Defining Criteria for the Selection of Measures to Increase Energy Efficiency in Public Buildings

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Abstract. Buildings, although one of the largest energy consumers in the world, also represent big potential to reduce energy consumption, dependence on fossil fuels and carbon dioxide emissions, through the implementation of energy efficiency measures. Improvement of energy efficiency of existing buildings requires a dedicated, serious and detailed approach. Investors are often guided by economic criteria, which greatly influence on investments and interventions, potentially causing some negative side effects (comfort reduction, use of energy-intensive materials, etc.). Therefore, it is very important to rely on methods that provide detailed and affordable cost, technical and environmental analysis. Energy efficiency methods are often based on simple methods such as research, estimation of energy consumption, preliminary design, estimation of energy savings and financial cost-effectiveness. For example, in energy audits of buildings, annual energy consumption and cost-effectiveness are considered for analysis. For a more detailed assessment, a calculation tool based on the calculation of energy consumption of particular facility and the estimation of energy savings after the proposed energy efficiency measures is being used. The proposed measures generally represent a classic scenario of energy efficiency measures. In this paper, factors such as comparison of the share of fossil fuels and renewable energy sources (RES), the estimation of cost-effectiveness of the use of renewable energy technologies, aspect of embodied energy in materials and life cycle assessment in buildings are being considered. This paper defines the criteria for the evaluation of scenarios (functional groups of measures) for increasing energy efficiency of the building, which include, in addition to energy and economic aspects, environmental aspect. The six criteria have been defined for evaluation of energy efficiency scenarios related to: annual energy consumption, total annual primary energy, share of RES in primary energy, direct and indirect carbon emissions, embodied energy in applied materials and investment per scenario. For each criteria an expression for its calculation is given. Defined criteria are calculated for six scenarios of increasing the energy efficiency of Mechanical Engineering Faculty, University of Sarajevo. Based on the calculated different values of criteria of considered aspects, it is possible to identify in more detail way critical points, advantages and disadvantages of different combinations of energy efficiency measures, which can further serve to identify the best strategy necessary for evaluation of energy performance of the building before and after the intervention.

1. Introduction

Buildings, although one of the largest energy consumers in the world, also represent big potential to reduce energy consumption, dependence on fossil fuels and carbon dioxide emissions, through the implementation of energy efficiency measures. The developers of regulatory and legal documentation on the energy efficiency of buildings, determine the energy building efficiency as a property of an object
and its engineering systems to ensure a given level of thermal energy consumption to maintain optimal parameters of the indoor microclimate. Energy efficiency gains are achieved through the use of effective thermal insulation, the heat pumps installation, modern window frames and doors that prevent losing of the warm air, the use of high-efficiency boiler plants and internal temperature control devices [1]. During the planning measures for energy efficiency improvement of the building, it is not uncommon to come up with conflict aims and interest, and due to it, it is necessary to find balance to achieve well-planned energy concept, without compromising indoor quality environment or external environment.

Building management is very often in difficult position in situation when there is a need to improve building condition from the energy aspect, due to the limited budget or it is often guided by economic logic, which greatly influences investments, and interventions, causing some negative side effects (comfort reduction, use of energy-intensive materials, lack of adequate cooling system etc.). Conceptual phase of building design is the best time for integration of sustainable strategies [2]. Improvement of energy efficiency of existing buildings requires a dedicated and serious approach, based on methods that provide detailed and affordable cost, technical and environmental analysis. When these mechanisms are incorporated in initial phase of construction, implementation costs are reduced in comparison when it would be implemented in later stages of construction. Design of building with the aim to achieve efficient usage of energy, decreases economic costs during the period of building use due to the decrease of energy consumption, which is compensated in large part with the initial higher investment [2].

Energy efficiency methods are often based on simple methods such as research, estimation of energy consumption, preliminary design, estimation of energy savings and financial cost-effectiveness. Analysis are often hampered by heterogeneity and insufficient reference data [3]. For example, in energy audits of buildings, annual energy consumption and cost-effectiveness are considered for analysis. For a more detailed assessment, a calculation tool based on the calculation of the energy consumption of particular facility and the estimation of energy savings after the proposed energy efficiency measure is being used. The proposed measures generally represent a classic scenario of energy efficiency measures. In the analysis, factors such as comparison of the share of fossil fuels and renewable energy sources (RES), the estimation of cost-effectiveness of the use of renewable energy technologies or the aspect of embodied energy in materials and life cycle assessment in buildings are rarely considered. Very often buildings after implementation of only certain energy efficiency measures, after some period and especially when there are higher outside temperatures, feel a lack of adequate cooling system, when natural ventilation is not good enough to achieve inside comfort.

Approach to the building as complete system encourages designers to treat building as a whole, as one body or one system, in which all its individual parts constantly influence each other and depend on each other [4]. With an integrated approach to implementation of energy efficiency measures by respecting regulations and standards for buildings, provides a quality and healthy inside environment, without the risk of higher energy consumption and environmental pollution.

2. Defining criteria for evaluation of the energy efficiency measures
All the factors that influence on the decision are considered as criteria whose values should be optimal [5, 6]. It is necessary to find a solution that is the best according to all considered criteria at the same time, and the fact is that some are partially or completely conflicting at almost all levels of decision-making [7].

The following criteria for evaluation of energy renovation scenario of a building have been defined:

1. Annual energy demand for heating, cooling and sanitary water (kWh/a)
2. Primary energy consumption (kWh/a)
3. RES share in total primary energy (percentage)
4. Direct and indirect carbon dioxide emissions (kgCO₂/a)
5. Embodied energy in applied materials (kgCO₂)
6. Amount of investment (BAM).

2.1. Annual energy demand for heating, cooling and sanitary water
Criteria for annual energy demand for heating, cooling and sanitary water of a building are explained in this subsection.

**Calculation of the heating demand of building.** The calculation of annual demand energy for heating of climate zone is the sum of results for certain period (for example months) in one year. Calculation of \( Q_{H,nd} \) includes the following expression [8]:

\[
Q_{H,nd} = Q_{TR} + Q_{Ve} - \eta_{H,n} \cdot (Q_{int} + Q_{sol}) \quad (kW/h/a)
\]  

\( Q_{TR} \) – Modified heat by transmission for the climate zone (kWh/a)

\( Q_{Ve} \) – Heat required for ventilation/air conditioning for climate zone (kWh/a)

\( \eta_{H,gn} \) – Heat loss utilization factor (-)

\( Q_{int} \) – The internal thermal gains of the building (people, devices, lighting) (kWh/a)

\( Q_{sol} \) – Heat gains from solar radiation (kWh/a)

**Calculation of the cooling demand of building.** The energy required for cooling of the climate zone is calculated based on the following expression [8]:

\[
Q_{C,nd} = Q_{C,gn} - \eta_{n,cs} \cdot Q_{C,ht} \quad (kW/h/a)
\]

\( Q_{C,nd} \) – Cooling demand (kWh/a)

\( Q_{C,gn} \) – Total heat gains of building during cooling off period (people, lighting, appliances, solar gains) (kWh/a)

\( Q_{C,ht} \) – Total changed energy during the cooling-off period (kWh/a)

\( \eta_{H,gn} \) – Heat loss utilization factor (-)

Internal heat gains and heat gains from solar radiation are calculated in the same way as calculation of annual demand energy for heating, taking into account the value of internal design temperature, which is in this case taken for cooling period.

**Calculation of heat demand for sanitary water.** Sanitary water consumption depends on the type of building and the comfort needs. The consumption of hot water for particular type of building is given in [9].
The energy required for sanitary water that is delivered to user, depends on the quantity supplied and the water temperature. The energy required is calculated according to the following equation:

\[ Q_{pp} = m_{sw} \cdot c_{sw} \cdot \Delta \theta_{sw} \quad (kJ/(person \cdot a)) \]  

\( m_{sw} \) – Sanitary water demand (litres per person annually)

\( c_{sw} \) – Specific water heat capacity (kJ/kg K)

\( \Delta \theta_{sw} \) – The difference between the sanitary water temperature and the tap water temperature (K)

Based on the known value for sanitary water per person annually, known number of users in a building and the number of days of use, the total annual energy consumption for heating of sanitary water is obtained by the following equation:

\[ Q_{sw} = Q_{pp} \cdot n \cdot \tau \quad (kWh/a) \]  

\( n \) - Number of users in a building

\( \tau \) – Number of days of use

By summing the energy needs for heating, cooling and sanitary water, total energy demand is obtained:

\[ Q_n = Q_{H,nd} + Q_{C,nd} + Q_{sw} \quad (kWh/a) \]  

2.2. Primary energy consumption

Primary energy consumption for heating is defined as ratio between the heat demand and the product of calorific value of a fuel and efficiency of a heating system. It is calculated according to the following expression:

\[ B_{G,H,nd} = \frac{Q_{H,nd}}{H_d \cdot \eta_H} \quad (kg/a) \]  

\( Q_{H,nd} \) - Annual demand for heating (kWh/a)

\( H_d \) – Calorific value of a fuel (kWh/kg)

\( \eta_H \) – Efficiency of heating system

Primary energy consumption for cooling is calculated as ratio between the total annual cooling demand of a building and the coefficient of performance of a cooling system.

\[ E_C = \frac{Q_{C,nd}}{COP} \quad (kWh/a) \]  

\( Q_C \) - Annual demand energy for cooling (kWh/a)

COP – Coefficient of performance of the cooling system

In case that electricity is used for cooling, primary consumption for cooling is calculated as the product of annual electricity consumption \( (E_C) \) for building cooling and the primary energy factor for a country.
\[ E_{C,\text{prim}} = E_C \cdot k_{\text{prim}} \quad (\text{kWh}/\text{a}) \] (8)

\( E_C \) – Annual electricity consumption for cooling of building (kWh/a)

\( k_{\text{prim}} \) – Primary energy factor for electricity

Annual energy consumption for sanitary water is calculated by:

\[ E_{\text{sw}} = \frac{Q_{\text{sw}}}{\eta_{\text{sw}}} \quad (\text{kWh}/\text{a}) \] (9)

\( Q_{\text{sw}} \) – Annual required energy for sanitary water (kWh/a)

\( \eta_{\text{sw}} \) - The total degree of conversion efficiency of primary energy into the required energy for sanitary water

Primary energy consumption for sanitary water is calculated as the product of annual electricity consumption for sanitary water and primary energy factor for a specific country.

\[ E_{\text{sw,prim}} = E_s \cdot k_{\text{prim}} \quad (\text{kWh}/\text{a}) \] (10)

Total primary energy consumption is the sum of primary energy required for heating, cooling and sanitary water:

\[ E_{\text{total}} = B_{G,H,nd} + E_{C,\text{prim}} + E_{\text{sw,prim}} \quad (\text{kWh}/\text{a}) \] (11)

2.3. Share of RES in total primary energy

Expression share of RES in total primary energy is used for electricity and for specific country. The share of RES in energy consumption will be calculated as:

\[ R_{\text{RES}} = \frac{Q_{\text{RES}}}{E_{\text{prim}}} \quad (\%) \] (12)

For calculation of the share of RES in final energy for Bosnia and Herzegovina, according to a data of the Agency of Statistics of Bosnia and Herzegovina, share of RES in power grid is approximately 40%. In a case when the electricity is used for heating, cooling and for sanitary water in Bosnia and Herzegovina, the following expression may be used:

\[ Q_{\text{RES}} = B_{G,H,nd} + 40\% E_{C,\text{prim}} + 40\% E_{\text{sw,prim}} \quad (\text{kWh}/\text{a}) \] (13)

\( B_{G,H,nd} \) – Energy consumption from RES for building heating (kWh/a)

\( E_{C,\text{prim}} \) – Electricity consumption for building cooling (kWh/a)

\( E_{\text{sw,prim}} \) – Electricity consumption for sanitary water (kWh/a)
2.4. Carbon dioxide emissions (direct and indirect)
This criterion takes into account impact of energy consumption on carbon dioxide emission. The annual consumption of an individual fuel or the amount of energy obtained from an individual energy source is multiplied by the corresponding emission factor. Direct emissions are calculated:

\[ E_d = k \cdot m \quad (kgCO_2/a) \]  

\( E_d \) – Fuel emission factor (kgCO\(_2\)/kWh)
\( m \) – Consumption of a fuel (kWh/a)

The calculation of indirect emissions by electricity consumption is calculated according to the following relation:

\[ E_i = k \cdot N \quad (kgCO_2/a) \]  

\( E_i \) – Electrical grid coefficient for pollutant
\( N \) – Consumption of electricity (kWh/a)

2.5. Embodied energy
Considering that the determination of the energy used during the life of the building is a very complex process, and the data for calculation are incomplete and inaccessible, only the embodied energy of thermal insulation materials during the lifetime is considered in the paper.

\[ E_{embodied} = m \cdot E_e \quad (kgCO_2) \]  

\( m \) – Thermal insulation material mass (kg)
\( E_e \) – Carbon dioxide emissions from embodied energy (kgCO\(_2\)/kg)

2.6. Amount of investment
Amount of investment of implemented measures is calculated based on the data from manufactures of materials and equipment, and based on experience in implementation of energy efficiency measures on buildings. Investment cost (I (BAM)) represents the sum of all investments of measures implemented in renovation scenarios.

3. Calculation of defined criteria in a case of the building of Mechanical Engineering Faculty, University of Sarajevo

3.1. Building of Mechanical Engineering Faculty Sarajevo
Mechanical Engineering Faculty represents typical compact architecture of public educational buildings with the clean geometrical form. It was built in 1963. Structural system is consisted from concrete pillars and brick walls. Until 2011, the building was uninsulated. Previous windows were wooden and single-glazed. Roof is flat and does not have any thermal insulation at all. Lack of thermal insulation caused increased heat losses during the winter, colder boundary structural parts of the building, as well as damage caused by moisture and condensation due to thermal bridges.

In 2011, a pilot project was implemented on Faculty as result of the work of UN Joint Program, USAID 3E and Mechanical Engineering Faculty. The project included the repair of the façade, i.e. the installation of thermal insulation (EPS, d=10cm) on the envelope of the building, replacement of the windows with the PVC double glazed and upgrading of the heating system by replacing the existing
boiler. Existing roof and terrace were not thermally insulated, the adequate cooling system has not been provided, and lack of it could feel especially during the warmer period.

In this analysis, initial condition of the building, before implemented energy efficiency measures, was taken as a base point so the model could be universal.

3.2. Scenarios for improvement of energy efficiency of the Mechanical Engineering Faculty building
Scenarios include architectural measures such as thermal insulation of the building envelope, replacing windows, solar radiation protection devices; mechanical measures (selection of heating and cooling system) and implementation of RES technologies in some scenarios (heat pump, biomass boiler, solar panels for sanitary water, photovoltaic power plant). Different thermal insulation materials are used in scenarios because they differ beside insulation properties, price, and by the amount of embodied energy. Organization measures are not the subject of analysis, but it should be part of these measures, that include conceptual phase of designing, raising awareness, education, information, transformation etc.

**Scenario 1 (S1):** façade (EPS), roof (XPS), windows (PVC), solar device (interior shutters), heating system (condensing boiler), cooling system (split systems), ventilation (natural), sanitary water (electrical boilers).

**Scenario 2 (S2):** façade (EPS AF), roof (XPS, double roof), windows (alum), solar device (external blinds), heating system (condensing boiler), cooling system (split systems), ventilation (heat recovery system), sanitary water (electrical boilers).

**Scenario 3 (S3):** façade (hemp), roof (stone wool), windows (wood-alum), solar device (light shelves), heating system (pellet boiler), cooling system (split systems), ventilation (natural), sanitary water (electrical boilers), RES technologies (solar collectors for sanitary water).

**Scenario 4 (S4):** façade (stone wool, ventilation façade), roof (stone wool, green roof), windows (Alum), solar device (light shelves), heating system (combination condensing boiler and heat pump earth-water), cooling system (heat pump), ventilation (natural), sanitary water (heat pump).

**Scenario 5 (S5):** façade (EPS AF), roof (XPS), windows (PVC-alum), solar device (light shelves), heating system (combination condensing boiler and heat pump), cooling system (heat pump), ventilation (heat recovery system), sanitary water (heat pump).

**Scenario 6 (S6):** façade (stone wool), roof (stone wool), windows (wood-alum), solar device (light shelves), heating system (combination condensing boiler and heat pump), cooling system (heat pump ventilation (heat recovery system), sanitary water (heat pump), RES technology (photovoltaic plant on roof).

3.3. Calculation of defined criteria for Mechanical Engineering Faculty building
In this section, above defined criteria are calculated for the building of Mechanical Engineering Faculty, with the aim to evaluate different scenarios of energy efficiency measures and RES technologies. The compared energy data are expressed through specific indicators of energy consuming and parameters that characterize educational buildings as typology of the building, size, dynamic of use, number of users and characteristics of HVAC. Based on the real condition and data for Mechanical Engineering Faculty, six scenarios with different energy efficiency measures and RES technologies were being created.

For calculation of demand for heating and cooling of the Faculty building, KiExpert 2011 from Knauf Insulation was being used. The Program was developed in accordance with the latest regulations regarding the calculation of thermal protection and rational use of energy, with harmonized and accepted European standards, and the official algorithm adopted by Ministry of Construction and Physical Planning of Croatia [10].
Input data for calculation of demand for heating and cooling are:
1. Climate data from the nearest weather station
2. Composition and surface of building components depending on the orientation of the building
3. Ventilation losses and number of air changes
4. Number of working hours of the heating system in a week
5. The number of operating hours of cooling system per week.

These data are entered for each scenario, and as a result, the energy demand for heating and cooling is obtained and it was further used for calculation of defined criteria.

4. Results and discussion

In Table 1, calculated values of the defined criteria for six scenarios with different energy efficiency measures are shown. Criteria were calculated based on the expressions given in Section 2.

| Scenario/Criteria | S1   | S2   | S3   | S4   | S5   | S6   |
|-------------------|------|------|------|------|------|------|
| C1\(^a\) (kWh/a)  | 185,782 | 162,225 | 160,356 | 166,638 | 148,404 | 173,496 |
| C2\(^b\) (kWh/a)  | 250,115 | 228,578 | 222,198 | 93,614 | 81,607 | 98,080 |
| Fossil fuel       | 190,986 | 173,258 | 53,035 | 71,380 | 61,190 | 75,146 |
| RES               | 59,129 | 55,320 | 169,163 | 22,234 | 20,417 | 22,934 |
| C3\(^c\) (%)      | 24    | 24    | 76    | 24    | 25    | 46    |
| C4\(^d\) (tCO\(_2\)/a) | 69    | 64    | 29    | 26    | 23    | 27    |
| Direct            | 20.5  | 18.1  | 0     | 7.6   | 6.1   | 8.2   |
| Indirect          | 48.8  | 45.6  | 29.2  | 18.3  | 16.8  | 18.9  |
| C5\(^e\) (tCO\(_2\)) | 26    | 23    | 36    | 34    | 23    | 53    |
| C6\(^f\) (BAM)    | 761,813 | 2,126,828 | 2,001,547 | 2,432,053 | 2,450,920 | 3,018,643 |
| RES (kWh/a)       | 22,306 | 22,000 |

\(^a\) C1 – annual required energy (heating, cooling and DHW), \(^b\) C2– total primary energy, \(^c\) C3– RES share in primary energy, \(^d\) C4– CO\(_2\) emissions, \(^e\) C5– embodied energy, \(^f\) C6– investment, RES – RES technologies

Considering criteria C1, scenario S5 has at least annual energy demands and consequently the lowest primary energy consumption from all scenarios. Scenario S1 has highest annual energy demands and total primary consumption, and measures that were implemented in this scenario are most common measures proposed in energy audits, and the same one without some improvements (cooling system and roof insulation), that were implemented on the building of Mechanical Engineering Faculty in 2011. Scenario S3 has the largest share in RES, 76 %, due to the use of solar collectors on the roof for sanitary water, and scenarios S6 is the second one by the share of RES in total primary energy with 46 %, with using photovoltaic plant on the roof for production of electricity. Scenario S3 does not have direct carbon dioxide emissions because of a pellet boiler and because biomass is considered as CO\(_2\) neutral. S1 has the highest CO\(_2\) emissions due to the highest primary energy consumption.

Considering criteria C5, embodied energy in thermal insulation, it was calculated per total weight and thickness of applied thermal insulation material during lifetime. According to it, scenario S6 has the highest amount of embodied energy, where stone wool is being used for insulation of façade and the roof. Comparing for example stone wool in S6 and EPS that was used in S1, S2 or S5, according to the manufacturer, the weight of stone wool for façade (kg/m\(^2\)) is in the range from 110-160 in dependence was it used for façade or roof, and weight of EPS (kg/m\(^3\)) for façade is 15 or for XPS 25 kg/m\(^3\). On the second place is S3, in which hemp is used for insulation of façade and stone wool for the roof. The weight (kg/m\(^3\)) of hemp is 100, and two types of stone wool are being used for the roof, Thermal (120
kg/m$^3$) and Top (160 kg/m$^3$). Comparing values, not by the total weight, than by embodied carbon (kgCO$_2$/kg) in chosen thermal insulation material, hemp in S3 is on the first place, which has the lowest amount of embodied carbon 0.345 kgCO$_2$/kg, stone wool for insulation of façade and the roof (S3, S4 and S6) has 1.05 kgCO$_2$/kg, EPS AF used for insulation of the façade in S2 and S5 has 1.93 kgCO$_2$/kg, EPS in S1 for thermal insulation of façade has 2.5 kgCO$_2$/kg, XPS used for insulation of the roof (S1, S2 and S5) has 3.73 kgCO$_2$/kg.

Last, but one of the most decisive criteria, total investment per scenario, shows that the scenario S6 has the most expensive combination of energy efficiency measures and RES technology. Scenario S1 has the lowest investment, which is one of the understandable reasons that it is most often recommended as combination of energy efficiency measures. It can be concluded, that it satisfies investment aspect, but energy and environmental aspect are not satisfied due to the highest energy consumption (annual energy demands and primary energy), carbon dioxide emissions and embodied carbon in thermal insulation material. S3 has average annual energy demands and total primary energy consumption in comparison with other scenarios from energy aspect, acceptable investment factor, and from environmental aspect, hemp is more natural insulation material and the newest alternative insulation on the market. S3 has the largest share of RES from all scenarios by using solar collectors on the roof that produce about 22,306 kWh/a of electricity for sanitary water needs. Scenario S6 has the largest investment, but its combination of measures is consisted of architectural measures as stone wool for thermal insulation of façade and roof, wood-alum windows, external light shelves, and mechanical measures as combination of condensing boiler and heat pump earth-water for heating, heat pump for cooling and sanitary water, heat recovery system and use of photovoltaic plant on the roof for producing approximately 22,000 kWh/a of electricity or 46 % share of RES in total primary energy. Although these measures in combination are the most expensive that other combinations, this investment is cost-effective in the next few years because it would achieve savings (financial and energy) through production of its own energy.

5. Conclusion
Aim of the paper was to introduce and show importance of energy and environmental aspect in the methodology of implementation energy efficiency measures in buildings, in recommendations for improvements in energy audits, in addition to the investment aspect, which is very often crucial and limiting factor. Energy aspect in defined criteria was reflected through total energy annual demand and total primary energy, while environmental aspect included share of RES in total primary energy, achieved through implementation of different RES technologies, carbon dioxide emissions and embodied energy in applied materials. In the paper, criteria that were defined cover all three mentioned aspects. Their calculation was implemented in a case of Mechanical Engineering Faculty Sarajevo.

The defined criteria represent a tool for evaluation of different option for improvement energy efficiency and RES technologies, for both new and existing buildings with the aim of achieving the desired effect. The use of multicriterial analysis can optimize scenarios for improvement of energy efficiency of existing buildings, giving the desired meanings to individual criteria.

Number of aspects and criteria is not limiting, and it can be expanded depending on the needs and demands of investor, such as indicative period of use of the heating and cooling system or payback period for proposed measures. For more detailed analysis and selection of scenario which will meet requirements of a particular aspect of interest or combination of multiple aspect, it is recommended to use multicriterial tool, which is especially important in situations when conflicting interest or goals are encountered. By applying multicriterial analysis, it facilitates the analysis, evaluation and selection of optimal combination of energy efficiency measures and RES technologies of any building.
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