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# Conducting an Energy Audit of a Building: An Initial Phase in Establishing an Energy Management System

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*Abstract* – **The energy management system enhances building energy efficiency through continuous optimization of energy consumption, reducing costs and carbon dioxide emissions. Energy auditing, a core element of systematic energy management, uses methods of energy analysis to evaluate energy usage and identify efficiency measures. This paper examines an existing building where energy auditing is conducted as the first step in implementing an energy management system.**

*Keywords* – **Energy Audit, Energy Management System, Energy Efficiency, Energy Analysis, Optimization of Energy Consumption.**

## I. INTRODUCTION

The methodology of systematic energy management was developed to achieve positive changes in the field of energy efficiency and energy management in buildings [1]. The objective of implementing an energy management system in the analyzed building is the continuous improvement of energy performance, with the primary goal of reducing energy production costs and minimizing negative environmental impacts as much as possible. To achieve these objectives, the established system must have a strong technical foundation and support from individuals responsible for the management, optimization, and controlled utilization of resources within the building.

In accordance with the fundamental principles of the energy management system, an energy audit is conducted in the building as the initial phase of the Plan-Do-Check-Act (*PDCA*) cycle [2]. The methodology for conducting an energy audit encompasses gathering data regarding the building's energy usage, identifying and assessing potential savings, and concluding with proposed measures to improve the building's energy performance. In the Republic of North Macedonia, the conduction of energy audits for buildings is governed by the Energy Efficiency Law, which was adopted in 2020 [3].

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## II. OVERVIEW OF THE BUILDING'S EXISTING CONDITION

The analyzed building is an independent, free-standing structure situated in an area that lacks protection from wind exposure. It features a single ground floor with an overall interior floor area of 139 [$m^2$]. The height of the interior walls ranges from 2.28 [m] to 3.37 [m], influenced by the sloping roofs in specific rooms. The overall volume of the building is 436.82 [$m^3$].

Annually, the building operates for a total of 220 days, corresponding to 2,640 operating hours per year. Within the heating season, the building is operational for 124 days.

Concerning the climatic conditions at the site of the building, it is located in a temperate zone characterized by a degree-day value of 2,635 [°C-day] and a specified outdoor winter design temperature of -18 [ºC]. The average annual temperature is 11.1 [ºC].

The building comprises six rooms. Except for the storage room, where the design indoor temperature in winter is 16 [ºC], the remaining five rooms have a design indoor temperature of 20 [ºC].

From an economic standpoint, the building owner utilizes personal funds to cover all energy-related costs.

The structural and enclosing elements of the building are shown in Fig. 1.

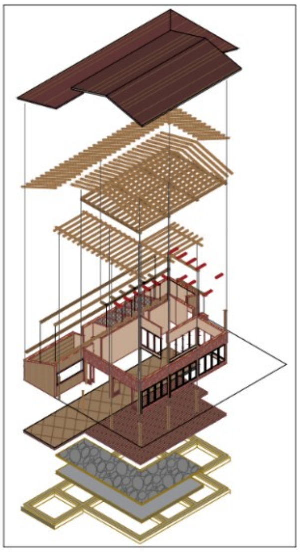

Fig. 1. Construction layout of the building

The building's structural components are constructed from reinforced concrete. The flooring system features reinforced concrete along with thermal insulation composed of mineral wool, which was incorporated during the building's construction phase. The walls lack thermal insulation. The roof structure is constructed from wood and has undergone renovation, incorporating high-quality insulation materials. This includes a layer of mineral wool, a vapor barrier membrane, an air gap, and a waterproofing layer, with the roofing surface finished with ceramic tiles. The building's exterior doors and windows feature wooden frames and are equipped with double glazing composed of standard glass, which does not provide any shielding against solar radiation.

Fig. 2 presents the values of the heat transfer coefficients for the enclosing elements of the building envelope, calculated according to [4].

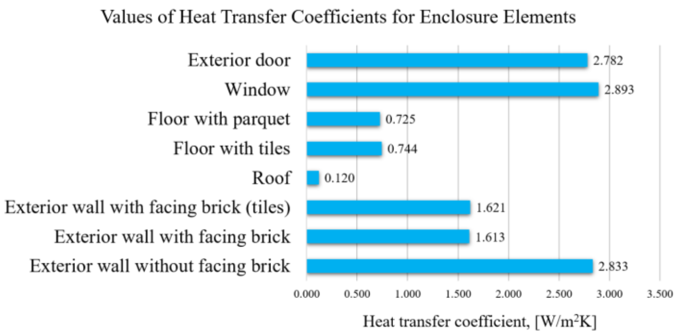


Fig. 2. Values of the heat transfer coefficients for individual elements of the building envelope, [W/m$^2$K]

The highest amount of heat is transferred through the windows of the building and the exterior walls that lack a facade brick layer on the outer side of the structure, while the lowest heat transfer occurs through the roof. This is a result of the prior renovation efforts, which incorporated high-quality insulation.

According to the established calculation methodology [5], the total heat losses for the building were determined to be 32,747.303 [W]. The living area accounts for the majority of these losses, representing 55% of the total, largely due to the extensive number of windows and exterior doors that make up a considerable portion of the building envelope in this section. Additionally, the windows and doors are in poor condition, with high levels of air infiltration, which further contributes to significant heat loss in this area. The lowest heat losses, 3%, occur in the auxiliary room, which is also the smallest room in the building.

In the storage room located in the southwestern part of the building, a conventional hot-water boiler is installed, operating for 1,488 hours per year. This boiler utilizes extra-light fuel oil as its energy source for generating heat for space heating, which possesses an energy content, $H_d$, of 42,300 [kJ/kg] and a density, $\rho$, of 860 [kg/m$^3$]. The fuel is combusted in a 45 [kW] boiler that features a heat exchange surface area of 3.6 [m$^2$] and a water capacity of 110 [l]. The operational efficiency of the boiler is recorded at 81%. Water serves as the heat transfer medium, circulating within the system at a temperature range of 90/70 [ºC].

The heat energy distribution system operates as a horizontal two-pipe hot-water configuration featuring a lower distribution layout, characterized by a singular circulation loop. This system incorporates steel pipes of various diameters and is equipped with 20 sectional radiators made of steel sheet, which provide the necessary heating energy to the building. The system comprises a total of 20 *Termik* radiators, all of type R500, with a total installed capacity of 32,168 [W]. The majority of these radiators are situated in the living area, with each radiator delivering a heating output of 2,156 [W]. Temperature control within the rooms is achieved manually through the use of radiator valves.

The system is equipped with a single *Grundfos* circulation pump featuring automatic regulation, which operates at a power of 27 [W] and can withstand a maximum pressure of 10 [bar]. Its annual energy consumption is recorded at 174 [kWh/year].

The total installed capacity of lighting sources in the building is 1,752 [W]. Based on the conducted calculations, it is concluded that the energy required for lighting the building amounts to 4,182 [kWh/year]. Fluorescent lamps represent 62% of this energy demand, while incandescent lamps contribute the remaining 38%.

The provision of domestic hot water is facilitated by an electric water heater produced by *Gorenje*, which has a power rating of 2 [kW] and a storage capacity of 110.7 [l]. The electric water heater operates for a total of 440 [h/year].

During the summer period, part of the building is air-conditioned using five air conditioning units manufactured by *Fujitsu*, with a total installed cooling capacity of 10 [kW]. Each air conditioning unit functions for a cumulative total of 240 [h/year].

Based on the calculations performed, it was determined that the total energy consumption for both air conditioning and domestic hot water heating is 3,280 [kWh/year].

## III. Analysis of Energy, Economic and Environmental Performance

According to the Rulebook for energy characteristics of buildings [6], the total annual required energy, $Q_{an}$ [kWh/year], is calculated using Eq. (1):

$$Q_{an} = Q_{H,nd} + W_{H,nd} + W_{L,nd} + W_{W,nd} + W_{C,nd} \quad (1)$$

Table I presents the calculated values for the total and specific annual required energy for the individual consumer categories within the building.

Table I
Annual Energy Demand

| System type | | Energy demand | |
|---|---|---|---|
| | | $Q_{an}$ [kWh] | $Q_{an,f}$ [kWh/m$^2$] |
| Heating system | $Q_{H,nd}$ | 48,728 | 350.561 |
| Fans/pumps | $W_{H,nd}$ | 174 | 1.252 |
| Lighting system | $W_{L,nd}$ | 4,182 | 30.086 |
| Electrical appliances and devices | $W_{W,nd}$ and $W_{C,nd}$ | 3,280 | 23.597 |
| Total | | 56,364 | 405.496 |

When calculating the final energy consumption of the building, in order to account for losses that occur during the operation of various systems and devices, it is necessary to consider the efficiency of energy utilization [7]. The efficiency of individual systems and devices should be emphasized: the efficiency of the circulation pump is 8.6%, in accordance with the technical specifications provided by the manufacturer; fluorescent lamps achieve an efficiency of 33%, while the efficiency of incandescent lamps is 10%; the electric water heater has an efficiency of 37%; and the cooling factor of the air conditioning units is 4.43 [W/W].

According to Fig. 3, it can be concluded that the heating system represents the most significant portion of annual final energy consumption, comprising 74.89%. This indicates that thermal energy constitutes the largest segment of the building's overall energy consumption and serves as the primary contributor to carbon dioxide ($CO_2$) emissions.

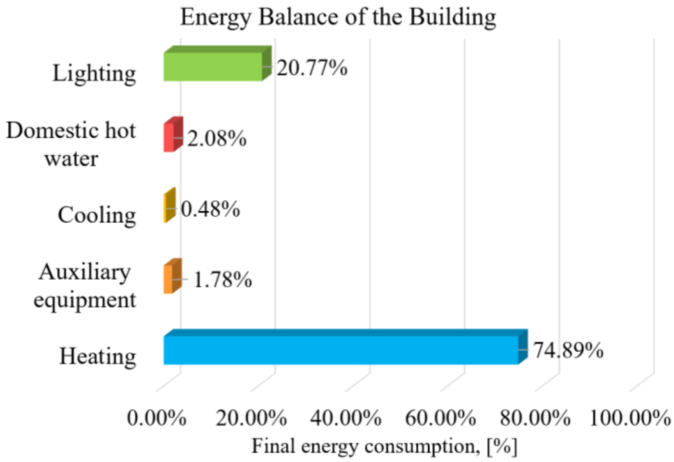


Fig. 3. Energy balance of the building for final energy consumption on an annual basis

The lighting system is the second most significant energy consumer in the building, contributing to 20.77% of the overall energy consumption.

The total final energy consumption for the building is 114,152 [kWh/year].

The primary energy consumption across various energy categories in the building is calculated by multiplying the final energy consumption values by the conversion factor from final to primary energy, depending on the type of energy source [7]. The total primary energy consumption for the building is calculated to be 169,117 [kWh/year].

The electricity consumption, based on the final energy consumption values per consumer category, is 28,664 [kWh/year].

The consumption of extra-light fuel oil, $B_{e.l.oil}$ [kg/year] is calculated using Eq. (2) [8]:

$$B_{e.l.oil} = \frac{Q_{H,nd}}{H_d \cdot \eta} \cdot 3.600 \qquad (2)$$

The efficiency of the heating system, denoted as $\eta$, is determined by multiplying the efficiencies of each component that constitutes the entire system [9], leading to an overall efficiency of 57%. According to the conducted calculation, the annual fuel consumption amounts to 8,460 [l]. Based on the review of available invoices for water consumption, the annual water consumption for the building is 300 [$m^3$].

Table II provides an overview of the energy and cost balance on an annual scale.

The most substantial annual expenses arise from the use of extra light fuel oil for generating thermal energy to heat the building, which constitutes 59% of the building's total annual energy expenditures. Additionally, electricity costs represent a notable 39% of these expenses.

It is important to emphasize that the unit price of energy carriers during the period of the energy audit of the building was adopted based on the available data provided by the Regulatory Commission for Energy, Water Services, and Waste Management Services of the Republic of North Macedonia [10, 11, 12].

TABLE II
ENERGY AND COST BALANCE ON AN ANNUAL BASIS

| Type of energy carrier | Annual consumption | | | Costs [MKD] |
|---|---|---|---|---|
| | Energy carriers | | Energy [kWh] | |
| Electricity | 28,664 | [kWh] | 28,664 | 408,175 |
| Extra light fuel oil | 8,460 | [l] | 85,488 | 613,350 |
| Water | 300 | [$m^3$] | - | 16,628 |
| Total | | | 114,152 | 1,038,153 |

The calculation of carbon dioxide ($CO_2$) emissions was conducted using $CO_2$ emission factors per unit of energy fuel, while considering the overall primary energy consumption [4].

As shown in Fig.4, the total annual $CO_2$ emissions include direct emissions resulting from the combustion of extra light fuel oil for thermal energy production for heating, $EM_{e.l.oil}$, and indirect emissions arising from electricity usage for various energy requirements of the building, $EM_{el.e}$, expressed in [$kgCO_2$/year].

The specific $CO_2$ emissions for the calculated primary energy amount to 323 [$kgCO_2/m^2$ year].

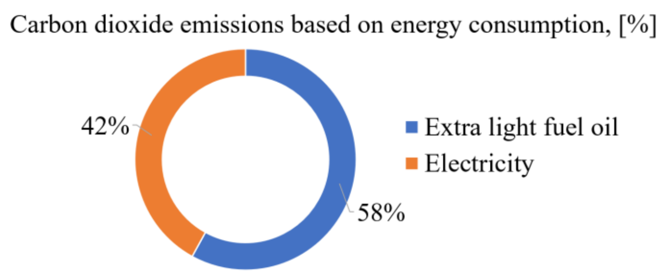


Fig. 4. Percentage of direct and indirect carbon dioxide ($CO_2$) emissions

## IV. Conclusion

In accordance with the conducted energy analysis, energy efficiency indicators of the building can be defined, which relate to the intensity of energy utilization and serve as a means to monitor the building's energy consumption [13]. The total specific heating energy demand amounts to 350.561 [kWh/m$^2$ year], classifying the building into energy class F. The obtained low energy classification of the building in its current state indicates the need for performance improvements in the building's systems, thereby achieving a higher energy class through the systematic implementation of appropriately selected measures.

The assessment of the building's existing condition is conducted comprehensively and systematically, providing a quantitative evaluation of each individual component of the building. This approach facilitates the determination of the scope of measures required to improve performance [14]. The results of the conducted assessment of the existing condition of the examined building components are graphically presented in Fig. 5.

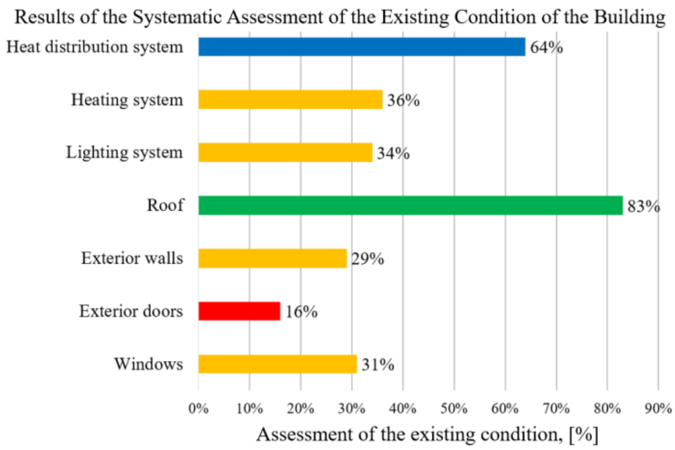


Fig. 5. Results obtained from the systematic assessment of the existing condition of the individual building components

According to the results presented in Fig. 5, the following conclusions can be drawn:

- The present state of the building's exterior doors is assessed at 16%, signifying an urgent requirement for remedial measures. Consequently, to enhance the overall efficiency of the building, it is advisable to replace all exterior doors with energy-efficient alternatives.
- The assessment of the exterior walls is 29%. To mitigate this issue, it is advisable to insulate the exterior walls using a material that exhibits excellent thermal performance.
- The assessment of the windows is 31%, which indicates the need for urgent corrective action – replacing all windows in the building with energy-efficient ones, which would contribute to a significant reduction in heat losses.
- The assessment of the lighting system is 34%. By changing the type of light sources, significant energy savings can be achieved, thereby reducing costs.
- The assessment of the heating system is 36%. The recommended measure is to replace the energy source with an environmentally acceptable fuel with minimal emissions and a more economically viable fuel.
- The heating distribution system has a rating of 64%, indicating that more complex measures for improving the system's condition are not necessary. What is recommended is an evaluation or potential improvements that do not require significant financial investment or a long payback period. Measures that could be implemented include installing thermostatic valves on radiators or room thermostats. However, depending on the type of new energy source, a complete reconstruction of the heating distribution system may be required.
- The roof of the building has the highest rating of 83%, and there is no need to take any corrective actions.

Following the assessment of the current state of the building, along with the evaluation of energy consumption, techno-economic factors, and environmental impact, a strategy for implementation can be established. Subsequently, the proposed measures can be systematically applied in alignment with the building's energy management system.

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