Chapter 26
Key Indicators for Evaluating the Energy Efficiency Improvement of the Renovated Building Facades

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Abstract Adopting the circular economy (CE) principles in building sector can reduce the quantity of materials used for the renovation of existing buildings, improve their energy performance and sustainability and minimize harmful emissions embodied in building materials. The main key indicators for energy performance evaluation of buildings, related to CE principles are: transmission losses, heating and electricity energy consumption, greenhouse gas emissions (GHGs), thermal comfort and financial costs for building maintenance. The building stock from the sixties and seventies is still in use, but from the aspect of energy efficiency, it shows a low level. From that reason, all these buildings have to be renovated. The effects of the renovation can be followed by the values of the key indicators. A simulation of a renovated scenario of an existing building was carried out and the results are presented in this paper. The analyzed building was built only in nature concrete without any facade thermal insulation. One of the renovation conditions was the appearance of the building should not be changed. An aerogel thermal plaster, which is nanomaterial with high thermal properties, was applied on the building facade. The results shows that the energy performance of the building is significantly improved in terms of reducing the heating energy consumption by 65%, electrical energy consumption by 40%, CO_2 emissions by 55%, PM10 particles by 46%, and the financial costs by 49%. According to the key indicators, it is found out that the renovation with appropriate material can significantly improve the building functionality.

Keywords CE · Key indicators · Energy efficiency · Emissions · Renovation

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L. Bragança et al. (eds.), *Creating a Roadmap Towards Circularity in the Built Environment*, Springer Tracts in Civil Engineering,
https://doi.org/10.1007/978-3-031-45980-1_26

26.1 Introduction

Buildings are responsible for 40% of annual energy consumption and 36% of annual greenhouse gas (GHG) emission in EU. From this reason, improving the energy efficiency and sustainability of the building stock is critical for meeting EU climate targets [1]. Circular economy (CE), especially in the building sector, strive to reduce the pollution, extend the building's lifespan, reduce the material waste and favorite the use of long-lasting building materials and products.

Proper renovation by using sustainable materials with low embodied energy will lead to the fulfillment of both goals, namely energy efficiency and circularity. The key indicators for evaluation the energy efficiency improvement of the buildings such as energy consumption, greenhouse gas emissions and costs are very important, especially in the process of renovation of existing buildings. In order to assess the efficiency of the measures taken to improve the energy performance of old buildings that were built without thermal insulation and whose function and architectural appearance are compromised, a dynamic energy simulation of the renovated scenario was made. For the simulated scenario, a sustainable and low embodied energy thermal insulation material was applied on the façade walls and the values of the key indicators were registered. The key indicators show a significant improvement of the energy performance of the building.

26.2 Key Indicators

26.2.1 Energy Consumption

Buildings energy consumption prediction is essential to achieve energy efficiency and sustainability [2]. Buildings energy consumption is mostly highly dependent on buildings characteristics such as shape, orientation, envelope and building materials. The comparison of the energy consumption for the original building and the improved scenario, is one of the most important key indicators for the buildings energy efficiency improvement. Different types of the energy consumptions, such as energy consumption for heating, electricity energy consumption for: cooling, lightning, equipment etc., are analyzed and presented in this paper.

26.2.2 Greenhouse Gases

Building construction and operations account for 36% of global final energy use and 39% of energy-related carbon dioxide CO_2 emissions [3]. These emissions from building operation arise from the energy used for heating and/or cooling, hot water supply, ventilation and air conditioning, lighting, and from the embodied energy for the production of building materials [4].

Cutting the GHGs in the building sector is a key indicator for not only the energy efficiency improvement, but also it is much more important from aspect of the climate changes and CE measures in the building sector. In order to assess the improvement that the application of the new façade material has on the building energy performance, the CO_2 emissions and PM10 particles in case of the original building and in case of the improved scenario of the selected building are defined and the comparison of both scenarios are presented in this paper.

26.2.3 Financial Costs for Maintenance

Maintenance and operation costs are part of the buildings life cycle costs [5]. The maintenance of the analyzed building is highly dependent of the heating and cooling conditions and the corresponding bills are responsible for the high financial costs of the building. The reduction of the bills for heating and cooling is a key indicator for the improvement of the energy efficiency of the building.

26.3 Façade Material

Aerogel-based building products are currently considered to be promising insulation materials mostly due to the fact they have high thermal performances with limited thickness. Furthermore, they have a very low embodied energy, lower than traditional insulation products [6–12]. In order to keep the original appearance of the building and at the same time to improve the thermal comfort, energy efficiency and costs, aerogel thermal plaster is used as a facade insulation material in the improved renovated scenario. The aerogel thermal plaster has a thermal conductivity of 0.028 W/mK and even applied in a small thickness has a great insulating effect as a result of its nano porous structure [7]. Due to the composition and method of application, aerogel plasters perfectly mimic the texture of natural concrete, while the original material remains preserved under the plaster. The cost of the aerogel is still high, which prevents its intense use in construction.

26.4 Energy Simulation

A dynamic energy simulation of the original building and the improved scenario in which the facade is renovated by applying the aerogel thermal plaster has been carried out by using Design Builder and EnergyPlus software [13]. The goal was to

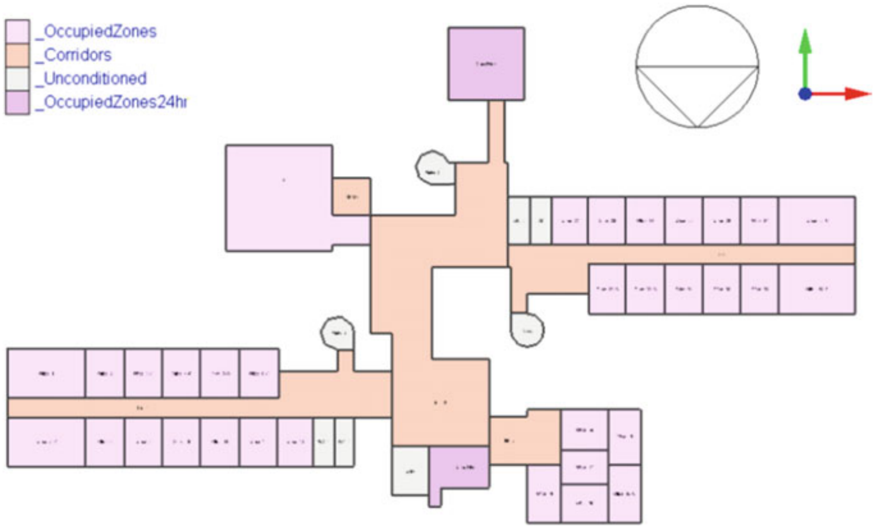

Fig. 26.1 Thermal zones division—ground floor

evaluate the energy efficiency improvement of the building by comparison of the key indicators for both cases, the existing building and the improved scenario.

The selected case study building is an office building, considered as a cultural heritage from the post-earthquake period in Skopje. The structure and the facade are designed are built in concrete, with no insulation and the appearance of the facade is untreated natural concrete. The selected building floor plan is shown in Fig. 26.1, where the principle of dividing the building into thermal zones can be find out. The building is divided into 140 thermal zones.

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. The designed room temperature in the offices is 20 °C, and in the halls and corridors is 15 °C. The outdoor climate data are defined by appropriate measurements. The building general information such as gross area, volume, openings etc. are presented in Table 26.1.

26.5 Results

26.5.1 Heating Energy Consumption

The simulation results of the existing condition of the building show that the building is a large energy consumer during winter time. This is due the lack of thermal insulation of the building's envelope. This implies large financial costs for maintaining the

Table 26.1 Thermal zones summary

Zone summary	Area [m²]	Volume [m³]	Above ground gross wall area [m²]	Underground gross wall area [m²]	Window glass area [m²]	Total openings area [m²]
Total conditioned area (m²)	2647.7	8085.9	2468.9	9.69	658.8	712.3
Total unconditioned area (m²)	694.5	2103.8	694.7	325.57	43.3	49.3

thermal comfort. By improving the heating energy consumption which is defined as a key indicator for the energy efficiency evaluation, it can be concluded the energy efficiency is significantly improved in the renovated scenario (see Fig. 26.2), which leads to reduced financial costs for maintenance and improved thermal comfort. Figure 26.2 shows the graphs of the average monthly values for heating energy consumption in kWh, for both, the existing condition and improved scenario, also shown in Table 26.2.

In the actual scenario, or existing condition, the average monthly heating energy consumption is 27 684.9 kWh (see Table 26.1), which means 332 218.8 kWh annually or 125.3 kWh/m2. Scenario 1 showed a reduction of the heating energy by 65%, which means that the average monthly heating energy consumption is 8 765.8 kWh (see Table 26.1). This means that the annual heating energy consumption in the improved scenario is 105 186.6 kWh or 40 kWh/m2.

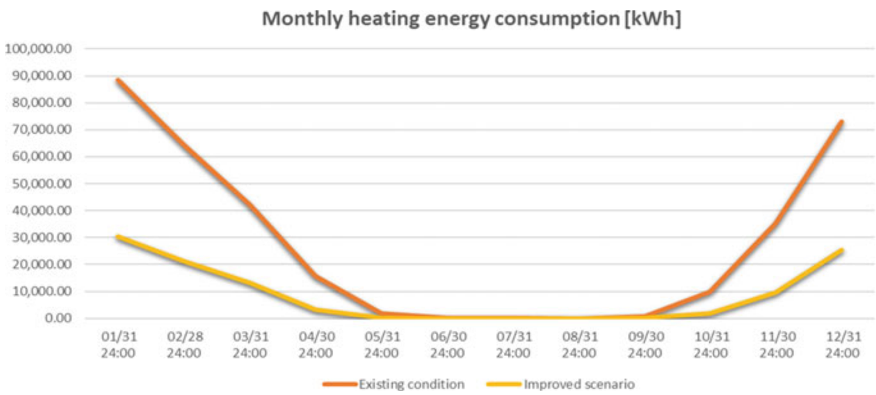

Fig. 26.2 Comparisons of monthly heating energy consumption between actual scenario and improved scenario

Table 26.2 Key indicators summary

Key indicators	Existing condition	Improved scenario
Heating energy [kWh]	27 685	8 765.7
Electricity heating energy [kWh]	6 133.5	2.96
Electricity cooling energy [kWh]	865.5	646.2
Total electricity energy [kWh]	16 157	9 736
CO_2 emissions [kg]	14 022.5	7 017.9
PM10 particles [kg]	1.3	0.7

26.5.2 Electricity Energy Consumption

The total electricity energy consumption is divided into electricity for additional heating (electric heaters); electricity for cooling (air conditioners); electricity for lighting and electricity from electrical appliances and equipment. The results show that apart from high consumption of thermal energy for heating, the building also consumes electricity for heating, which indicates the poor thermal insulation of the building, that despite the high consumption of heating energy, the heating system in the coldest months does not satisfy the thermal comfort and additional electrical heating is used. In addition, the simulations show high-energy consumption for cooling during the summer, which again indicates the poor thermal characteristics of the building envelope.

The average monthly total electricity energy consumption (heating, cooling, appliances and lighting) for the existing condition is 16 154 kWh, i.e. 193 848 kWh annually or 73.1 kWh/m^2 (see Fig. 26.3 and Table 26.2). The simulations of the improved scenario show an improvement in the consumption of total electricity (See Fig. 26.3 and Table 26.2) and also in both, electricity for heating and electricity for cooling the building (See Table 26.2 and Fig. 26.4). The average monthly total electricity energy consumption (heating, cooling, lighting equipment) is reduced by 40%, or 9 736 kWh, i.e. 116 832 kWh annually or 44 kWh/m^2.

The electricity energy consumption for heating, cooling and maintenance of the building, is key indicator for evaluating the energy efficiency improvement, thermal comfort and financial costs of the building.

26.5.3 CO_2 Emissions and PM10 Particles

Figure 26.5 shows the comparisons of the monthly CO_2 emissions of the building between actual scenario (existing condition) and the improved scenario. In the existing condition the monthly CO_2 emissions are 14 022.5 kg. The improved scenario shows much lower CO_2 emission i.e. the average monthly emissivity is 7 017.9 kg, which means that there is a reduction of the CO_2 emissions by 50%. (See

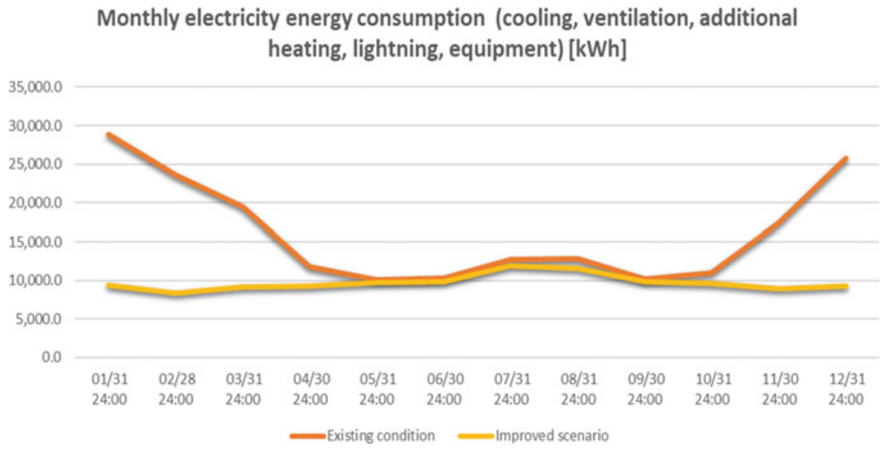

Fig. 26.3 Comparisons of total monthly electricity energy consumption between actual scenario and improved scenario

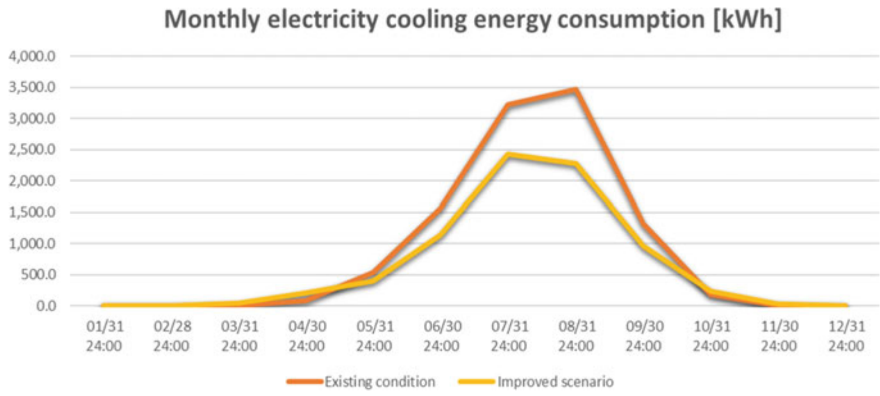

Fig. 26.4 Comparisons of monthly electricity energy consumption for cooling between actual scenario and improved scenario

Table 26.2 and Fig. 26.5). Reducing the CO_2 emissions is not just a key indicator for energy improvement evaluation, but also an indicator for CE implementation by proper buildings renovation. The same situation is with the PM10 particles reduction. From Fig. 26.6 and from Table 26.2 it can be concluded that great reduction of PM10 particles in the improved scenario is achieved. In the existing condition, the building emits an average of 1.3 kg monthly, or 15.6 kg annually. The improved scenario shows lower emission of PM10, i.e. an average of 0.7 kg monthly or 8.4 kg annually. It can be concluded that by adding insulation on the building envelope, the PM10 emissivity is reduced by 46.1% compared to the actual scenario. The PM10 emission is a key indicator for reducing the air pollution.

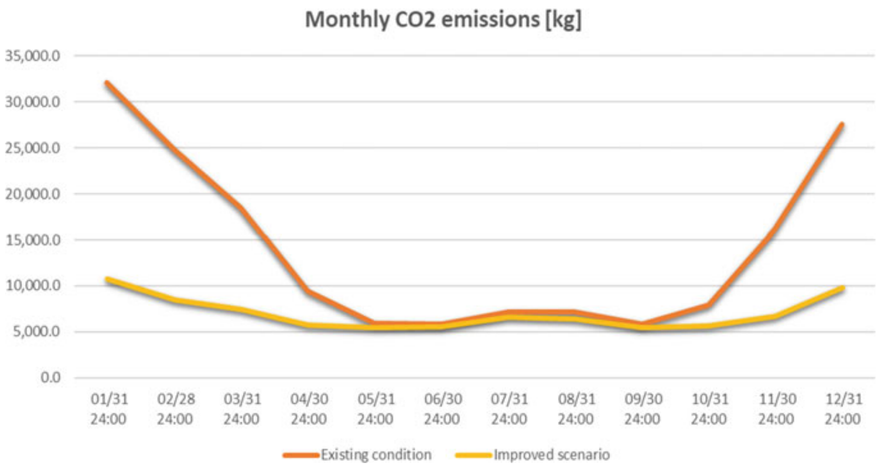

Fig. 26.5 Comparisons of monthly CO_2 emissions between actual scenario and improved scenario

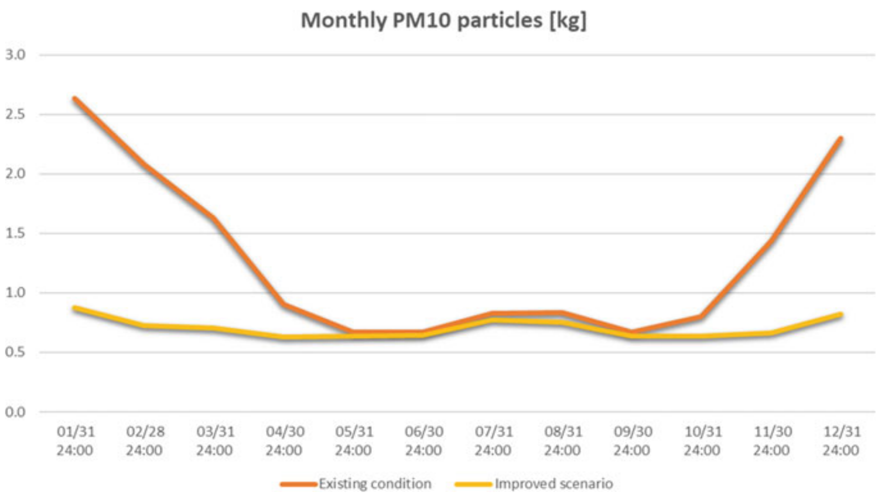

Fig. 26.6 Compariosons of monthly PM10 particles between existing condition and improved scenario

26.5.4 Financial Costs

Finally, a financial analysis are carried out for existing situation improved scenario, (See Fig. 26.7). It can be seen that the annual building's maintenance costs (heating and cooling) are reduced by 49% in the improved scenario compared to the existing condition. The highest costs are observed during the winter months, while the lowest during May, June and September, when the outside temperature is closest to the inside

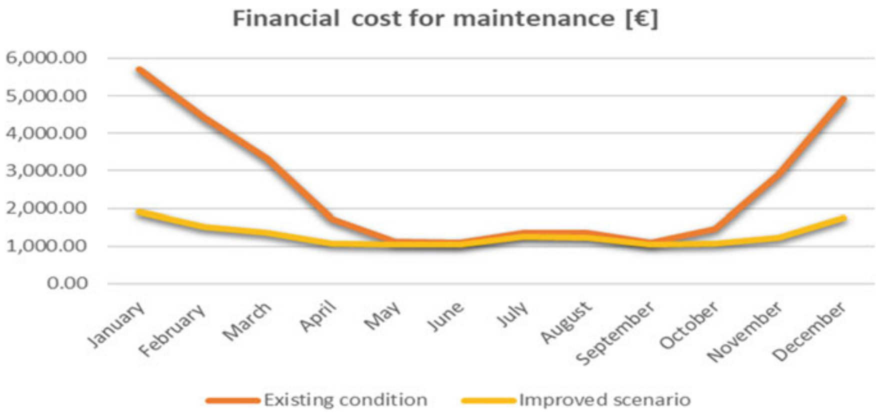

Fig. 26.7 Comparisons of monthly PM10 particles between actual condition and improved scenario

temperature. This analysis proves the role of the thermal insulation of the envelope in the reducing of the building's maintenance costs.

26.5.5 Key Indicators Summary

The key indicators that play the most important role in the evaluation of the energy efficiency improvement of the building are summarized in Table 26.2. By com-paring the indicators of the actual scenario (existing condition) and the improved scenario, it can be concluded that the proper building renovation can significantly reduce energy consumption, emissions, financial costs, and improve the general energy performance of the building.

26.6 Conclusion

Reducing the building's energy consumption and greenhouse gases, lowering the financial costs, improving the thermal comfort and lifespan of the building, are both energy efficiency and CE key indicators which must be analyzed before the renovation of existing buildings. All of the above mentioned key indicators are analyzed in this paper in order to evaluate the improvement of the energy performance of an existing building after its renovation. For that purpose, a simulation of both, the existing condition of the building and the improved renovated scenario with new façade material application were made. The results showed that the buildings energy efficiency is significantly improved in terms of reducing the heating energy consumption by 65%, electrical energy consumption by 40%, CO_2 emissions by 55%, PM10 particles by 46%, and the financial costs by 49%. It can be concluded that the key indicators play a big role in the energy efficiency and CE improvement evaluation.

References

1. EEA (2022) Building renovation: where circular economy and climate meet. Eur Environ Agency
2. Amal A. Al-Shargabi, Abdulbasit Almhafdy, Dina M Ibrahim, Manal Alghieth, Francisco Chiclana (2022) Buildings' energy consumption prediction models based on buildings' characteristics: Research trends, taxonomy, and performance measures, J Build Eng, 54
3. Abergel T, Dean B, Dulac J, Hamilton I, Wheeler T (2018) Global status Report—Towards a zero-emission, efficient and resilient buildings and construction sector
4. Röck M Ruschi M, Saade M, Balouktsi M, Rasmussen Nygaard F, Birgisdottir H, Frischknecht R, Habert G, Lützkendorf T, Passer A (2020) Embodied GHG emissions of buildings—The hidden challenge for effective climate change mitigation, Appl Energy, 258
5. Krstic H, Marenjak S (2020) Analysis of buildings operation and maintenance costs, UDK 624.012.004.5:69.003.12, Gradzevinar 4
6. Curto DD, Cinieri V (2020) Aerogel-based plasters and energy efficiency of historic buildings. Literature review and guidelines for manufacturing specimens destined for thermal tests. Sustain 2020, 12, 9457; https://doi.org/10.3390/su12229457
7. Stahl Th, Brunner S, Zimmermann M, Ghazi WK (2016) Thermo-hygric properties of a newly developed aerogel based insulation rendering for both exterior and interior applications. Energy Build, 44, pp 114–117
8. Handojo DU, Xiaodong L, Eng TJN (2022) Sustainable production in circular economy: aerogel upscaling production. Environ Sci Pollut Res 29:20078–20084, Springer
9. Carty L (2017) Analysis of the effects of aerogel insulation on the thermal performance of existing building envelopes, Edinb Napier Univ, 09013398
10. Ganobjak M (2019) Aerogel materials for heritage buildings: Materials, properties and case studies. J Cult Herit, Elsevier
11. Castro-Díaz M, Osmani M, Cavalaro S, Parker B, Lovato T, Needham P, Thompson J, Philippe K, Ruiz F (2022) Impact of circular silica aerogel on plasterboard recycling. loughborough university. In: Conference Contribution. https://hdl.handle.net/2134/21435765.v1
12. Ibrahim MP, Biwole HP, Achard P, Wurtz E, Ansart G (2015) Building envelope with a new aerogel-based insulating rendering: Experimental and numerical study, cost analysis, and thickness optimization. Appl Energy 159:490–501
13. Strand KR, Crawley BD, Pedersen OC, Liesen JR, Lawrie KL, Winkelmann FC, Buhl WF, Huang YJ, Fisher ED (2016) EnergyPlus: A New-Generation Energy Analysis and Load Calculation Engine for Building Design, Conference: ACSA Technology Conference. Massachusetts, Cambridge