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Evaluation of the Effect of Energy Efficient Measures Applied in Public-Service Buildings †

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Abstract: A detailed assessment of the effect of implementing energy saving measures (ESMs) in administrative buildings, is presented in the following work. The main objective is to study the impact of these measures on energy consumption and to refine the difference between actual and predicted energy costs. To achieve this goal, extensive research is conducted, covering 44 administrative buildings in different areas in Bulgaria. After implementing a total of 144 ESMs in these buildings, the effect of the measures was followed over a four-year period. The results of the research show a significant reduction in energy costs after the implementation of energy saving measures in administrative buildings. This has a double benefit—it optimizes the financial resources of the organizations that use the buildings, and it contributes to the reduction of greenhouse gas emissions.

Keywords: energy saving measures; energy consumption; energy saving; administrative buildings

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1. Introduction

The European Union (EU) energy sector is experiencing a number of energy policy challenges that affect both the economy and the environment [1]. Recently, policies aimed at saving energy and investing in energy efficiency programs have become relatively important, especially in public buildings such as administrative ones [2]. Optimizing energy consumption and introducing energy-efficient measures is becoming an urgent task, aimed at reducing carbon footprints and protecting the environment [3]. The implementation of energy saving measures in administrative buildings has long-term benefits that extend not only to individual buildings, but also to society as a whole [4].

Energy efficiency in administrative buildings plays an important role in the pursuit of sustainable and responsible energy use and environmental protection [5]. Depleting available energy resources and increasing energy costs, placing emphasis on energy efficiency is essential for the future of the energy sector [6]. The implementation of energy saving measures in administrative buildings not only reduces energy consumption but also reduces the carbon footprint [7]. Also, energy efficient measures have a long-term and positive effect on the economic development of EU member states [8]. Reducing energy dependence and increasing energy efficiency contribute to creating a stable and sustainable economy, while at the same time reducing the energy costs of organizations. The improvement of the working conditions in administrative buildings has a direct effect on the productivity and motivation of the employees. When employees work in a comfortable and energy-saving environment, they are more productive, creative, and engaged in their work [9]. This creates a positive work environment and increases job satisfaction, which has a positive impact on the work process and final outputs [10]. Combined with reduced energy costs, this contributes to the sustainability of businesses and increases their economic performance [11,12].

The modern challenges facing society encourage us to reduce energy dependence and invest in the energy efficiency of administrative buildings [13,14]. This requires cooperation and commitment from all participants in the process—from governments and municipal bodies to the business sector and citizens [15]. It is important to emphasize that energy efficiency in administrative buildings is not only the responsibility of the organizations that manage them, but also of society as a whole [16,17].

The presented work examines the importance and benefits of implementing energy saving measures in public service buildings. There are presented analyzes and real examples to support the effectiveness of such measures and encourage their implementation in practice. A detailed assessment of the effect of the introduced energy efficient measures has been made, thereby enriching the knowledge of their potential for saving energy and resources. There are also considered the opportunities to improve energy efficiency in public service buildings by changing approaches and introducing modern technologies. The study of energy efficient measures in these buildings is crucial for the management of energy resources. The results of this article would be an inspiration for introducing innovative approaches in the construction and energy sector aimed at optimizing energy efficiency.

2. Methodology

The aim of the presented research is to investigate how administrative buildings engage and use energy and how they can be made more efficient. By analyzing the specific energy consumption of these buildings, it will identify the potential opportunities for improvement and optimization of energy costs.

2.1. General Characteristics of the Public Buildings, Surveyed for Energy Efficiency

The presented study focuses on 44 administrative buildings, which are located in 4 different zones (Z1, Z2, Z3 and Z4) in the territory of Bulgaria, Figure 1.

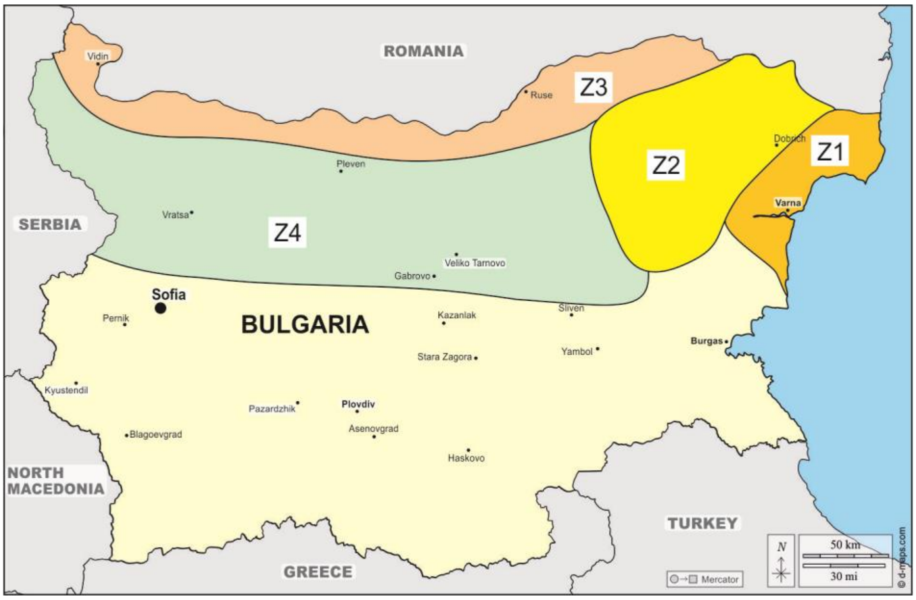

Figure 1. Selected zones in Bulgaria.

The study is based on data from Appendix 2 of [18], as well as the information provided in Table 1.

Table 1. Classification and parameters of public administrative buildings.

Zones	Z1	Z2	Z3	Z4
Number of public administrative buildings	8	8	12	16
Total area, m^2	16,085	17,003	24,717	29,368

These buildings have a total area of 87,173 m^2 and were built between 1961 and 1997. The smallest administrative building has an area of 1620 m^2 and belongs to one of the buildings located in Z1, and the largest has an area of 6528 m^2 and is in Z4. To conduct research on the energy consumption of these buildings, energy efficiency surveys were performed. These surveys were conducted in two time periods: the first from 2015 to 2021, before the implementation of energy-saving measures, and the second— four years after the implementation of these measures. The rules and guidelines according to which the studies were performed were according to the work presented in [18,19].

2.2. Application of Energy-Efficient ESMs

In the present study, administrative buildings are considered as a group of objects with common energy-saving measures, which are distributed as follows: 1. Replacement of windows; 2. Thermal insulation—rehabilitation of walls; 3. Thermal insulation—rehabilitation of roofs/attic spaces; 4. Thermal insulation—rehabilitation of floors; 5. Replacement/modernization of the heating system; 6. Energy efficiency optimization of the electrical system.

Separate energy surveys were prepared for the 44 buildings and 146 energy-saving measures were prescribed (see Table 2).

Table 2. Implementation of EEMs in public buildings.

No.	ESMs by Zones				
	Z1	**Z2**	**Z3**	**Z4**	**Total**
1	6	5	10	11	32
2	8	8	12	16	44
3	6	6	9	13	34
4	2	2	3	3	10
5	3	3	4	5	15
6	3	2	3	3	11
Total	28	26	41	51	**146**

In most of the 44 administrative buildings, a basement and two or three floors are distinctive, and there are single cases without a basement or with a fourth floor. The windowpanes used in these buildings are predominantly wooden or metal, but poor condition is observed with deformed and unsealed frames. The walls are made of brick or concrete structures and are uninsulated. The roofs of the buildings are also uninsulated and have ventilating air space. During the repair process, numerous changes in the heating system are discovered. These changes include the installation of thermostatic and secret valves on the radiators, replacement of pipes, fittings, and others. In some cases, replacement of the boiler and the heating installation is also planned, which contributes to optimizing the heating system and reducing energy costs. Regarding the electrical system, the optimization includes the replacement of lighting fixtures that are in poor condition. This improves lighting efficiency and reduces energy consumption.

The results of the studied ESMs packages for increasing energy efficiency from Table 2 reveal that the first four energy-saving measures focus on the building envelope and elements (windows, walls, roofs, floors) of the existing public service administrative buildings. The first three ESMs are applied in almost all surveys of administrative buildings and have relatively short investment payback periods. The fourth measure, related to floor insulation, is found in about 25% of buildings. What is common across all four measures is the lack of isolation. This highlights the need for insulation to reduce heat loss and achieve significant energy savings. The fifth measure to increase energy efficiency is applied in about 28% of the administrative buildings. It is noted that the heat losses before the implementation of the ESMs were significant, especially in cases where the administrative buildings were supplied with heat from a central heat supply or used amortized sub-stations. The remodeling of the electrical system is rare, while the replacement of lighting fixtures with energy-saving ones is a more frequently applied measure. This highlights the importance of optimizing the electrical system and using energy-saving lighting to reduce energy consumption in administrative buildings.

According to the methodology [19], energy savings cannot be directly measured, as they represent the actual lack of energy consumption or the need for such consumption. Based on this concept, savings are determined by comparing the measured consumption before and after the implementation of a certain energy-saving measure or set of measures, making the necessary corrections related to possible changes in conditions. Such an approach allows us to assess the actual benefits of implementing ESMs and provides an accurate assessment of energy saved and reduced energy costs after the implementation of the relevant measures in administrative buildings.

After the implementation of the ESMs, the information on the consumed energy is extracted from the invoices or through devices with direct readings, provided by the energy supplier for the relevant period. This process usually takes place on the first day of the month.

If solid fuels, such as pellets or liquid fuels such as diesel are used for heating, invoices from suppliers usually cover the entire heating season, not monthly. Therefore, on the first day of the following month, it is necessary to determine the fuel consumed in the previous month. This process is essential to accurately measure energy consumption and savings, especially when heating with solid or liquid fuels.

The survey report also includes weather conditions. For the period from October to April, when the heating season takes place, information on the average monthly temperature is presented. This weather data is essential because temperature conditions play an important role in determining energy consumption and the effectiveness of the implemented ESMs.

The base energy consumption before the implementation of the ESMs for the administrative buildings was determined based on an energy efficiency survey. This process includes gathering information on energy consumption and energy carriers used over the past three years. Due to the influence of weather conditions on the consumed energy for heating, the base consumption for each month is determined by the "Degree-days" method. This dependence is calculated by analyzing data on energy consumption for heating in the previous three years before the survey and after the implementation of the ESMs. This is how the real energy savings that occur after the implementation of the foreseen measures are determined.

3. Results and Discussions

The study on the effect of implementing ESMs in administrative buildings with public services produced the following results:

3.1. Results from the Implementation of Energy Efficient Measures

Of the proposed 146 ESMs in the administrative buildings in the four zones, only 144 have been implemented. Measure 4 has not been implemented in two of the buildings located in Z1 and Z2. This is due to the fact that:

- the clear section of the doors in the basement of an administrative building in Z1 will be reduced, and the fire and emergency safety requirements will not be met.

- it was found that there is no need to renovate the floor in an administrative building in Z2.

The implementation of all the remaining 144 energy-saving measures was successful and on time. Due to the large number of buildings studied (44 in total), it is not possible to provide a detailed description of each measure. Instead, a brief general description of the most common ways to increase energy savings is presented. In most administrative buildings, the following measures are applied to improve energy efficiency:

Replacement of windowpanes: In 32 buildings, window replacements were carried out, and n-chamber (where n = 3–5) aluminum frames and glass units with low-emission glass were installed in them.

Thermal insulation of external walls: An 8 cm thick expanded polystyrene (EPS) thermal insulation system is often used. This system includes two plaster layers, integrated fiberglass mesh and structural plaster. Sometimes gluing of the thermal insulation, doweling and addition of two-layer putty, fiberglass mesh and finishing coating with polymer plaster are applied.

Roof improvement: For thermal insulation, materials such as 14 cm thick extruded polyurethane (XPS) or 12 cm thick stone wool are used. In some cases, cement screed is used for slope, vapor barrier layer, two layers of waterproofing and 6 cm gravel backfill. In other buildings, 10 cm thick XPS is preferred, with a protective reinforced cement-sand screed and roll waterproofing with pebbles.

Improvement of the heating installations: installation of an energy-efficient boiler system, a new pipe network, heating elements (radiators) and a hot water installation are being carried out.

Optimization of the electrical system: By replacing existing lighting fixtures with new energy-efficient options and installing electronic lighting control modules. These modules include programmable clocks, switching relays, and motion sensors with ambient light sensing.

3.2. Results of the Annual Energy Savings

Figures 2–5 present the energy savings for the period 2018–2021, distributed by zones.

It is observed that the largest absolute energy savings are realized in Z4. Before the implementation of energy-saving measures, the energy used in a year was 44% of the energy consumed by all buildings. This is due to the fact that this zone includes the most buildings, which have a large, heated area and consumes more energy for heating.

After the introduction of the ESMs in the administrative buildings and the completion of the repair activities by zone in 2018, 8755 MWh of energy were saved, of which 8181 MWh were related to thermal energy, and 574 MWh were related to electrical energy. The saved thermal energy is due to implemented measures, such as renovation of the building's envelope elements, replacement or modernization of the heating systems and improvement of the air conditioning and ventilation systems. This contributed to the reduction of heat losses and more efficient use of heating energy. Saved electrical energy is also related to measures to optimize the electrical system and replace energy-inefficient elements, such as lighting and heating systems, with more modern and energy-saving alternatives. This includes the installation of energy-efficient lighting fixtures, the installation of electronic control modules and motion sensors that optimize the use of electrical energy.

The realized/planned energy savings by the different zones for the period 2018–2021 are shown in Figures 6–9. The presented percentages in all figures do not add up to 100%, since they represent a fragment of the initial achieved/estimated energy savings per year for each of the four zones in terms of the baseline energy consumption for each zone.

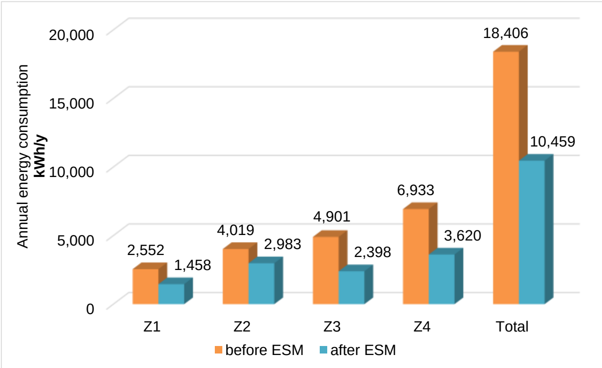

Figure 2. Energy consumption before and after implementation of ESM in 2018.

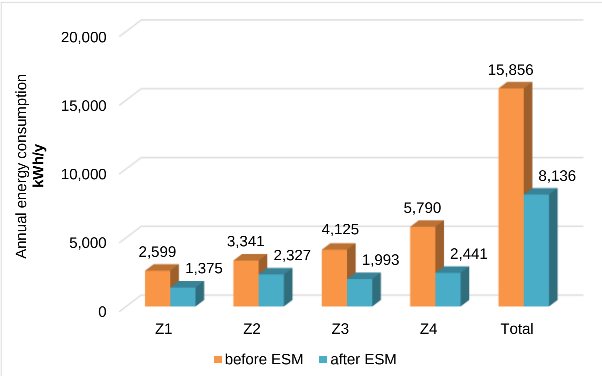

Figure 3. Energy consumption before and after implementation of ESM in 2019.

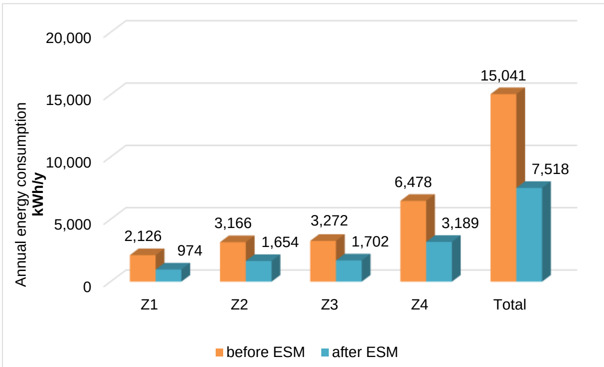

Figure 4. Energy consumption before and after implementation of ESM in 2020.

The highest percentage is the realized energy savings in 2019, in zone 4—56.1%, and the lowest is in zone 1—50.2%.

Before the implementation of the ESMs in the administrative buildings by climatic zones, it is expected that about 50% of the required energy will be saved. The study shows that for about 51% of the administrative buildings there is information on achieved energy savings. The comparison with the results of the energy surveys shows that the difference between the actual energy consumption in the administrative buildings and that predicted in their energy surveys is minimal and insignificant. This highlights the successful implementation of ESMs and energy efficiency in these buildings.

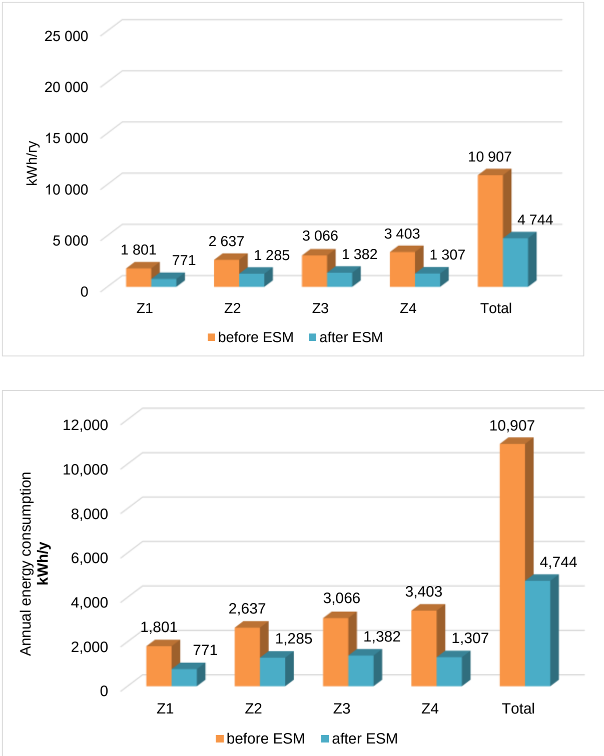

Figure 5. Energy consumption before and after implementation of ESM in 2021.

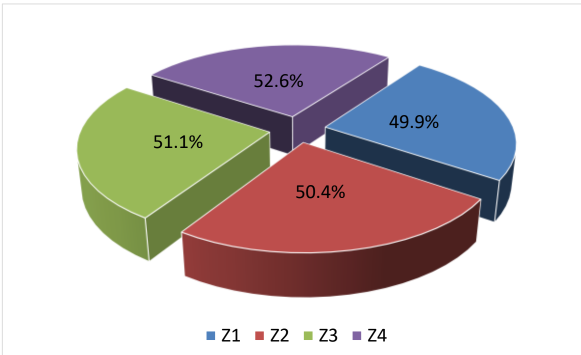

Figure 6. Percentage of achieved/estimated energy savings in 2018.

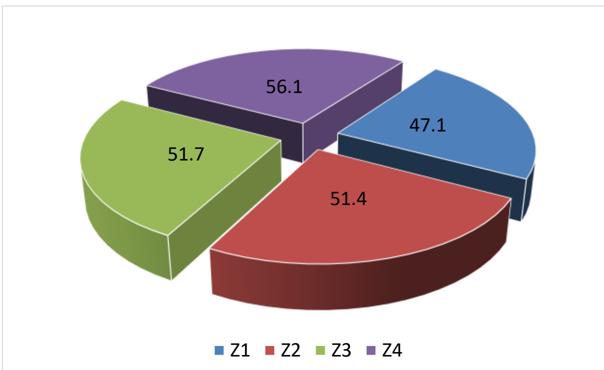

Figure 7. Percentage of achieved/estimated energy savings in 2019.

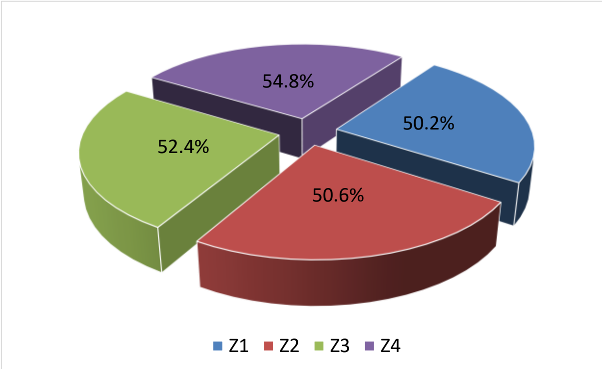

Figure 8. Percentage of achieved/estimated energy savings in 2020.

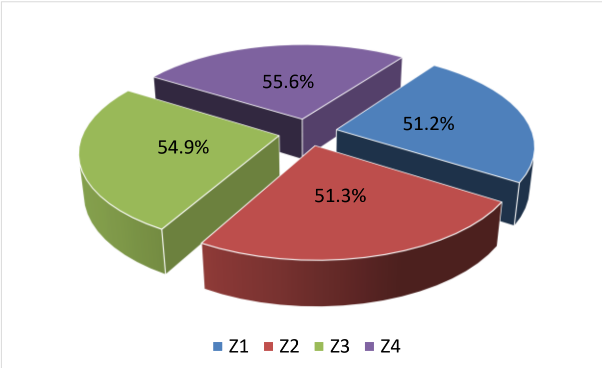

Figure 9. Percentage of achieved/estimated energy savings in 2021.

3.3. Results of the Saved CO_2 Emissions

The estimation of the saved emissions is carried out by data analysis, comparing the energy efficiency of the various facilities by zone with the reference values of the coefficient of ecological equivalent of energy resources and energy, which are regulated in [19].

Figure 10 presents the emission saved CO_2 for the period 2018–2021, distributed by zones.

As a result of the successful introduction of the ESMs, zone Z4 is distinguished by the most significant savings of 897 tCO_2 in 2021. This result notably contributes to the protection of the environment and the reduction of carbon emissions in this zone.

The CO_2 savings per unit of BGN (“lev”) invested is estimated to be 0.25 kg/BGN annually. This is relevant when assessing the effectiveness of investments. These predictions are essential for formulating strategies to reduce carbon emissions and achieve a more sustainable and environmentally responsible environment. Emphasis on the energy efficiency of buildings and sites is critical to achieving global climate goals and protecting the environment for future generations. The continuation of such research and innovation plays an important role in the sustainable development of our society.

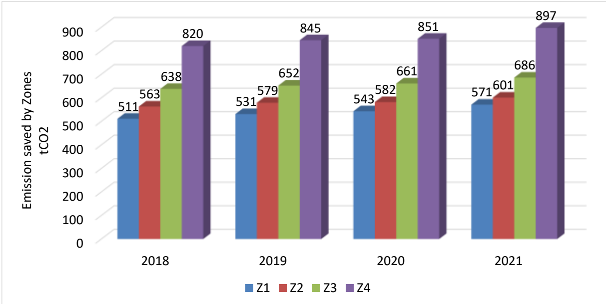

Figure 10. Saved CO_2 emissions by zones.

4. Conclusions

Energy efficiency analyzes were carried out of 44 administrative buildings with a total area of 87,173 m^2, located in four zones in Bulgaria, during the period from 2018 to 2021. As a result of these analyses, an assessment of energy consumption was made before and after the introduction of a package of 144 energy-saving measures. The introduction of these measures has led to significant progress in energy saving in the buildings.

The savings achieved were equal to about 51% of the predicted energy consumption before the implementation of the measures. This means that the buildings achieved a significant reduction in energy dependence, and they are more efficient in their functioning. The results after the surveys and the implementation of the measures show that some of the most effective measures are the replacement of windows, the thermal insulation of walls and roofs, as well as the replacement of the heating system. These measures contributed to significant savings in heat energy.

In addition, the optimization of the electrical system, the replacement of inefficient lighting with energy-saving lighting fixtures and the use of electronic control modules also had a positive effect on the saving of electrical energy. These successful results demonstrate the significant contribution of energy efficient measures to the sustainable development and optimization of energy resources in administrative buildings. The reported savings underline the importance of such initiatives and create motivation for the wider implementation of energy-saving measures in the future.

In 2018, after the successful implementation of all 144 energy-efficient measures in the various zones, significant energy savings were achieved. A total of 8755 MWh of energy was saved by zone, with their electrical energy accounting for an insignificant fraction of this amount, only 547 MWh or approximately 6.66% of the total energy saved. Most of the energy saved by zone, namely 8181 MWh, is thermal energy, which highlights the effectiveness of measures related to heating and air conditioning in buildings. Average values of predicted and actual energy savings by zone are between 51.4% and 53.3%. This shows that in almost all cases, significant energy savings have been achieved after the introduction of ESMs. These results are encouraging and contribute to the achievement of energy efficient functioning of the buildings in the considered areas.

As a result of the introduction of energy efficiency measures, the saving of carbon emissions in the different zones has increased from 571 to 897 tCO_2 in 2021.

The achieved energy savings are of particular importance for the administrative buildings, as they not only provide financial benefits for owners and managers, but also contribute to reducing the negative ecological footprint and improving the sustainability of these buildings. The implemented ESMs are an important step towards creating an energy efficient and responsible society.

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