (5-8 cm) | Poor insulation (5-8 cm) |
| Thermal insulation | Central city heating | Central city heating |
| Heating | Air conditioning | Air conditioning |
| Cooling | Natural | Natural |

It is assumed that the average number of tenants in an apartment is 2.7 in accordance with the PRPR. [6]

Results are summarized in Table 1, and it is concluded that in the selected area, more precisely in the city quarter of Karpos 3, the residential “Russian” buildings contain a total of 1320 apartments with approximate number of the 3564 tenants. Most of the apartments are connected to the central city heating, but some of tenants abandoned central heating and they use electricity more often both for heating and cooling. This data are further used and implemented as input parameters when calculating thermal characteristics of both the existing and the ideally improved state of the buildings.

5. Methodology and results
Based on the results from the architectural and structural analyses, it can be concluded that the “Russian” buildings have a large percentage of representation in the quarter. They are in a good position to become sustainable and energy efficient according to their architectural and urban features. However, due to their poor thermal insulation, they are big consumers of energy in the district.

In order to properly approach further interventions into these buildings, the following methods of analysis of the thermal characteristics of buildings were used. Firstly, a software analysis was carried out in order to analyse thermal characteristics of the materials used in an existing typical “Russian” building. Subsequently, an improved scenario with a minimal and cost-effective intervention was made in order to meet the criteria for energy efficiency in accordance with current standards. Following sections explain methods and software used and results obtained from the research.
5.1. **Methodology for calculating thermal characteristics of the building**

The envelope of the building is composed of its external walls, the openings (windows and doors), the roof and the base floor structure. Analysis of the thermal characteristics of these structural elements was carried out in order to see the current energy efficiency situation as well as the potential for further improvement in a typical “Russian” apartment building type 1, with dimensions of 62.2 m²/11.8 m, see Figure 1 (a). The analysis was performed with the Knauf Term2 PRO-M software.

Calculation includes the following input parameters of the building (obtained from previously conducted analyses) such as: location; position of the building in relation to the exposure to wind; number of facades of the building exposed to the wind; way of ventilation of the building; type and purpose of the building; residential units in the building; geometry of the building which implies parameters for a useful heating surface, surface of the casing, volume of the casing and volume of the heated and ventilated space. The minimum outdoor design temperature was taken to be 0º C, the internal optimum project temperature was 20º C, the external average temperature was 12.4º C, the number of heating days was 170, the number of wet days was 60, the number of days of drying was 90, the number of heating days of the week was 7, the number of heating hours during the day was 24.

![Figure 4](image.png)

**Figure 4.** Position of an additional thermal insulation in a future improved scenario in order to avoid thermal bridges from the current state (red line indicates the insulation) [5].

The existing materials, from which the constructive elements were compiled, were inserted in the calculation of the current state. This is shown in detail by Figures 2 and 3. An additional layer of thermal insulation of 10 cm (extruded polystyrene XPS, as efficient and at the same time the most economical variant) was added to the existing structural elements in the calculation of the improved future scenario. These layers refer to outer walls, floor slab above the unheated space (basement) and roof construction, which is shown in Figure 4 [5]. Windows in existing state are considered as wooden frames and single-glazed glass windows, while in the improved scenario, as six-chamber pvc frames with double-glazed low-emission glasses 4 + 12 + 4 ( economical, efficient and the most commonly used variant). Different results were obtained in terms of the energy parameters such thermal transmittance or U value (W/ m²K), thermal resistance or R value, Rs, Rse (m²K / W), as well as the energy class of the building. These results are shown in Tables 2 and 3.
5.2. Thermal characteristics results of both already existing and future state of the building

After obtaining thermal values through the software analyses of structural elements of the already existing and the future state of the building, a comparison between the two states was made. Figure 5 shows an intersection of an external (facade) wall with its layers and their thermal parameters in the existing condition of the building. It can be clearly seen that the assembly of the wall does not satisfy the requirements of energy efficiency because its $U$ value is 0.659 W/m²K and is bigger than $U_{max}$, which, according to the Rulebook for energy efficient building, is not allowed to be more than 0.35 W/m²K for external walls [8].

**Figure 5.** Thermal parameters of an external wall (an existing state).

Figure 6 shows an intersection of an external wall with its layers and their energy parameters in a future improved scenario. A significant improvement of thermal values can be noticed and the assembly can satisfy the energy efficiency requirements by adding an additional thermal insulation layer (10 cm of extruded polystyrene). In the improved scenario, $U$ value is 0.241 W/m²K, which is smaller value than $U_{max}$. The same procedure was applied to other elements such as floor slab above basement, roof construction and windows. The results are shown in Tables 2 and 3.

**Figure 6.** Thermal parameters of an external wall (an improved future scenario).
5.3. Structural elements parametric analysis results
The results summarized in Table 2 refer to the analysis of the structure assemblies at the current existing condition of the building, from which it can be stated that none of the assemblies fulfil the standards in accordance to the Rulebook for Energy performance of buildings, from which the maximal thermal transmittance coefficients in non-transparent (U max) and in transparent structures (U w max) are determined [7] and [8].

Table 2. Thermal parameters of the structural elements in the existing (current) condition of the building.

| Main structural elements of the building | Building materials | Total width (cm) | Calcul. type | U value (w/m²k) | U max (W/M²k) | R value (m²k/w) | Rsi value (m²k/w) | Rse value (m²k/W) | Sun permeab. factor (g) | Satisfactory level |
|----------------------------------------|-------------------|-----------------|--------------|----------------|--------------|----------------|-------------------|-------------------|----------------------|-----------------|
| External (façade) wall                 | Plaster 2 cm, reinforced concrete wall 14 cm, polystyrene 5 cm, exterior plaster 2 cm | 28              | classic EN6946 | 0.659          | 0.35         | 1.347          | 0.13              | 0.04              | 0                    | U > Umax not satisfactory |
| Ground floor slab structure            | Parquet 2.2 cm, cement layer 5 cm, reinforced concrete slab 10 cm, interior plaster 1.5 cm | 18.7            | classic EN6946 | 2.688          | 0.35         | 0.202          | 0.13              | 0.04              | 0                    | U > Umax not satisfactory |
| Roof structure                         | Plaster 2 cm, reinforced concrete slab 15 cm, vapour barrier, airspace 20 cm, wooden substructure 5 cm, bitumen patch 0.07 cm | 42.57           | classic EN6946 | 1.127          | 0.25         | 0.717          | 0.13              | 0.04              | 0                    | U > Umax not satisfactory |
| Windows and doors                      | Wooden framed windows with single glazed glass | / windows       | 4.6           | 1.8            | 0.217        | 0.13           | 0.04              | 0.87              | 0                    | U > Umax not satisfactory |

Table 3 refers to a future scenario for improving energy efficiency of the building, where an additional thermal insulation was added to the structural elements (explained in Figure 6).

When comparing results from Tables 2 and 3, it can be noticed that a significant improvement in sustainability and energy efficiency can be achieved with additional layers of thermal insulation in the assemblies as well as by the change of windows, where all elements meet the criteria for energy efficiency in accordance with the Rulebook for Energy Efficiency of Buildings [8].

6. Conclusion
In the selected city quarter, some of the biggest consumers of the energy are the "Russian" buildings which have the largest percentage of representation in the settlement. The main factors for energy consumers are: poor thermal insulation of the outer walls, roof and basic floor; numerous thermal bridges which occur as a disadvantage of the prefabricated systems; wooden framed windows with single glazed glass.

On the other hand, orientation, urban position, ratio of buildings, form and the volume as well as the architectural solution of the apartments in the buildings give great potential for achieving both energy efficiency and sustainability of the buildings of the entire neighbourhood. It is necessary to mention that these buildings can be adequately sanitised and renovated, and this intervention should be based on software analyses with scenarios for improving energy efficiency.
Table 3. Thermal parameters of the structural elements in the future scenario for improvement of the building’s energy efficiency and sustainability.

| Main structural elements of the building | Building materials | Total width (cm) | Calcul. type | U value (w/m²k) | Umax (W/M²k) | R value (m²k/w) | Rsi value (m²k/w) | Rse value (m²K/W) | Sun permeab. factor (g) | Satisfactory level |
|----------------------------------------|--------------------|-----------------|--------------|----------------|--------------|----------------|----------------|--------------------|----------------------|-----------------|
| Ground floor slab structure            | Exterior plaster 2 cm, reinforced concrete wall 14 cm, polystyrene 5 cm, XPS extruded polystyrene 10 cm, exterior plaster 2 cm Parquet 2.2 cm, cement layer 5 cm, Reinforced concrete slab 10 cm, XPS extruded polystyrene 10 cm, interior plaster 1.5 cm Interior plaster 2 cm, XPS extruded polystyrene 20 cm, reinforced concrete slab 15 cm, vapour barrier, airspace 20 cm, wooden substructure 5 cm, bitumen patch 0.07 cm | 28.7 | classic-EN6946 | 0.333 | 0.35 | 2.834 | 0.13 | 0.04 | 0 | U < Umax Structure is satisfactory |
| Roof structure                         | PVC window with six chambered frame and low-e double glazed glass (4+12+4) | / window s | 1.7 | 1.8 | 0.588 | 0.13 | 0.04 | 0.4 | | U < Umax Structure is satisfactory |

Software analyses were carried out in order to determine energy efficiency and sustainability potential of the buildings by comparing two conditions of the building, the existing one and the future condition with improved thermal characteristics. Based on the results of the analysis as well as on the answers of the surveyed tenants, it can be concluded that they have large expenses for heating and cooling of the apartments due to the poor thermal characteristics of the buildings.

This paper presents the principles how to properly find the most economical and the most effective energy saving solution for this type of urban neighbourhood built up with a large number of old and energy-inefficient buildings. The research data can be further used as an input parameter in creating a calculation model for both calculating real energy consumption and creating improved scenarios for energy saving. The same model can also be implemented in other settlements within the municipality of Karpos where there are more buildings of the analysed type.

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