# Evaluation of Energy Renovation Measures for Hospital Buildings using the PSI Method

**Dzana Kadric**
Faculty of Mechanical Engineering, University of Sarajevo, Bosnia and Herzegovina
mulahasanovic@mef.unsa.ba (corresponding author)

**Rejhana Blazevic**
Faculty of Mechanical Engineering, University of Sarajevo, Bosnia and Herzegovina
muhamedagic@mef.unsa.ba

**Hadis Bajric**
Faculty of Mechanical Engineering, University of Sarajevo, Bosnia and Herzegovina
bajric@mef.unsa.ba

**Edin Kadric**
Faculty of Mechanical Engineering, University of Sarajevo, Bosnia and Herzegovina
kadric@mef.unsa.ba

*Received: 25 October 2023 | Revised: 13 November 2023 | Accepted: 15 November 2023*

## ABSTRACT

**This study investigated the potential for energy savings and reduction in $CO_2$ emissions in hospital buildings in Bosnia and Herzegovina (B&H), through the implementation of energy renovation measures. The building sector in B&H is characterized by significant energy consumption, and hospitals account for a substantial portion of the total energy consumption in public buildings. This study analyzes certain energy renovation measures for selected hospital buildings, including the installation of thermal insulation on exterior walls and flat roofs, and the installation of a photovoltaic plant on the flat roof. The Preference Selection Index (PSI) multicriteria decision-making method was employed to evaluate and rank renovation scenarios based on energy, environmental, and financial criteria. The results indicate that the most preferred measure is the installation of a photovoltaic plant on a flat roof, resulting in significant primary energy and $CO_2$ savings, with an acceptable discounted payback period. The findings emphasize the effectiveness of energy renovation measures in enhancing energy efficiency and reducing the environmental impact of hospital buildings in B&H.**

***Keywords-hospital building; multicriteria analysis; PSI; energy consumption; energy efficiency, renewable energy; photovoltaic plant***

## I. INTRODUCTION

The building sector in Bosnia and Herzegovina (B&H), is the leading energy consumer, exceeding both the transport and industry sectors [1]. This sector is characterized by buildings with significant losses in transmission and ventilation, and thermal systems with low overall efficiency, suggesting substantial potential for energy savings through energy renovation measures [2-3]. In recent years, numerous renovation projects have been implemented in the B&H public sector, highlighting the need to improve energy efficiency in public buildings. The healthcare buildings in B&H [4] include a significant number of hospital buildings, representing 13% of the total heated area of all public buildings [3]. Within healthcare buildings, buildings constructed between 1974 and 1987 account for 44% of the total heated area and 50.6% of the total energy consumption, offering substantial potential for energy savings. Hospital buildings, due to their specific purpose, occupational regime, and design parameters with high internal temperature, are of particular importance and require careful analysis, especially to ensure appropriate internal microclimatic conditions [4]. As the energy consumption of hospital buildings is high, there is a significant potential for energy savings through the implementation of active and passive energy restoration measures [5-8]. These measures can lead to improved energy efficiency, reduced greenhouse gas (GHG) emissions, and an overall improvement in building structures [9]. In [6], a novel concept called "70-70-70" was proposed to significantly reduce GHG emissions in hospitals and contribute to the global goal of achieving a clean and climate neutral environment by 2050. This concept aims to achieve three key targets: a 70% reduction in the building's GHG emissions, utilization of renewable energy for 70% of the total energy consumption, and a 70% increase in the building's energy efficiency. This concept was tested in two existing buildings, showing that the proposed solutions led to a reduction of more than 70% in annual primary energy consumption. In [7], a survey was conducted in 12 hospitals and 70 healthcare centers in Spain, built between 1980 and 2005. This study focused on electric energy, Heating Ventilation and Air-Conditioning (HVAC), Domestic Water Heating (DWH), lighting systems, renewable energy, maintenance strategy, thermal insulation, and optimal building size. The study concluded that it is possible to save a significant amount of energy in healthcare buildings. In [8], focus was given on identifying and classifying passive strategies for energy optimization in the design of sustainable hospitals and health centers. This study was carried out in hospitals located in Shiraz, Iran, and used questionnaires, interviews, and literature as information-collecting tools. The data were analyzed using two Multi-Criteria Decision-Making (MCDM) methods: the Best-Worst Method (BWM) and Evaluation based on the Distance from the Average Solution (EDAS). The identified passive strategies were classified into three groups, thermal, acoustic, and lighting strategies, and each category was then prioritized. The most important selection criteria were "Reducing Energy Consumption", "Compatibility with Climate", and "Durability". The most suitable passive strategies in the thermal, acoustic, and lighting groups were "Optimizing Fenestration Design", "Using Naturally Ventilated Envelope", and "Using Sun Shading Devices", respectively. The study concluded that applying its results in the design of hospitals and health centers could reduce energy consumption.

The current study aims to analyze the best energy renovation scenario for a hospital building, using the Preference Selection Index (PSI) MCDM. MCDM is widely used in engineering [10-11] to support the decision-making process. The versatility of MCDM in the field of energy production and utilization is confirmed by its successful application of a modified VIKOR method [12], providing a comprehensive analysis of the optimal energy mix for national or local communities. The selected hospital building was constructed in 1980, with energy-inefficient envelope characteristics and thermotechnical systems. Seven scenarios were considered and evaluated, consisting of individual and combined measures, including energy renovation of the envelope and installation of a photovoltaic plant on a flat roof. For each scenario, the primary energy, carbon footprint, investment cost, and Discounted Payback Period (DPP) were calculated, which were also considered as MCDM criteria to evaluate and rank the renovation scenarios.

## II. METHODOLOGY

### A. Building Data

The selected hospital building is located in Sarajevo, B&H, and is part of a large hospital complex of 35,800 m$^2$ of heated area, while the building itself has 4,883 m$^2$ of heated area (13.6% of the total hospital building complex). The hospital complex is equipped with a central boiler room with highly efficient industrial steam boilers, with energy for heating and DWH supplied to the buildings via heating substations. Natural gas is used as a fuel and the system efficiency of the components, including the boiler room and the heating substation, is 95.04%. Two water tanks are installed at the heating substation for the DWH system. A radiator heating system is used for building heating without a mechanical ventilation system. The efficiency of the heating system inside the building (regulation and distribution system) is 98%, therefore the overall system efficiency including the boiler room, distribution, and internal installations and components is 93.1%. A central cooling system is installed, but it only serves a small portion of the building.

Fig. 1. Visual representation of the selected hospital building.

The building was constructed in 1980, and consists of a basement, ground floor, and four floors, with a flat roof, as shown in Figure 1. The building occupational regime is established on a permanent basis, with 365 operating days a year and 24 operating hours a day. In 2017-2018, old windows with aluminum profiles were replaced with new wooden frame windows. The new windows have a triple-pane insulating glass filled with argon and a heat transfer coefficient of 1.0 W/m$^2$K, aligned with the national regulations that target a $U_{win}$ of 1.4 W/m$^2$K for new windows installed in existing properties [4]. The energy renovation resulted in a reduction in heat loss and improved thermal comfort. However, no other energy renovation measures were implemented, leading to ongoing energy losses due to the low energy efficiency of the building envelope. Table I provides details about the building structure, including the total area of the base, the heated surface area, and the compactness ratio of the building. Table I also provides the heat transfer coefficients of the key construction elements. The external wall was constructed of clay blocks, without any thermal insulation. The flat roof was constructed from a reinforced concrete slab with 4 cm of thermal insulation. Based on [4], it was determined that the heat transfer coefficient of the external wall was significantly higher than the requirements set by national regulations, implying that this building's elements contribute to excessive energy losses.

TABLE I. DATA ON BUILDING GEOMETRY AND HEAT TRANSFER COEFFICIENT OF CONSTRUCTION ELEMENTS

| **Building parameters** | **Value** |
|---|---|
| Number of floors | B+G+4 |
| Net area of the heated space | 4,698 $m^2$ |
| The volume of the heated space | 16,787 $m^3$ |
| Building compactness ratio | 0.28 |
| External wall surface area | 2,260 $m^2$ |
| Heat transfer coefficient of external wall | 1.698 $W/m^2K$ |
| Windows surface area | 1,216 $m^2$ |
| Heat transfer coefficient of windows | 1.0 $W/m^2K$ |
| Roof surface area | 923 $m^2$ |
| Heat transfer coefficient of roof | 0.602 $W/m^2K$ |

### B. Modeling of Building Energy Performance

The energy performance of the building was modeled with the DesignBuilder software and its integrated EnergyPlus simulation tool [13]. Figure 2 shows a 3D model of the hospital building designed in DesignBuilder.

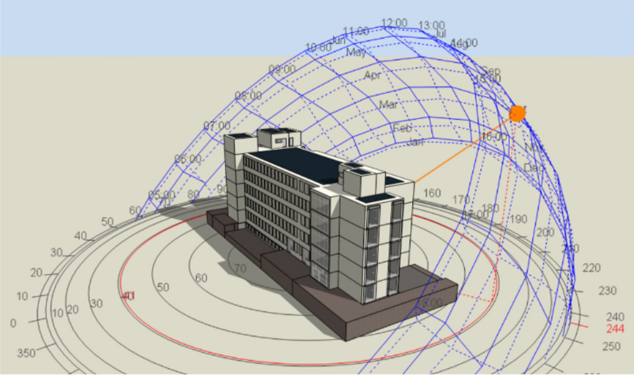

Fig. 2. 3D model of hospital building.

EnergyPlus uses hourly data for environmental conditions and calculations. Climatic data, monitored by the National Meteorological Service, include air temperature, atmospheric conditions, solar radiation, wind speed and direction, and are specific to the analyzed location (Sarajevo). The city is in a northern climate zone, with 43.85 latitude and 18.14 longitude, characterized by hot summers and cold and snowy winters. The Heating Degree Days (HDD) value for Sarajevo is 3,077. The warmest month is typically July, with an average temperature of 20.8°C, while the coldest month, January, averages 0.7°C. Solar radiation is highest in July and lowest in December [14]. Climatic data are essential to understanding the energy performance of buildings, as they directly impact heating and cooling needs and the potential for solar energy utilization.

The zoning of the building's interior space is performed according to the hospital layout with internal design temperatures of each zone specified by the BAS EN 12831 standard. The simulation results include the energy needs for heating, DWH, and electrical energy. The energy consumption of the cooling system is included in the electrical energy consumption, under the assumption that cooling is facilitated by devices with a coefficient of performance of 3. The total primary energy $E_{Prim}$ is calculated using the following equation:

$$E_{Prim} = \frac{Q_{H,nd}+Q_{DWH}}{\eta_{sist}} f_{p,gas} + E_{El} f_{p,el} \tag{1}$$

where $E_{Prim}$ is the building's annual primary energy (kWh/a), $Q_{H,nd}$ is the annual energy need for heating (kWh/a), $Q_{DWH}$ is the annual energy need for DWH (kWh/a), $\eta_{sist}$ is the overall system efficiency (%), $E_{El}$ is the annual electrical energy consumption from the electrical grid (kWh/a), and $f_p$ is the fuel primary energy factor (1.1 for natural gas and 1.614 for electricity) [4]. The annual $CO_2$ emissions are calculated by:

$$m_{\mathrm{CO2}} = \frac{Q_{\mathrm{H,nd}}+Q_{\mathrm{DWH}}}{\eta_{\mathrm{sist}}} c_{\mathrm{p,gas}} + E_{\mathrm{El}} c_{\mathrm{p,el}} \tag{2}$$

where $m_{CO2}$ is the annual $CO_2$ emission (kg/a) and $c_p$ is the fuel $CO_2$ coefficient per unit of energy (0.2 kg/kWh for natural gas and 0.745 kg/kWh for electricity) [4]. Electrical energy is calculated as the total electric energy reduced by the electricity generated from the photovoltaic plant, which impacts the reduction of $CO_2$ emissions as well.

### C. Energy Renovation Measures

To reduce the energy consumption and carbon emissions of the building, certain energy renovation measures were analyzed, including the installation of thermal insulation on the external walls and flat roof, and the installation of a photovoltaic plant on the flat roof. Previous energy-saving initiatives included window replacement, lighting system upgrades, and the installation of a modern central heating plant with new gas boilers. The current focus was on enhancing envelope characteristics and thermal comfort and incorporating renewable energy systems. These immediate energy-saving measures could be followed by future analysis of other energy-saving strategies, all to create a clean, climate-neutral environment.

The first measure (M1) considers the installation of 20 cm of rock wool as thermal insulation on the external wall. Rock wool is known for its excellent thermal properties, characterized by a low thermal conductivity of 0.033 W/mK, and offers additional benefits such as improved acoustics, indoor comfort, and fire safety. Implementing this measure will accordingly reduce the external wall heat transfer coefficient, improving the thermal comfort of the building by minimizing heat losses. Insulation will protect the building construction against weathering, thus increasing its lifespan. The cost of investment for this measure is € 101,023. The second measure (M2) considers installing thermal insulation on the flat roof using 25 cm perlite board with a thermal conductivity of 0.052 W/mK. As a result, the heat transfer coefficient of the roof will decrease, reducing heat loss through the roof surface area. The estimated investment cost for this measure is € 63,575. Installation of a photovoltaic plant on a flat roof is the third measure (M3). The surface area available for the installation of photovoltaic panels is an essential factor in determining the plant power output, which in this case is estimated to be 80 kW. The panels should be strategically oriented to the south and mounted at an optimal angle to maximize energy production. Photovoltaic panels convert solar energy into electrical energy, thereby providing a renewable source of electricity and reducing energy costs and carbon footprint. The estimated cost of investment for this measure is € 57,905.

The cost of investment for all three measures includes all associated expenses such as labor, materials, and actions involved in the renovation process, including demolition, assembly, installation, and disposal of materials and equipment. This method was selected due to its detailed approach, which considers a wide range of factors and costs associated with an investment [15] and ensures that the calculated cost is realistic and reflects all aspects of the investment process. In the context of a multicriteria analysis, individual measures are evaluated separately and combined into groups, resulting in seven renovation scenarios. For each scenario, the resulting primary energy, carbon footprint, and investment cost were calculated.

### *D. Financial Indicators*

The Discounted Payback Period (DPP) was used to evaluate the profitability of the renovation scenarios. This measures the time it takes for the initial investment to be returned in terms of discounted cash flows, thus considering the time value of money. DPP is a valuable tool in capital budgeting, helping businesses make informed investment decisions. The average cost of the final energy for natural gas and electricity was determined from hospital bills and was 0.072 €/kWh and 0.097 €/kWh, respectively. Using these data, the annual energy cost and the annual energy cost savings were calculated for each renovation scenario. In this study, the DPP was calculated using the method of [16], with a capital cost of 5.5%. A shorter DPP indicates a quicker return on the initial investment.

### *E. Preference Selection Index Method*

The Preference Selection Index (PSI) is a MCDM technique used to solve various decision-making problems without the need to assign relative importance or weights to criteria [17]. The PSI method has been used to solve decision-making problems in various fields, such as material selection [18], manufacturing [19], solar system application possibilities [20], etc. Compared to other MCDM methods, PSI is simpler and less computationally demanding. The procedure of evaluating and ranking the alternatives with the PSI method is described below.

- Step 1 - Definition of decision matrix: For a decision-making problem with $m$ alternatives and $n$ criteria, the decision matrix can be defined in the following mathematical form:

$$X = [x_{ij}]_{m\times n} = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \quad (3)$$

where $x_{ij}$ is the performance of alternative $i$ concerning criterion $j$.

- Step 2 - Decision matrix normalization: The decision matrix is normalized using the max normalization method depending on the type of criteria. The normalized performances of alternatives are calculated using the following equation:

$$R = [r_{ij}]_{m\times n} = \begin{cases} \frac{x_{ij}}{max_i x_{ij}} & j \in \mathcal{B} \\ \frac{min_i x_{ij}}{x_{ij}} & j \in \mathcal{C} \end{cases} \quad (4)$$

where $\mathcal{B}$ is beneficial and $\mathcal{C}$ non-beneficial criteria.

- Step 3 - Calculation of preference variation: The preference variation for each criterion is calculated using the following equation:

$$\text{PV} = [pv_j]_{1\times n} = \sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2 \quad (5)$$

where $\bar{r}_j$ is the mean of the normalized criterion $j$ and:

$$\bar{r}_j = \frac{1}{m}\sum_{i=1}^{m} r_{ij}.$$

- Step 4 - Determination of overall preference: In this step, the overall performance is calculated for each criterion. Before calculating the overall preference, it is necessary to first calculate preference deviation $\Phi = [\phi_j]_{1\times n}$ in the preference value PV. The deviation in the preference value of each criterion is calculated by:

$$\Phi = [\phi_j]_{1\times n} = 1 - pv_j \quad (6)$$

The overall preference of each criterion is calculated by:

$$\Psi = [\psi_j]_{1\times n} = \frac{\phi_j}{\sum_{j=1}^{n}\phi_j} \quad (7)$$

The sum of overall preferences for all criteria is equal to 1:

$$\sum_{j=1}^{n}\psi_j = 1$$

- Step 5 - Calculation of PSI: The PSI for each alternative is calculated by:

$$\text{PSI} = [psi_i]_{m\times 1} = \sum_{j=1}^{n} r_{ij}\psi_j \quad (8)$$

- Step 6 - Ranking alternatives: Alternatives are ranked according to their PSI in descending order so that the alternative with the highest PSI is ranked the first and the alternative with the lowest PSI is the last.

## III. RESULTS AND DISCUSSION

For each renovation scenario, the resulting primary energy, carbon footprint, cost of investment, energy cost savings, and DPP were calculated.

### *A. Building Energy Performances of Renovation Scenarios*

Table II presents the building parameters, including the heat transfer coefficients of the walls and roofs, before and after the renovation, and the installed power of the photovoltaic system. Data show that the implementation of measures M1 and M2 results in a decrease in the heat transfer coefficient of the building envelope, following the national regulations [4]. The installed power of the photovoltaic plant is 80 kW.

TABLE II. BUILDING PARAMETERS BEFORE AND AFTER RENOVATIONS

| Measure | Parameter | Baseline | After renovation | Target value [4] |
|---|---|---|---|---|
| M1 - Thermal insulation on exterior wall | $U_{wall}$ W/m$^2$K | 1.698 | 0.272 | 0.35 |
| M2 - Thermal insulation on flat roof | $U_{roof}$ W/m$^2$K | 0.602 | 0.218 | 0.25 |
| M3 - Photovoltaic plant | $P_{PV}$ kW | 0 | 80 | - |

Table III shows the calculated values of the primary energy, $CO_2$ emissions, cost of investment, and DPP for each renovation scenario. It also shows the energy cost savings associated with each renovation scenario.

TABLE III. RESULTING ENERGY, ENVIRONMENTAL AND FINANCIAL INDICATORS

| Scenario | $E_{prim}$ (MWh/a) | $CO_2$ (t/a) | Investment (€) | Cost savings (€/a) | DPP year |
|---|---|---|---|---|---|
| Baseline | 1,780 | 477.8 | - | - | - |
| S1: M1 | 1,565 | 438.9 | 101,023 | 14,206 | 9.3 |
| S2: M2 | 1,718 | 466.5 | 63,575 | 4,067 | 36.8 |
| S3: M1,2 | 1,527 | 432.5 | 164,598 | 18,273 | 12.9 |
| S4: M3 | 1,642 | 413.2 | 57,905 | 8,287 | 9.1 |
| S5: M1,3 | 1,427 | 374.3 | 158,928 | 22,492 | 9.2 |
| S6: M2,3 | 1,580 | 402.0 | 121,480 | 12,354 | 14.7 |
| S7: M1,2,3 | 1,389 | 367.9 | 222,503 | 25,007 | 12.7 |

Implementing the M1 measure results in an annual savings of 215 MWh of primary energy with a DPP of 9.3 years. Implementing the M2 measure results in the least primary energy savings, approximately 62 MWh per year. This measure also has a significantly longer DPP, which is expected since the existing roof structure already includes 4 cm of thermal insulation. Therefore, the implementation of this measure leads to modest savings in energy and $CO_2$ emissions with a significant investment cost. Implementing measure M3 results in high primary energy savings and the highest $CO_2$ emission savings compared to the other two measures, exhibiting the shortest DPP. The S5 renovation scenario, which involves installing thermal insulation on the exterior walls (M1) and photovoltaic panels on the roof of the building (M3), yields very high primary energy savings and the second shorter DPP, 353 MWh annually and 9.2 years, respectively. These findings indicate that the selected renovation scenario results in a reduction in building energy consumption and an improvement in energy and environmental indicators. This emphasizes the effectiveness of these measures in improving the energy efficiency of the building.

### *B. Multicriteria Analysis of Renovation Scenarios*

The PSI method was used to rank all seven scenarios. Primary energy, $CO_2$ emission, cost of investment, and DPP were considered non-beneficial criteria and were minimized in the performed analysis. PSI was calculated for each scenario, and scenarios were ranked from 1 (best solution) to 7 (worst solution), as shown in Table IV and Figure 3, which display the scenario rankings and their corresponding PSI values. The best energy renovation scenario was S4 (M3), the installation of a photovoltaic plant on a flat roof, with the highest PSI value of 0.9147. The second-best scenario was S5 (M1+M3), installing thermal insulation on external walls (M1) and photovoltaic panels on the building's roof (M3), ranked as a better solution than solely implementing M1. The S1 (M1) scenario, installing thermal insulation on external walls, ranked third with a PSI value of 0.8356. Installing thermal insulation on a flat roof (S2) ranked seventh with a PSI value of 0.7154. This is expected, as M2 results in the smallest primary energy and $CO_2$ savings and has a very long DPP.

TABLE IV. RANKING OF RENOVATION SCENARIOS

| Scenario | Measure | PSI | Rank |
|---|---|---|---|
| S4 | M3 | 0.9147 | 1 |
| S5 | M1+M3 | 0.8768 | 2 |
| S1 | M1 | 0.8356 | 3 |
| S7 | M1+M2+M3 | 0.8229 | 4 |
| S6 | M2+M3 | 0.7747 | 5 |
| S3 | M1+M2 | 0.7589 | 6 |
| S2 | M2 | 0.7154 | 7 |

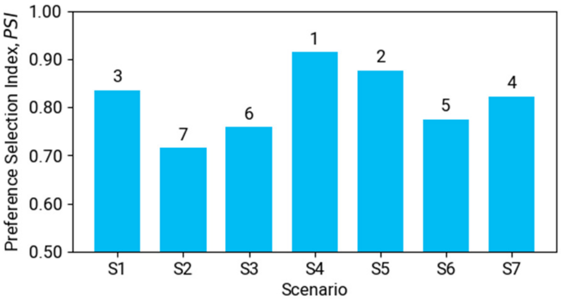

Fig. 3. PSI of renovation scenarios.

Figure 3 shows a visual representation of the PSI values for all the renovation scenarios analyzed. As previously shown in Table IV, the highest PSI was obtained for S4, representing the measure M3, the installation of a photovoltaic plant on a flat roof. The lowest PSI was obtained for S2, representing measure M2 (installing thermal insulation on the flat roof).

## IV. CONCLUSION

This study analyzed the benefits of implementing energy renovation measures in a hospital building in Bosnia and Herzegovina, revealing that there is substantial potential for energy and $CO_2$ savings. The analysis considered certain energy renovation measures, including the installation of thermal insulation on the exterior wall and the flat roof, and the installation of a photovoltaic plant on the roof. Based on these measures, seven scenarios were generated, consisting of individual measures or their combinations. The resulting primary energy, $CO_2$ emissions, cost of investment, and DPP were calculated for each renovation scenario. The results demonstrated that energy renovation measures can significantly improve the energy efficiency of hospital buildings, reduce emissions, and contribute to the global objective of achieving a clean and climate-neutral environment, with acceptable DPP. The PSI method was used to evaluate and rank the scenarios and select the best one. The results indicated that the most preferred scenario was S4 - installation of a photovoltaic plant on the flat roof, resulting in a significant reduction in primary energy and carbon footprint and the shortest DPP of 9.1 years. The second-best scenario was S5 - installing thermal insulation on the exterior walls and photovoltaic panels on the building's roof, resulting in very high primary energy and $CO_2$ savings with adequate DPP. In conclusion, the evaluation and ranking of renovation scenarios can be successfully performed using the PSI method considering energy, environmental, and financial criteria. The proposed method illustrates the effectiveness of MCDM methods in optimizing the energy renovation process in buildings. These methods are adaptable to a variety of technologies, conditions, and data availability, thus offering a broad spectrum of practical uses and strategic decision-making processes. Future studies could include combined methods of Life Cycle Assessment (LCA) and MCDM in a similar research problem.

## REFERENCES

[1] "5th Annual Report under the Energy Efficiency Directive," Ministry of Foreign Trade and Economic Relations, Sarajevo, Boznia and Herzegovina, Oct. 2021.

[2] D. Arnautovic-Aksic *et. al.*, "Typology of Residential Buildings in Boznia and Herzegovina," Energetska Efikasnost, Sarajevo, Boznia and Herzegovina, 2016.

[3] M. Nišandžić, "Typology of Public Buildings in Boznia and Herzegovina," United Nations Development Program, 2017.

[4] "Rulebook on minimum requirements for energy performance of buildings," Official Gazette of Federation of Boznia and Herzegovina, 81/19, 2019.

[5] A. Buonomano, F. Calise, G. Ferruzzi, and A. Palombo, "Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings," *Energy*, vol. 78, pp. 555–572, Dec. 2014, https://doi.org/10.1016/j.energy.2014.10.042.

[6] M. Prada *et al.*, "New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance – Hospitals," *Science of The Total Environment*, vol. 718, May 2020, Art. no. 137446, https://doi.org/10.1016/j.scitotenv.2020.137446.

[7] J. García-Sanz-Calcedo, A. Al-Kassir, and T. Yusaf, "Economic and Environmental Impact of Energy Saving in Healthcare Buildings," *Applied Sciences*, vol. 8, no. 3, Mar. 2018, Art. no. 440, https://doi.org/10.3390/app8030440.

[8] A. Balali and A. Valipour, "Prioritization of passive measures for energy optimization designing of sustainable hospitals and health centres," *Journal of Building Engineering*, vol. 35, Mar. 2021, Art. no. 101992, https://doi.org/10.1016/j.jobe.2020.101992.

[9] F. A. AlFaraidy and S. Azzam, "Residential Buildings Thermal Performance to Comply With the Energy Conservation Code of Saudi Arabia," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3949–3954, Apr. 2019, https://doi.org/10.48084/etasr.2536.

[10] T. Eldamaty, A. G. Ahmed, and M. M. Helal, "GIS-Based Multi Criteria Analysis for Solar Power Plant Site Selection Support in Mecca," *Engineering, Technology & Applied Science Research*, vol. 13, no. 3, pp. 10963–10968, Jun. 2023, https://doi.org/10.48084/etasr.5927.

[11] S. Alshehri, "Multicriteria Decision Making (MCDM) Methods for Ranking Estimation Techniques in Extreme Programming," *Engineering, Technology & Applied Science Research*, vol. 8, no. 3, pp. 3073–3078, Jun. 2018, https://doi.org/10.48084/etasr.2104.

[12] M. Mrkić-Bosančić, S. Vasković, and P. Gvero, "Optimization of energy mix and possibilities of its application in energy transition using multicriteria approach," *Thermal Science*, vol. 27, no. 3 - Part B, pp. 2501–2512, 2023, https://doi.org/10.2298/TSCI221013224M.

[13] "DesignerBuilder v. 6.1.8.0.21" [Online]. Available: https://designbuilder.co.uk/download/previous-versions/425-designbuilder-v6-1-8-021-1/file.

[14] "The Weather Year Round Anywhere on Earth - Weather Spark." https://weatherspark.com/.

[15] D. Kadrić, A. Aganovic, S. Martinović, N. Delalić, and B. Delalić-Gurda, "Cost-related analysis of implementing energy-efficient retrofit measures in the residential building sector of a middle-income country – A case study of Bosnia and Herzegovina," *Energy and Buildings*, vol. 257, Feb. 2022, Art. no. 111765, https://doi.org/10.1016/j.enbuild.2021.111765.

[16] S. B. Bhandari, "Discounted Payback Period-Some Extensions," in *ASBBS Annual Conference Proceedings*, Las Vegas, NV, USA, 2009, vol. 16.

[17] K. Maniya and M. G. Bhatt, "A selection of material using a novel type decision-making method: Preference selection index method," *Materials & Design*, vol. 31, no. 4, pp. 1785–1789, Apr. 2010, https://doi.org/10.1016/j.matdes.2009.11.020.

[18] P. V. Reddy, R. M. Reddy, P. S. Rao, D. M. Krishnudu, R. V. S. Reddy, and A. E. Kumar, "Parameters Selection for Enhanced Mechanical and Wear Properties of Natural Fiber Reinforced Hybrid Composites Using PSI Technique," *Journal of Natural Fibers*, vol. 19, no. 15, pp. 10111–10125, Nov. 2022, https://doi.org/10.1080/15440478.2021.1993484.

[19] R. Attri and S. Grover, "Application of preference selection index method for decision making over the design stage of production system life cycle," *Journal of King Saud University - Engineering Sciences*, vol. 27, no. 2, pp. 207–216, Jul. 2015, https://doi.org/10.1016/j.jksues.2013.06.003.

[20] A. Kashani Lotfabadi, A. Hajinezhad, A. Kasaeian, and S. F. Moosavian, "Energetic, economic, environmental and climatic analysis of a solar combisystem for different consumption usages with PSI method ranking," *Renewable Energy*, vol. 197, pp. 178–196, Sep. 2022, https://doi.org/10.1016/j.renene.2022.07.134.