Analyses of the energy efficiency enhancement in Bulgarian health care premises

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Abstract. The presented study examines how hospital buildings in Bulgaria consume energy, reduce emissions, and save energy. The study uses data from energy efficiency surveys of 38 hospital buildings, where 137 energy-saving measures were implemented between 2015 and 2021. These hospital buildings range in size from 465 m² to 19,026 m², with a total studied area of 151,306 m², divided into three groups for analytical convenience. The study presents detailed findings on annual energy savings, with the highest savings achieved in Group 2 (G2), reaching an impressive 51.1% in 2021. Furthermore, the study analyzes the reduction in carbon emissions, with Group 2 again showing the largest decrease, reducing emissions by 2,097 tCO2 in 2019. These results underscore the significant positive impact of the implemented energy-saving measures, demonstrating substantial improvements in the energy efficiency of the studied hospital buildings. In addition, to highlight the financial and environmental benefits of the reduced energy consumption and lower carbon emissions, the study also offers a valuable model for similar initiatives in other regions. It emphasizes the critical importance of energy efficiency and how targeted measures can effectively contribute to sustainable development in the healthcare sector. This comprehensive analysis provides policymakers, healthcare administrators, and energy efficiency advocates with valuable insights and effective strategies for reducing energy use and emissions in hospital buildings. By showcasing the success of these measures, the study aims to inspire broader adoption of energy efficiency practices, ultimately contributing to global sustainability efforts.

1 Introduction

In recent years, plans related to energy efficiency have been developed in the field of energy policy, which have gained an important place on the agenda of the European Union (EU) member states governments [1, 2]. These plans have become some of the most debated issues related to environmental sustainability, resulting from global warming, the depletion of non-renewable sources, the increasing growth in energy consumption per

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capita and the ever-increasing demands of fossil fuel reduction [3]. On the one hand, global warming, and the risk of running out of conventional sources are directly related to electrical energy production. On the other hand, the increasing global energy consumption and its negative impact on the environment is an issue considered by many financial institutions, scientists and engineers, working in healthcare facilities [4, 5]. Following the implementation of policies, aimed at saving energy resources and investing in energy efficiency audit programs, non-residential healthcare buildings such as hospitals have been observed to be some of the most energy-dependent building units [6]. It is distinctive for them that they have a huge negative impact on the environment, which is due both to the high energy consumption from continuous operation and to the large volume of hospital buildings that were built before 1990 [7]. The need for a proper energy strategy in healthcare buildings, such as medical centers, hospitals and other health care facilities (sanatoria, psychiatric clinics, etc.) is due, above all, to the constant presence of many people in the buildings, some of whom pass daily and others who stay in them for 24 hours and more [8]. Energy management in healthcare facilities is an important factor, the poor management of which leads to an increase in the operational costs of energy consumption [9]. Reducing costs in hospital buildings is a significant contribution to environmental sustainability and improving competitiveness [10]. For most of the medical devices used in X-ray diagnostics, operating rooms, intensive care units, rehabilitation centers etc., large amounts of energy are required to function according to their intended purpose [11]. However, the largest energy users in healthcare facilities are heating, cooling, lighting and domestic hot water, which are most often covered by cogeneration of electricity, gas and oil and in some cases by renewable energy sources using wind, solar energy, etc. [12-14]. One of the main challenges in healthcare facilities is to find financially profitable energy solutions to reduce energy consumption costs [15]. Energy management is engaged in this direction, which is used as a strategic tool to achieve competitiveness, environmental sustainability and is focused on energy efficiency surveys [16].

According to the nature of work in each area in healthcare facilities, energy managers monitor energy consumption, which is different depending on the needs of each individual hospital unit. For example, in a hospital building in an operating room of any department, where surgical interventions are performed, there is an intensive sector with high energy consumption, which is required due to the controlled microclimate, ventilation needs, heating, cooling, lighting and the use of the multiple devices for monitoring the vital signs, and so on. This sector has considerably high energy consumption compared to the administrative sector of the hospital, where there is also heating, cooling, office equipment, but the energy consumption is low [17].

Energy efficiency surveys are usually carried out by energy service companies [18]. They cover strategies and technologies designed to reduce energy consumption, save CO_2 emissions and other costs. Therefore, rational energy consumption in healthcare facilities has the necessary and sufficient conditions for improving energy efficiency [19].

Continuous and specific 24/7 operation of healthcare facilities consequently leads to continuous energy surveys. When improving the energy performance of hospital buildings, by replacing/improving floors, roofs, walls, ventilation, heating rooms etc., a long duration is observed in the implementation of construction and installation works (CIW) [20]. Above all, this is due to the regulated access and constant 24/7 occupancy of the premises in the health facilities.

The ultimate importance of patient health, combined with the need to reduce energy resources, requires dynamic solutions for energy consumption in hospital buildings. This necessitates the development of energy strategies, based on a thorough knowledge of the existing ways of upgrading hospitals, which combined with finding the necessary methodologies, provide reliable solutions for energy consumption and saving resources in this type of non-residential buildings. Therefore, it is necessary to know well the energy consumption in hospital buildings before the expected energy savings and after the implementation of energy saving measures (ESM) [21]. There is an ever-increasing need to find new approaches to solving problems and obtaining sustainable solutions for energy consumption, energy conservation and carbon reduction in energy performance surveys of both new and old hospital buildings. On the one hand, reducing energy consumption and, on the other hand, saving resources in healthcare facilities will lead to an increase in the quality of healthcare services offered to the end user.

The presented study aims to introduce an analysis of energy consumption, emissions reduction and improving energy efficiency in hospital buildings in Bulgaria. This will help improve energy strategies in healthcare facilities by choosing appropriate technologies to implement energy-saving measures, which in turn will lead to resource savings.

2 Methodology

The object of the present study are 38 hospital buildings that can be successfully used for analysis of energy consumption, energy saving and carbon emissions. For the purpose of the study, data from the energy surveys before and after the energy-saving measures were used.

2.1 Hospital buildings located in different climatic zones of Bulgaria

From the variety of energy consumption data, before and after energy efficiency surveys, of non-residential buildings in Bulgaria, 38 hospital buildings were selected. For the sample to be correct, almost uniform public and municipal hospital buildings, in different climatic zones of Bulgaria, were selected, according to Appendix 2 of [21], presented in Figure 1 and Table 1. To facilitate the study, they are divided into three groups, presented in Table 1.

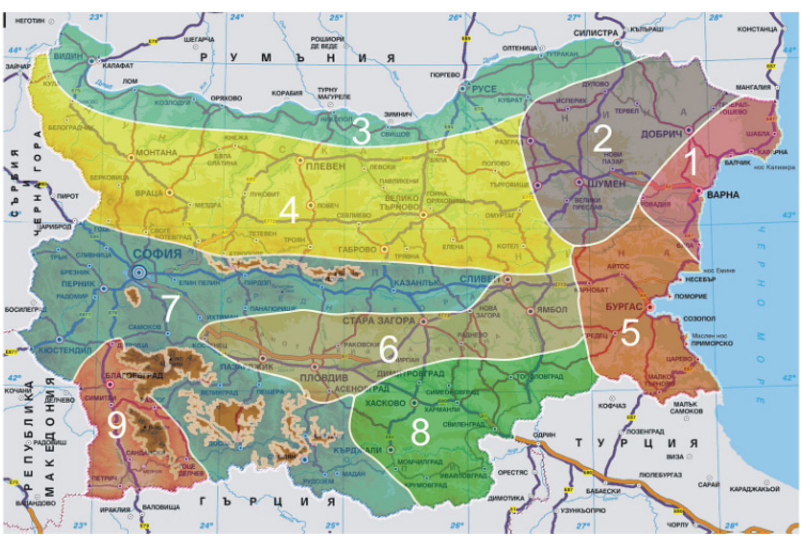

Fig. 1. Climate zones.

The buildings, selected in the study, were built between 1925 and 1995. Their energy consumption was analyzed with the help of the data collected through the surveys carried out in the period 2015-2021 before and after the implementation of ESM, when the construction and installation works have already been completed.

Table 1. Classification and characteristics of hospital buildings.

Group Category	Climate zones	No.	Area, m^2
G1	4	11	22 291
G2	7	18	85 128
G3	1, 2 and 5	9	43 887

The examined hospital buildings have an area between 465 and 19,026 m^2. The total area of all of them is 151,306 m^2, and the distribution by groups is given in table 1. All surveys for energy efficiency of hospital buildings were conducted according to the requirements of [18] and [21].

From Table 1, it is observed that the investigated hospital buildings are located in 5 climate zones, shown in Fig.1, according to [21], and are located on an area of 151,306 m^2.

2.2 Energy saving measures

An assessment of the energy savings is made by applying six energy-saving measures, which were implemented in the individual buildings and are shown by groups in Table 2 a. Replacement of windows; b. Thermal insulation – rehabilitation of walls; c. Thermal insulation – rehabilitation of roofs/attic spaces; d. Thermal insulation – rehabilitation of floors; e. Replacement/modernization of the heating system; f. Energy efficiency optimization of the electrical system.

Table 2. Energy saving measures.

Group Category	Energy saving measures, No.						
	a	**b**	**c**	**d**	**e**	**f**	**Total**
G1	6	6	10	3	10	2	37
G2	13	18	16	4	11	4	66
G3	9	8	8	4	7	3	39
Total	28	32	34	11	28	9	**142**

Data on energy consumption after the implementation of energy-saving measures are most often obtained from the measurement equipment of the energy supplier company. Also, it could be done by the direct read out of the readings of their devices, or from the invoices that the company presents. In cases where diesel fuel or pellets are used, the invoices of the suppliers do not give a real idea of the fuel consumption in the given month. Therefore, on the 1st of the month, the available amount of diesel fuel in the tank must be determined and the amount consumed for the month must be calculated.

The main factor is the average monthly ambient temperature for the place where the object is located. It must be calculated by entering values for the individual months of the year.

Before selecting and implementing an energy-saving measure, the so-called baseline for each of the investigated buildings - An energy survey of each hospital building is carried out. The purpose of this research is to analyze the current state of energy needs based on the consumed amounts of energy in the last 3 years. A positive correlation between the energy consumed for heating the buildings and the climatic conditions has been proven. In this regard, the basic consumption for the month is determined by the dependency "Energy consumed - degrees Celsius". It was built on the basis of the information on the energy used for heating, in the three years preceding the energy survey and accordingly, the implementation of the energy-saving measures.

3 Results and discussion

Based on the research done, to determine energy consumption, carbon emissions and energy savings in hospital buildings, the following results were obtained:

3.1 Results and analysis after energy saving measures

Table 2 shows that there are 142 planned energy-saving measures in the investigated hospital buildings. In group G1, 37 ESMs were proposed and 35 ESMs were implemented. In two of the hospital buildings, the following two ESMs have not been fulfilled:

• „Thermal insulation - rehabilitation of floors", is not implemented, because it will lead to a reduction of the light section of the doors in the basement. This will lead to significant non-compliance with the normative requirements for fire and emergency safety.

• „Replacement/modernization of the heating system", was not implemented due to the fact that the measure prescribed in the project proposal could not be combined with the existing heating supply system.

In group G2, which has the most hospital buildings, 66 ESMs were proposed and all of them were implemented. There is no data on the presence of problems during the execution of the ESMs.

In group G3, 39 ESMs were proposed and 36 ESMs were implemented. In three of the hospital buildings, the following three ESMs have not been fulfilled:

• "Thermal insulation of floors" was not implemented, as the basement is not heated. In addition, the calculations show that the investment payback period from the introduction of the measure determines a very long payback period (comparable to the operational period). This evidence is a basis for accepting the claim that the current energy-saving measures is ineffective.

• "Thermal insulation of basement floors" was not implemented, as it would have reduced the clear section of the doors in the basement, thus failing to comply with the requirements for fire and emergency safety, due to which the measure could not be put into service.

• Measure ***"d"*** was not implemented, respectively: "Thermal insulation of floors – to an unheated basement and to the ground". The measure was not implemented because it would have reduced the clear section of the doors in the basement, thus failing to comply with the requirements for fire and emergency safety, due to which the measure could not be put into service. In addition, the amount of the investment for its implementation determines a payback period considerably longer than the operating one, which makes the measure cost-ineffective.

3.2 Analysis of the annual energy savings

Table 3, 4, 5 and 6 show the energy saved for the period 2018-2021, distributed by the groups.

The largest energy savings were realized in the hospital buildings of group G2. This is due to the fact that this group includes hospital buildings with the largest heated area, which also consume more energy for heating. As a result of the implementation of ESM for G2, 30,165 MWh of energy have been saved, of which 28,896 MWh of thermal energy and 1,269 MWh of electrical energy.

Table 3. Energy saving per year by groups for 2018.

2018	Consumption before ESM	Actual consumption	Savings	Savings	Saved electricity equivalent
	MWh	***MWh***	***MWh***	***%***	***MWh***
G1	7 119	3 561	3 558	50.0	1 063
G2	20 304	10 023	10 281	50.6	2 616
G3	3 592	1 811	1 781	49.6	1 538
Total	31 015	15 395	15 620	50.4	5 037

Table 4. Energy saving per year by groups for 2019.

2018	Consumption before ESM	Actual consumption	Savings	Savings	Saved electricity equivalent
	MWh	***MWh***	***MWh***	***%***	***MWh***
G1	6 510	3 255	3 255	50.0	1 069
G2	14 393	7 182	7 211	50.1	3 338
G3	4 368	2 199	2 169	49.7	876
Total	25 271	12 636	12 635	50.0	5 283

Table 5. Energy saving per year by groups for 2020.

2018	Consumption before ESM	Actual consumption	Savings	Savings	Saved electricity equivalent
	MWh	***MWh***	***MWh***	***%***	***MWh***
G1	1 729	863	865	50.1	562
G2	16 736	8 285	8 452	50.5	2 084
G3	3 452	1 728	1 724	49.9	1 596
Total	21 917	10 876	11 041	50.4	4 242

Table 6. Energy saving per year by groups for 2021.

2018	Consumption before ESM	Actual consumption	Savings	Savings	Saved electricity equivalent
	MWh	***MWh***	***MWh***	***%***	***MWh***
G1	6 894	3 389	3 505	50.8	1 050
G2	8 258	4 036	4 221	51.1	1 821
G3	2 243	1 122	1 120	50.0	659
Total	17 395	8 547	8 846	50.9	3 530

Electrical energy is mainly saved when implementing a measure: "Energy-efficient optimization of an electrical system", when replacing electric heating with a local heating system. Taking into account the specifics of the implemented energy-saving measures, which are mainly the renovation of the enclosing elements of the hospital buildings and the replacement or modernization of the building's heating system, it is normal for the saved electrical energy to be an insignificant part (4.2%) of the total saved energy.

On Figures 2, 3, 4 and 5 are shown the energy consumption by groups and for the period before and after implementation of energy-saving measures.

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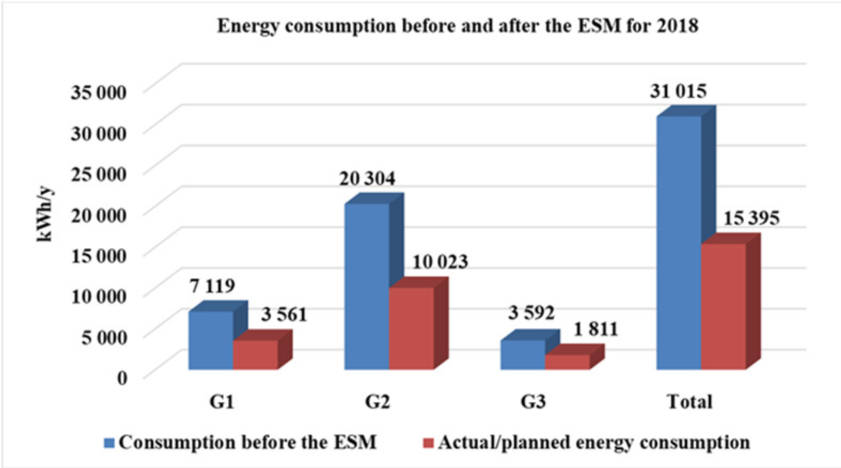

Fig. 2. Energy consumption before and after the ESM for 2018.

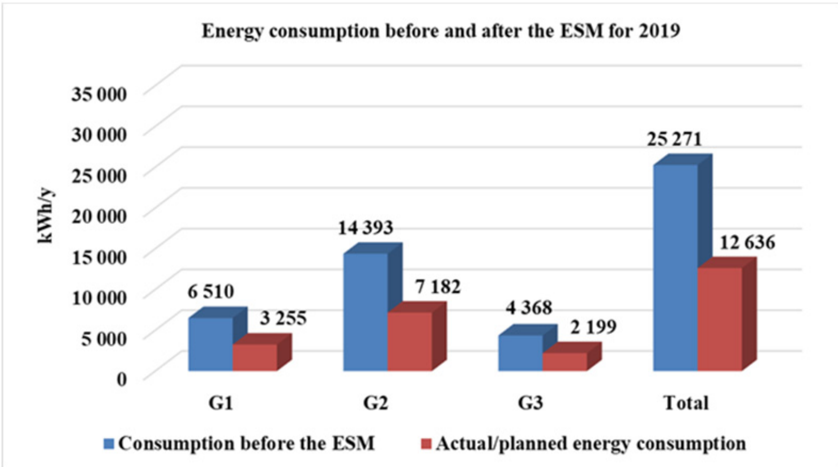

Fig. 3. Energy consumption before and after the ESM for 2019.

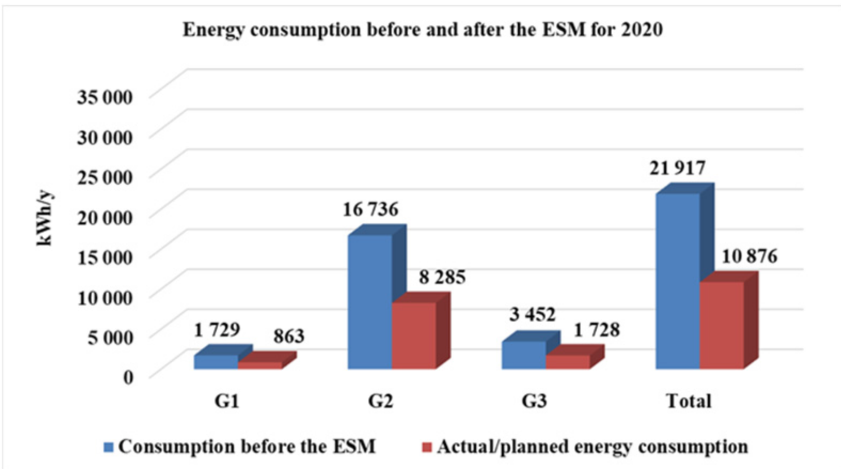

Fig. 4. Energy consumption before and after the ESM for 2020.

Overall, for all groups of hospital buildings, around 51% of energy consumption was expected to be saved before implementing the measures. The predicted and actual savings by group are quite close, ranging from 49.7% for Group 3 (G3) in 2018 to 51.1% for Group 2 (G2) in 2021. This consistency indicates that the energy-saving measures were effectively implemented and accurately estimated.

Given that detailed information on the actual energy savings achieved is available for all hospital buildings, and comparing these results with those from other public building rehabilitation projects, it can be concluded that the obtained results are reliable. The greatest energy savings in G2 are due to the fact that the buildings in this group have a larger heated area, which consumes more energy for heating. Consequently, more significant energy savings are achieved in this group as compared to others.

This comprehensive analysis highlights the substantial impact of energy-saving measures across various hospital buildings, reinforcing the importance of targeted interventions in achieving energy efficiency. The study's findings are valuable not only for demonstrating the effectiveness of these measures but also for providing a replicable model for similar projects in other regions. By showcasing the success of these energy efficiency initiatives, the study aims to inspire broader adoption of such practices, ultimately contributing to global sustainability efforts. This underscores the critical role of energy efficiency in the healthcare sector and its potential to significantly reduce both energy consumption and carbon emissions on a large scale.

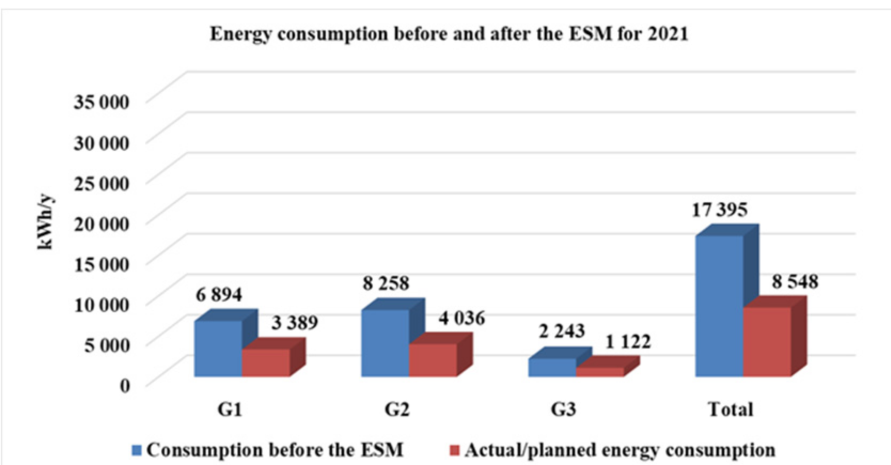

Fig. 5. Energy consumption before and after the ESM for 2021.

3.3 Analysis of the saved CO_2 emissions

The assessment of the saved emissions by the studied buildings, was made on the basis of the Reference values of the coefficient of ecological equivalent of energy resources and energy, published in [22], for the indicators of energy consumption and the energy characteristics of buildings. CO_2 emission savings by groups are shown in Figures 6, 7, 8 and 9.

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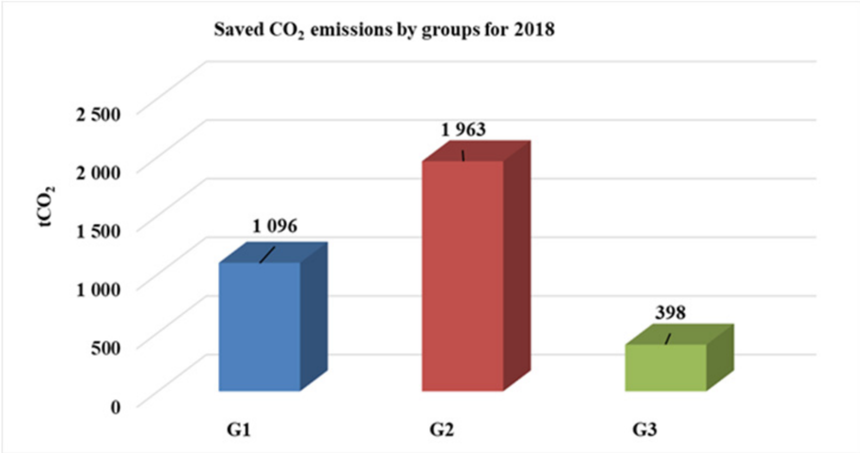

Fig. 6. Saved CO_2 emissions for 2018.

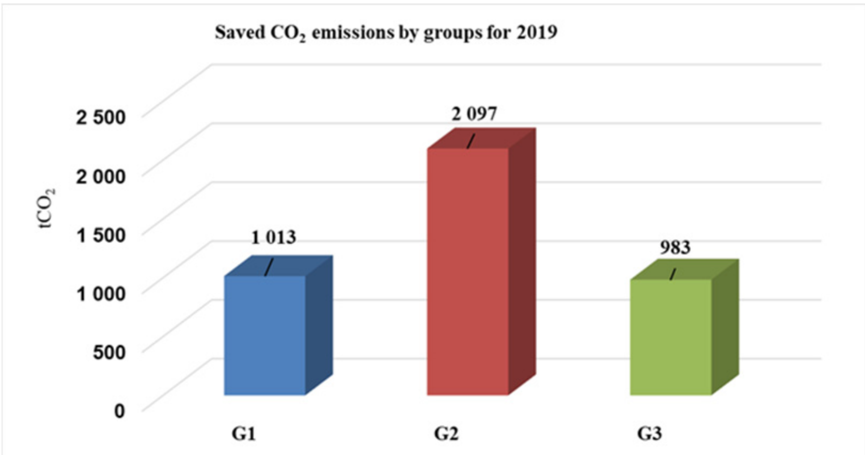

Fig. 7. Saved CO_2 emissions for 2019.

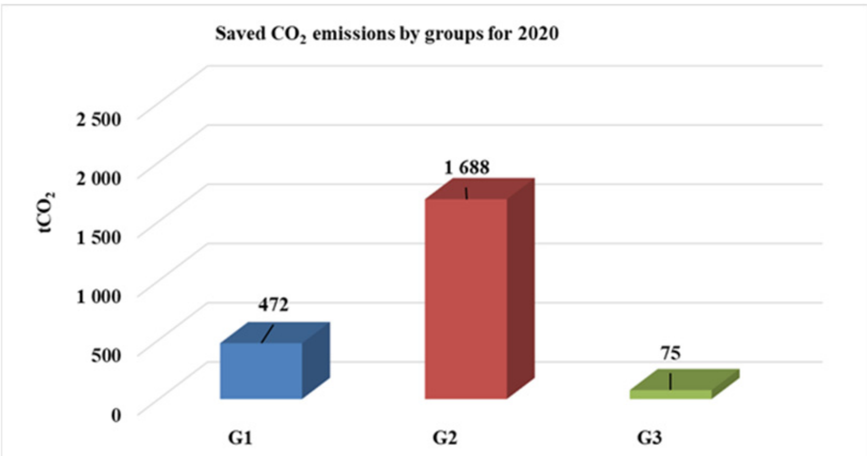

Fig. 8. Saved CO_2 emissions for 2020.

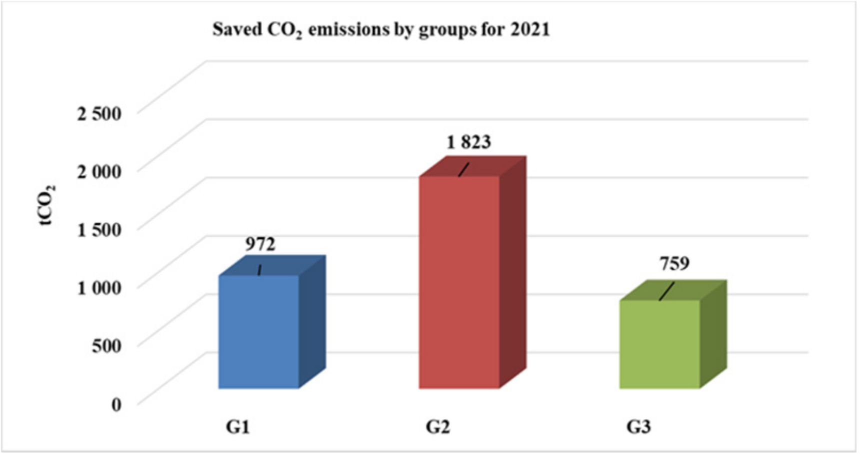

Fig. 9. Saved CO_2 emissions for 2021.

Among the groups, G2 stands out with the highest savings, reaching 2,097 tons of CO_2 per year. This significant reduction underlines the effectiveness of the energy-saving measures implemented in this group. When considering the cost-effectiveness of these measures, it is expected that for every BGN invested, approximately 0.23 kilograms of CO_2 emissions are saved annually. This metric highlights not only the environmental impact but also the economic value of investing in energy efficiency in hospital buildings. It indicates a favourable return on investment, where relatively small financial inputs yield substantial reductions in carbon emissions, contributing to both sustainability goals and financial savings in the long term.

3.4 Summary analysis from the construction and installation works and the introduction of ESM

In the process of implementation of the CIW in the hospitals, a number of problems occurred, as it was impossible to close the hospitals and vacate the building in order to implement the energy efficiency measures. This led to difficulties in developing schedules for the execution of the construction and installation works and to repeated revisions of the schedules due to the impossibility of their implementation.

The activities on the implementation of the energy-saving measures at the sites are performed with good quality, as evidenced by the opinion of the hospital management. When visiting the studied hospital buildings in the period until 2021, most of them express satisfaction with the quality of implementation and the results during operation - increased comfort in the premises and reduced energy consumption. In some of the sites, poor quality implementation of some of the measures was also found. Despite the number of listed problems in the implementation of energy efficient measures, it should be noted that there are no hospital buildings in which construction and installation works have not been completed.

4 Conclusion

Based on the study of the three groups of 38 hospital buildings, for the period 2015-2021, on an area of 151,306 m^2, an analysis of energy consumption, energy savings and carbon emissions before and after the introduction of ESM was made. The study showed that buildings are located in five of the climate zones. The planned ESMs are 142, and the implemented are 137. The non-implementation of the measures is due to a total of five unimplemented measures:

1) "Thermal insulation – rehabilitation of floors", as the clear section of the doors in the basement will be reduced, and the fire safety and emergency necessities will not be met.

2) "Heating system replacement/modernization", due to the fact that the prescribed measure in the design proposal cannot be completed with the existing heat energy supply system in G1.

3) "Underfloor insulation” because the basement is unheated. In addition, the intentional savings from the measure and the investment value for its application shows a payback period much higher than the working one, which makes the measure unsuccessful.

4) "Thermal insulation of the floor structure in the basement", since the clear segment of the entrances in the basement will be reduced, and the fire and emergency safety necessities will not be met, therefore the measure could not be put into operation.

5) "Thermal insulation of the floor - to the unheated basement and to the ground", due to the fact that the light section of the entrances in the cellar will be reduced, and the necessities of fire and emergency safety will not be met, therefore the measure could not be put in action.

In addition, the investment value for its application shows a payback period much higher than the working one, and consecutively the measure is unsuccessful in G3.

The largest energy savings were realized in the hospital buildings of group G2, which is due to the fact that this group includes hospital buildings with the largest heated area, which also consume more energy for heating. As a result of the implementation of ESM for G2, 30,165 MWh of energy have been saved, of which 28,896 MWh of thermal energy and 1,269 MWh of electrical energy. Electrical energy is mainly saved when implementing a measure “Energy-efficient optimization of an electrical system”, when replacing electric heating with a local heating system. Considering the specifics of the implemented energy-saving measures, which are mainly the renovation of the enclosing elements of the hospital buildings and the replacement or modernization of the building's heating system, it is normal for the saved electrical energy to be an insignificant part (4.2%) of the total saved energy. With the most saved 2,097 t CO_2 per year is G2.

During the visit to the studied hospital buildings in the period 2018-2021, the managements of the hospitals were on the opinion that the quality of execution of the construction and installation works is sufficient. The results after the introduction of ESM in the actual operation of hospital buildings, are: increased comfort in the premises and reduced energy consumption, which have contributed to the reduction of the energy resources needed.

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References

1. EP, Dir. 2012/27/US*, J. of the EU* (2012)
2. EP, Dir. 2018/2002*, J. EU* (2018)
3. S. Bilgen, R. S. E. R **38** (2014)
4. J. Heeraman, R. Kumar, P. Chaurasiya, H. Beloev, I. Iliev, C. S. T. E **45** (2023)
5. H. Beloev, I. Stoyanov and T. Iliev, *Good Practices in Implementing Energy Efficiency Measures in "Angel Kanchev" University of Ruse*, in Proceedings of the 8th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, pp. 1-4, (2022), doi: 10.1109/EEAE53789.2022.9831424

6. I. Genovski, K. Hristov, E3S Web of Conferences **207**, 02004 (2020)
7. M. Psillaki et all, *Energies* **16**, 755 (2023)
8. N. Matera, D. Mazzeo, P. M. Congedo, A. T. E **221**, 119773 (2023)
9. K.B. de Oliveira, O.J. de Oliveira, S **14**, 15, 9730 (2022)
10. P.A. Jensen, L. Thuvander, P. Femenias, H. Visscher, C. M. E **40** (2022)
11. A. Roletto, M. Zanardo, G.R. Bonfitto, D. Catania, F. Sardanelli, S. Zanoni *Eur Radiol Exp.* **8**, 35 (2024)
12. D. Mazzeo, C. Baglivo, S. Panico, M. Manieri, N. Matera, P.M. Congedo, *Energies* **16**, 7285 (2023)
13. J. Alabid, A. Bennadji, M.Seddiki, Renew. Sustain. Energy Rev 159, 112161 (2022)
14. K. Hristov, I. Genovski, IOP Conf. Series: Earth and Env. Sc **1128**, 012024 (2023)
15. H. I. Beloev et al, IOP Conf. Ser.: Earth Environ. Sci. **1128** 012005 (2023)
16. Z. Ullah, A.R. Nasir, F.K. Alqahtani, F. Ullah, M.J. Thaheem, A. Maqsoom, *Buildings* **13**, 2143 (2023)
17. R. Alotaiby, É. Krenyácz, *Society and Economy*, **45** (2023)
18. Ministry of Energy, *Regulation No. 35/15.05.2015* (Sofia, Bulgaria, 2021)
19. R. Rodriguez, G. Svensson, *Sustainability* **13**, 6132 (2021)
20. EP, Dir. 2010/31/US, J. of the EU (2010)
21. MRDPW, *Ord.No.7* (Sofia, Bulgaria, 2015)
22. MRDPW, *Ord. No. E-RD-04-1* (Sofia, Bulgaria, 2016)