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BUILDING ENERGY SIMULATION ANALYSYS BASED ON IN-SITU MEASUREMENTS BEFORE AND AFTER INSULATION APPLICATION

Abstract

The architecture of the post-earthquake period in Skopje is an important cultural heritage of the city. According to the standards of that time, the buildings were built without thermal insulation materials. Compared with today's energy efficiency standards, those buildings have poor energy efficiency and they're big energy consumers which are responsible for tones of CO2 emissions annually. In order to improve their energy performance, and at the same time to achieve a minimal impact on the authentic façade appearance, a façade nanomaterial is used with high thermal properties, such as aerogel based thermal plaster with natural concrete look. First, a dynamic energy performance simulation of the existing condition of a selected building is made using BIM technology, based on "in situ" measurements of the building. The existing energy condition of the building is compared with the actual energy bills for heating and electricity. Second, an energy simulation with added thermal insulation material on the envelope is made, which is defined as improved scenario. Finally, comparative analyses between the existing condition and the improved scenario are carried out. It can be concluded that BIM and energy simulation technologies give very accurate results comparing to the actual condition of the building. According to the simulation results, adding the new material on the façade make a significant improvement of the building's energy performance, such as a reduction of the heating energy consumption in the improved scenario by 68 % compared to the existing condition of the building. Also, the electricity energy consumption was reduced by 40% and CO2 emissions by 50% in the improved scenario. The results showed that the application of the aerogel based thermal plaster on the façade walls, not only improves its energy efficiency, comfort and emissivity of the building, but also has a minimal impact on its authentic architectural appearance.

Keywords:

Energy simulation, energy efficiency, BIM technology, in situ measurements, nano-materials, architectural heritage

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1. INTRODUCTION

The post-earthquake architecture, built after the great earthquake in 1963, also known as architecture of Modernism represents an important cultural heritage of the city of Skopje. [1] According to the construction standards of that time, the buildings were built in lack of thermal insulation materials, [2] which resulted with a bad thermal comfort, high costs for heating, cooling and maintenance, degradation and decay. These buildings need to be properly renovated according to today's energy efficiency standards. [3] On the other hand, the authentic appearance of the architecture that is considered as a cultural heritage should not be compromised in the renovation process. Recently, the use of nanomaterials as thermal insulation building materials has been increased. A façade nanomaterial such as aerogel based thermal plaster with good thermal insulation properties, which has a minimal impact on the original architectural appearance of the building is used for the analysis. In order to see the real energy condition of the building and also its possible improvements by using nanomaterials on the façade walls, a dynamic energy simulation of the building is carried out by using BIM technology.

2. SELECTION OF "CASE STUDY" BUILDING AND "IN SITU" MEASURMENTS. SELECTION OF FAÇADE NANOMATERIALS

2.1. BUILDING DESCRIPTION

The Hydro-meteorological Service building in Skopje is a famous Modernist building built in the post-earthquake period in a specific architectural style, known as "brutalist" architecture, which means that the whole building is constructed in raw exposed natural concrete known as "concrete – brut", (Figure 1). The selected case study building is considered as a cultural heritage of Skopje, not only for its brutalist appearance, but also for its unique plan and design. The building has a complex composition of one central volume that unites the other six separate volumes in a dynamic futuristic structure, further emphasized by the three cylindrical towers that rise from the central volume and end connected in a triangular structure, (Figure 1).



Figure 1. Different views of Macedonian Hydrometeorological Service building [4]

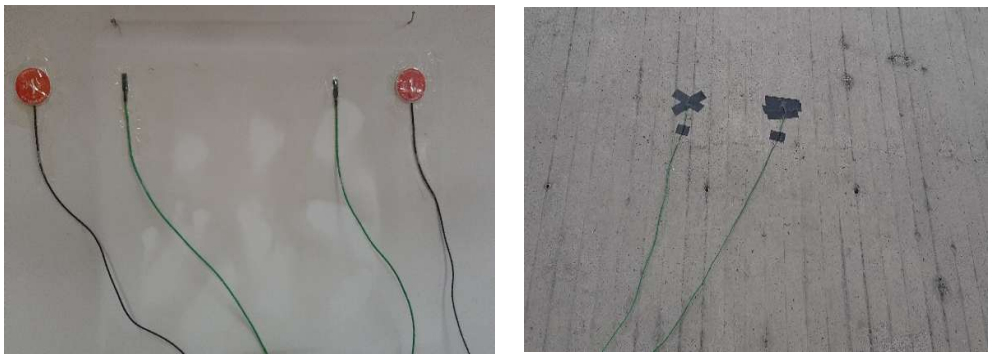
.2. “IN SITU” MEASURMENTS

In order to determine the real U values of the concrete facade walls of the building, "in situ" measurements of the heat flux and the surface temperatures of the facade walls was performed. The measurements were conducted in the period from 6th to 13th of March, 2020. The measurements were performed by TRSYS01 [5] which is a high-accuracy building thermal resistance measuring system with two measurement locations, (Figure 2).



Figure 2. TRSYS01 - a building thermal resistance measuring system [5]

The sensors were placed on the both sides of the façade wall (a – inside sensor position; b – outside sensor position), shown in figure 3. Two of the internal sensors measure the heat flux trough the wall, and the other two sensors the surface indoor surface temperature of the wall. The other pair of external sensor measure the outdoor surface temperature of the wall. After the eight days measurement the data was processed by LoggerNet software and U values calculations were made.



a) *b)*

Figure 3. “In situ” measurements sensor positions on the facade wall a) inside b) outside

Figure 4 shows the graph of the U values measures of the façade wall which average value is 1.5 W/m^{2}K. The allowed U value for external façade walls is 0.35 W/m^{2}K, which indicates the fact that the building has very poor thermal properties. Figure 5 shows the graph of the surface temperatures of the wall, from which can be concluded that there is a big difference between them, which means that a lot of energy is used for heating the indoor space.

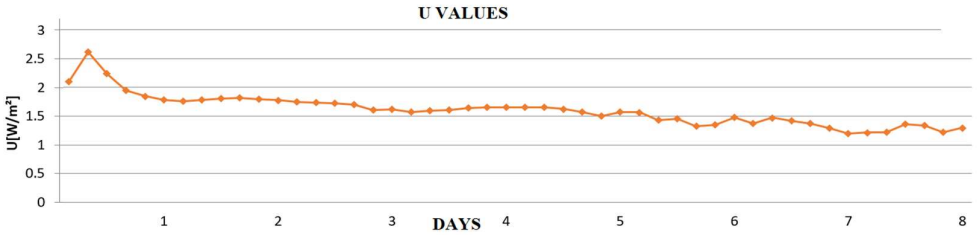


Figure 4. Average U values during eight days period of measurement

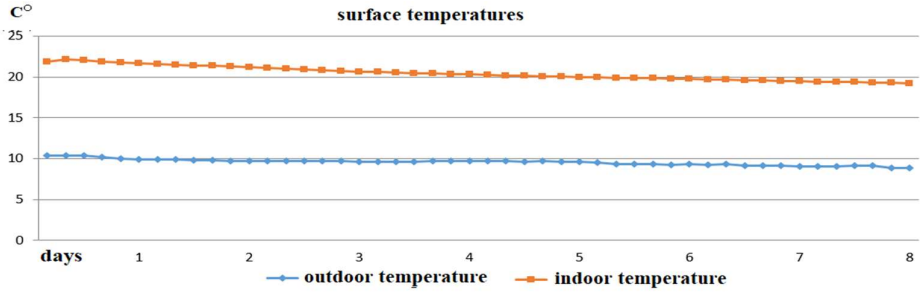


Figure 5. Average values of surface wall temperatures during eight days period of measurment

2.3. NANOMATERIALS SELECTION AND PROPERTIES

The research showed that aerogel based thermal plaster has a low thermal conductivity λ ranging from 0.028-0.014 W/mK, thanks to its porous nano structure. [6] In the buildings renovated with this type of plaster, energy savings could be over 50%. [7] According to the criteria for protection of cultural heritage, aerogel plasters have a mild impact on the authenticity of buildings, but it is important that they are compatible with the chemical composition of the original materials, which can be easily removed without damaging them and there is no need for additional fastening that would damage the original material. [8] They have great flexibility in applying uneven surfaces, architectural details and isolating thermal bridges. [9] Due to the composition and method of application, aerogel plasters perfectly mimic the texture of natural concrete and it's difficult to distinguish (Figure 6), while the original material remains preserved. The thermal characteristic of the added aerogel plaster on the façade walls are shown in table 1.



Figure 6. Facade nanomaterial concrete texture

Table 1. Facade nanomaterial thermal properties

Aerogel based thermal insulation plaster thermal properties	
λ (W/mK)	0.028
c (J/kgK)	990
ρ (kg/m³)	220
d (m)	0.06
μ [-]	4-5

Two dynamic energy simulations have been conducted: a simulation of the existing condition and of an improved scenario by adding aerogel plaster to the facade walls. Conventional thermal insulation materials such as rock wool and eps are added to the rest of the envelope (floor slab and roof). The fenestration has been replaced by aluminum framed double glazed low emission glass with U value of 1.06 W/m^{2}K

3. ENERGY MODELING AND SIMULATION

3.1. MODELING, ZONING, GEOMETRY AND MATERIALS

The building is modeled in Design Builder and the dynamic simulation is made in Energy Plus which are both BIM oriented softwares. The modeled capacity of the building is 150 employees, organized into several types of offices and departments. Figure 7 shows the ground floor division of thermal zones. All four facades of the building are exposed to wind, its entrance part is north oriented, surrounded by vegetation. Each room is modeled as different thermal zone due to the many different parameters that define it (number of people, electrical equipment, room orientation, etc.). The building is divided into a total of 140 thermal zones, including the zones on the ground floor, first floor, towers and basement. Each of the zones has its own design temperature, orientation, number of people, lighting, electrical equipment and appliances, type of heating, cooling, ventilation, glazing area, etc. Figures 7 and 8 show the ground floor thermal zones divided in the following groups: occupied zones (zones with people, conditioned during working hours); corridors (no people, but conditioned during working hours); unconditioned zones (stairs and toilets); occupied zones for 24 hours (zones with people conditioned all the time). The designed room temperature in the offices is 20°C, and in the halls and corridors is 15°C. The outdoor climate data are obtained simultaneously by the software Energy Plus..

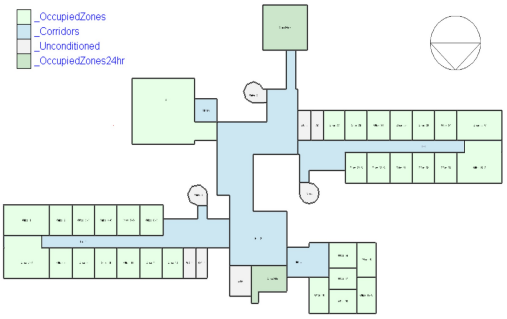


Figure 7. Thermal zones – ground floor

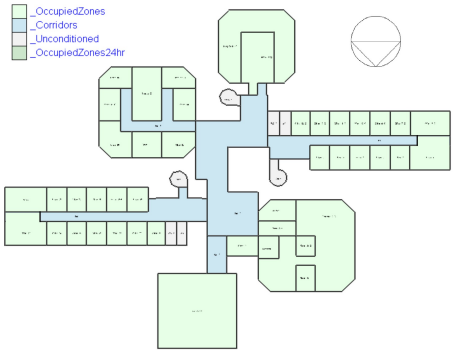


Figure 8. Thermal zones – first floor

Table 2 shows some of the most important parameters of the building geometry, summarized for all zones (conditioned and unconditioned). The building envelope is mainly composed of reinforced concrete solid walls without external finishing layer, except in certain parts, where a brick masonry wall appears. The facade walls, the roof and floor slab are not insulated. The facade fenestration is made of aluminum framed single glazed windows with and U value of 5.7 W/m^{2}K. All of the building parameters indicate its poor energy performance and bad thermal comfort.

Table 2. Thermal zones summary

Zone summary	Area [m^2]	Volume [m^3]	Above Ground Gross Wall Area [m^2]	Underground Gross Wall Area [m^2]	Window Glass Area [m^2]	Openings Area [m^2]
Total conditioned area (m^2)	2647.7	8085.9	2468.9	9.69	658.8	712.3
Total unconditioned area (m^2)	694.5	2103.8	694.7	325.57	43.3	49.3

3.2. RESULTS

First, a simulation of the existing condition of the building was conducted, and the results were compared with the actual heating and electricity bills. A comparison between the U values obtained from the software simulation and the results obtained from the "in situ" measurements was also made. The coincidences of the bills with the simulated condition for both electricity and heating energy consumption are over 90% (Figure 9 and 10). The simulated U value of the measured wall is 1.73 W/m^2K, which is slightly higher than the measured one of 1.5 W/m^2K. From the comparative analysis between the real existing condition ("in situ" measures and bills) and the simulated existing condition, it can be concluded that the used BIM technology gives very accurate results.

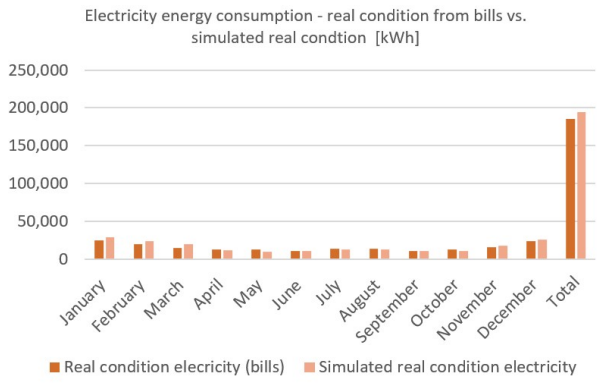


Figure 9. Electricity consumption (bills and simulation)

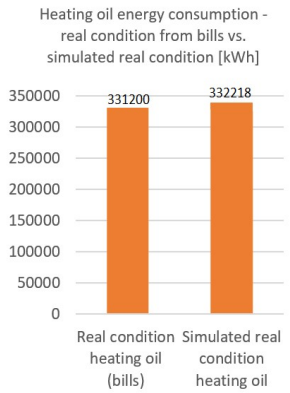


Figure 10. Heating consumption (bills and simulation)

The second simulation results of the improved scenario, showed significant improvements in terms of total heating energy consumption and total electricity energy consumption (electricity for heating, cooling, lighting and appliances), as well as a drastic reduction in CO_2 emissions. The comparative analysis between the heating energy consumption of the existing condition and the improved scenario showed a big reduction in the improved scenario by 68%. The total heating energy consumption in the existing condition is 332,218.5 kWh annually, ie an average of 27, 684.8 kWh monthly. The total heating energy consumption in the improved scenario is 105,188.4 kWh

annually, ie an average of 8,765.7 kWh monthly.The graphs of the heating energy consumption for both, existing condition and improved scenario are shown on figure 11.

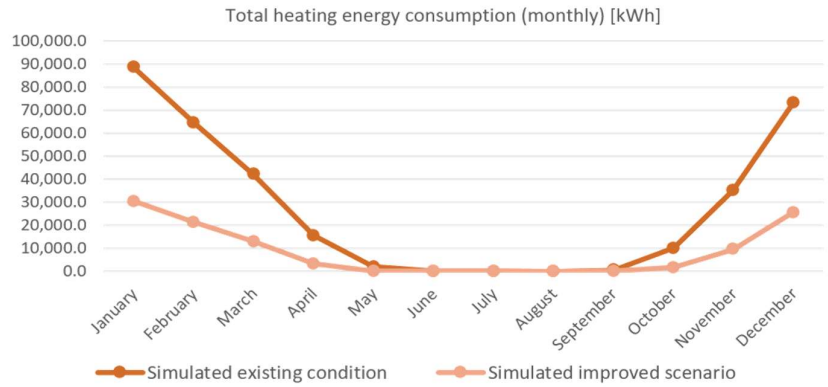


Figure 11. Heating energy consumption (existing condition and improved scenario)

The comparative analysis between the electricity energy consumption of the existing condition and the improved scenario showed a reduction in the improved scenario by 40%. The total energy consumption for electricity in the existing condition is 193,888 kWh annually, ie an average of 16,157 kWh monthly. The total electricity energy consumption in the improved scenario is 116,833.1 kWh annually, ie an average of 9,736.1 kWh monthly. The graphs of the electricity energy consumption for both, existing condition and improved scenario are shown on figure 12.

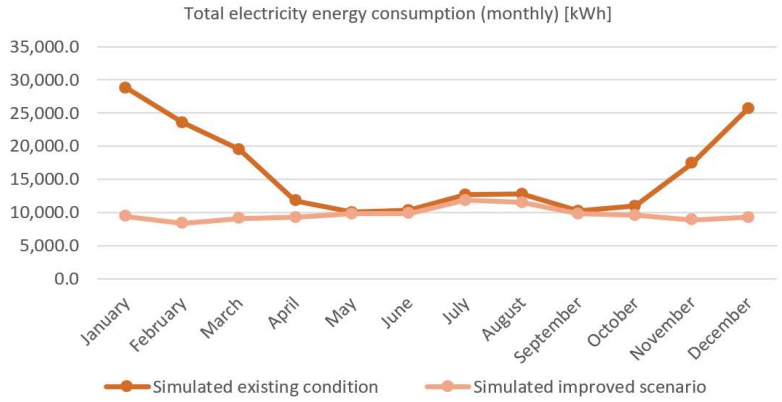


Figure 12. Electricity energy consumption (existing condition and improved scenario)

The CO_2 emissions in the existing condition are 168,269 kg annually, ie an average of 14,022 kg monthly, while the CO_2 emissions in the improved scenario are 84,215 kg annually, ie an average of 7,018 kg monthly. The reduction of CO_2 emissions in the improved scenario is 50%.

4. DISCUSSION AND CONCLUSION

The "case study" building is an important cultural heritage that needs to be properly renovated. From the investigated nanomaterials, the aerogel plaster has a minimal impact of the authenticity of building's facade. Based on the "in situ" measurements and on dynamic energy simulations of existing condition and the improved scenario, comparative analysis between the two conditions were obtained. The analysis showed a significant reduction of the heating energy consumption in the improved scenario by 68 % compared to the existing condition of the building. Also, the electricity energy consumption was reduced by 40% and CO_2 emissions by 50% in the improved scenario. Finally, it can be concluded that the application of the aerogel based thermal plaster on the facade walls, not only improves its energy efficiency, comfort and emissivity, but also has a minimal impact on the authentic appearance of the building. BIM technology has proven to be an excellent method and sophisticated tool for getting the accurate results in this type of architectural and also scientific analysis.

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