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Araştırma Makalesi

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Sıfır Enerjili Sağlık Tesislerine Doğru: Ameliyathanelerdeki Enerji Talebini Azaltma

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Öne Çıkanlar:

- Ameliyathanelerde kullanım dışı saatlerde (gece modu) hava akış hızının azaltılması ile soğutma enerjisi tüketimi 13,4 kWh/m^2 azaltılabilir.
- Hava akış hızında %50 oranında bir azalma ile soğutma dönemi ameliyathane iklimlendirmesinde %11,3 oranında elektrik tasarrufu sağlanabilir.
- Gece modu uygulaması ile hastane elektrik tüketiminde %2,33 oranında iyileştirme sağlanabilir.
- Gündüz saatlerinde soğutma amaçlı elektrik tüketimi, soğutma sezonundaki tüm gün tüketimin %77,3'ünü oluşturmaktadır.

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Amaç:
Bu çalışmada, hastane ameliyathanelerinde havalandırma sistemlerinin işletilmesi bağlamında enerji tüketiminin azaltılmasına yönelik bir öneri sunulmaktadır. Çalışmanın amacı, ameliyathanelerde kullanım dışı saatlerde (gece modu) hava akış hızının azaltılmasının soğutma enerjisi tüketimi üzerindeki etkilerini araştırmaktır.

Metot:
Çalışmada, ameliyathanelerin kullanım dışı saatlerinde iklimlendirmede hava akış oranının %0'dan %50'ye kadar azaltılmasının İzmir ili için enerji tasarrufuna etkisi analitik olarak hesaplanmıştır. Hesaplamalar TS825 standardına uygun olarak gerçekleştirilmiş ve ameliyathane soğutma gereksinimi detaylı bir şekilde analiz edilmiştir.

Sonuç:
Araştırmada, gece modu saatleri 20:00-08:00 olarak belirlenmiştir. İzmir ilinde bulunan bir ameliyathane için soğutma sezonunda, kullanım dışı saatlerde iklimlendirme hava üfleme debisinin %50 oranında azaltılması durumunda, 60 m² büyüklüğündeki ameliyathanede yaklaşık %11,3 (803,3 kWh veya 13,4 kWh/m²) elektrik tasarrufu sağlanabileceği hesaplanmıştır. İncelenen ameliyathane için hava değişim katsayısı 26,2 ACH olarak bulunmuştur. Elde edilen sonuçlara göre, ameliyathanelerde, kullanılmadıkları saatlerde, hava debisi azaltılabilir. Özellikle soğutma ihtiyacının yüksek olduğu gün içi saatlerde sağlanacak tasarruf miktarının daha yüksek olması beklenmektedir. Ameliyathanelerdeki soğutma kaynaklı elektrik tüketiminin yalnızca %22,7'si gece modu saatlerinde (20:00–08:00) gerçekleşirken, kalan %77,3'ü gündüz saatlerinde tüketilmektedir. Özellikle, gündüz soğutması toplam soğutma talebinin %65,7'sini oluşturmasına rağmen, elektrik tüketiminin orantısız bir şekilde %77,3'ünü temsil etmektedir.

Anahtar Kelimeler: Sıfır enerji hastane, Enerji verimli ameliyathane, Ameliyathane soğutması, Sürdürülebilirlik için soğutmanın optimize edilmesi

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Research Article

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Towards Zero Energy Healthcare Facilities: Reducing Energy Demand in Operating Rooms

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Highlights:

- Cooling energy consumption can be reduced by 13.4 kWh/m² by lowering the airflow rate during non-use hours (night mode) in operating rooms.
- Implementing a 50% reduction in airflow rate results in an 11.3% electricity savings during the cooling period for operating room air conditioning.
- Applying night mode operation can improve overall hospital electricity consumption by approximately 2.33%**.**
- During daytime, cooling accounts for 77.3% of total electricity consumption in the operating room throughout the cooling season.

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Abstract: The concept of zero-energy healthcare facilities represents a crucial strategy in mitigating global warming and combating climate change. This study proposes a method to reduce energy consumption specifically by optimizing the operation of ventilation systems in hospital operating rooms. The primary focus is to evaluate the impact of lowering the airflow rate during non-use hours (referred to as night mode) on cooling energy consumption. Using actual hourly usage data, night mode hours were defined as 20:00 to 08:00. For Izmir province, analysis showed that implementing a 50% reduction in airflow rate during these hours could lead to an electricity savings of 11.3%, equivalent to 803.3 kWh, during the cooling season in a single operating room. These findings demonstrate a significant opportunity to improve energy efficiency in hospital settings by adjusting ventilation system operation according to room usage, contributing to the broader goal of zero-energy healthcare facilities and environmental sustainability.

Keywords: Zero energy hospital, Energy efficient operating room, Operating room cooling, Optimizing cooling for sustainability

1. Introduction

Healthcare facilities are among the highest energy consumers compared to other building types. Hospitals, in particular, have high energy demands due to their 24-hour uninterrupted operations, with energy consumption levels reaching up to 2.5 times those of typical commercial buildings. Major contributors to this high energy use include medical devices, heating and cooling systems, and ventilation systems—critical components for maintaining hygiene and infection control. The substantial energy consumption in healthcare facilities not only raises operating costs but also significantly increases carbon emissions [1]. The World Bank estimates that the healthcare sector contributes approximately 5% of annual global CO_2 emissions, amounting to 2.6 billion metric tons. In the United States, hospitals and clinics are estimated to account for 10.3% of the total energy consumption within the commercial sector [2, 3].

Operating rooms (ORs) are among the most energy-intensive spaces in a hospital, primarily due to stringent ventilation, filtration, pressurization, and thermal comfort requirements. Studies report that ORs consume 3–6 more kWh/m^2 than average hospital areas. For example, a US survey found healthcare buildings average 545 $kWh/m^2 \cdot yr$, whereas a Spanish study measured OR ventilation demands of 1685 $kWh/m^2 \cdot yr$ (thermal energy; ~1021 $kWh/m^2 \cdot yr$ if adjacent zones like scrub rooms are included). A German measurement of ORs found about 1.2 $kWh/m^2 \cdot day$ (438 $kWh/m^2 \cdot yr$). These figures vastly exceed typical commercial building EUIs and illustrate the heavy load of 24/7 high-volume HVAC [4-5].

In recent years, aligned with sustainable development goals and efforts to combat the climate crisis, the concept of the "Zero Energy Hospital" or "Net Zero Energy Hospital" has gained significant interest in the healthcare sector. This approach aims to ensure that hospital buildings generate as much energy annually from renewable sources as they consume, effectively reducing their net energy consumption to zero. This concept is based on two fundamental strategies. The first is to reduce the building's energy demand by enhancing energy efficiency. Key measures include improved insulation, efficient HVAC systems, LED lighting, smart building management systems, and passive design strategies. The second strategy focuses on supplying renewable energy to meet the remaining energy needs. Renewable technologies such as photovoltaic solar panels, wind turbines, hydrogen, and geothermal systems can be employed to achieve this. It is important to distinguish between net zero energy and carbon neutrality. Net zero energy buildings generate as much energy as they consume over the year from renewable sources, whereas carbon neutral (or net zero carbon) buildings offset the carbon emissions associated with their operations. Carbon neutrality encompasses not only operational energy but also embodied carbon emissions—those associated with the materials and processes involved in construction. Achieving net-zero energy goals in hospitals is a crucial step toward sustainability. However, a broader approach to reducing the carbon footprint of healthcare facilities should also address supply chain management, transportation, waste management, and other operational activities [6]. A key step towards achieving zero-energy hospitals is to improve energy efficiency while increasing the share of renewable energy sources. Among renewables, photovoltaic (PV) solar energy systems are the preferred initial option [7]. New cogeneration systems are also being explored to enhance energy efficiency in hospitals. Assareh and colleagues [8] proposed a novel cogeneration system to meet the energy demand of a hospital in Rome, Italy. Their optimization results indicated that the system could reduce CO_2 emissions by 2.1 tons per hour, with an exergy efficiency reaching 25.1%.

One notable example of a zero-energy hospital worldwide is the Kaiser Permanente Santa Rosa Medical Office Building in California. Covering an area of 8,110 m², this facility is recognized as the first healthcare building in the United States to achieve net zero energy status. The building is entirely self-powered and designed to minimize energy consumption, making it the first proven net zero healthcare building in the country [9]. Another notable example in the United States is the Pueblo Community Health Center East Side Clinic in Colorado. Opened in 2022, it is the first zero-energy outpatient healthcare facility in North America. The 5,950 m² clinic is a conversion of a former supermarket building. Its total on-site energy use is fully balanced by on-site energy production, a fact verified by the New Buildings Institute. The clinic incorporates several energy efficiency measures, including advanced insulation, a ground source heat pump, an energy recovery ventilation system, and LED lighting. Additionally, a photovoltaic (PV) solar panel system with a total capacity of 280 kW was installed on the roof and parking lot. These features contributed to a reduction of over 50% in energy consumption and 66% savings in operating costs. The clinic's total annual energy consumption was 423,024 kWh, while the photovoltaic system produced 435,744 kWh annually, successfully achieving the net zero energy target [10]. Grønnköpingkið University Hospital, located in the Nordic region, is renowned as the greenest hospital in the world. It is a pioneer in sustainable healthcare, minimizing energy consumption through the use of renewable energy systems, high-efficiency insulation technologies, and intelligent building management systems [11].

Various strategies have been developed to transform hospital polyclinic buildings into zero-energy structures, as demonstrated by studies conducted at the University Medical Center in the Netherlands. These studies revealed significant energy-saving potential in hospital buildings and proposed innovative solutions to achieve this goal [12]. A study on a hospital building in Taxila, Pakistan, conducted a techno-economic assessment for converting the facility into a hybrid grid-connected net zero energy hospital. The analysis showed that with a 220 kW photovoltaic solar system integrated with the grid, 70.7% of the hospital's energy demand could be supplied by solar energy, while the remaining 28.3% would come from the grid. The system's payback period was calculated as 2.53 years, with an estimated annual economic gain of 10.24% [13]. The Net Zero Energy Buildings (NZEBs) design approach is widely adopted in Malaysia's construction industry. However, there remain reservations regarding the implementation of NZEB principles specifically in healthcare building projects [14]. In the European Union, reducing energy consumption in healthcare buildings—recognized as some of the most energy-intensive building types—is a key objective of government policy. Sleiman et al. [15] proposed an automated early design support workflow, supported by a suite of tools, to facilitate the development of nearly zero-emission healthcare buildings. Their approach was validated through multiple real-world demonstrations across various countries as part of the European project STREAMER.

Although the concept of zero-energy hospitals has not yet been fully implemented in Türkiye, there are important steps taken in this direction. As of January 1, 2023, buildings with a total construction area of over 5000 m² in Türkiye are required to be constructed as Nearly Zero Energy Buildings (nZEB). This regulation is expected to encourage the integration of renewable energy systems and the adoption of energy-efficient technologies in hospital infrastructure moving forward [16]. In parallel with energy efficiency efforts, a hospital group has tried to start the clean energy era in the healthcare sector. This hospital group, which operates in Türkiye, is investing in Solar Power Plants (SPP) to meet the energy needs of its branch. The installed power of these plants is planned to be approximately 75 MWp. This initiative represents a significant step toward reducing the carbon footprint of healthcare facilities and promoting the use of renewable energy sources in the sector.

The most important innovation of this study is its ability to demonstrate to the Ministry of Health and the Ministry of Finance that energy savings can be achieved in HVAC systems with inverter-controlled motors without requiring any initial investment cost. Turkey has recently prioritized identifying efficiency measures that can be implemented with minimal or no investment. This study presents a significant energy-saving opportunity that aligns well with this national approach. Specifically, by simply adjusting operational schedules via automation systems, existing inverter-controlled HVAC motors can operate in a more energy-efficient "night mode" without additional hardware costs. This makes the proposed method particularly valuable for public sector stakeholders, especially the Ministry of Finance, which is actively seeking low-cost savings solutions. The results of this study can serve as a model for broader implementation across healthcare facilities in Türkiye, potentially leading to substantial cumulative savings in national energy expenditure while maintaining clinical safety standards.

Hospitals are among the structures with the highest energy consumption. A significant portion of this energy, approximately 36%

to 46%, is attributed to air conditioning systems. These systems are essential for maintaining the necessary environmental conditions for patient care, infection control, and equipment functionality. Within hospitals, certain areas are especially critical in terms of air conditioning needs. Operating rooms and intensive care units (ICUs) are priority areas due to their stringent requirements for temperature, humidity, and air quality. Ensuring efficient operation of air conditioning systems in these areas not only helps reduce overall energy consumption but also supports patient safety and health outcomes. Optimizing HVAC performance in these critical zones can involve the use of advanced control systems, energy-efficient equipment, regular maintenance, and real-time monitoring. Hospitals aiming to improve sustainability and reduce operational costs should prioritize these strategies in their energy management plans [17]. Indoor comfort conditions in operating rooms vary depending on the type of surgery performed, and the indoor temperature is typically set between 18-26°C. For example, lower temperatures of 15-18°C are preferred in open heart surgeries to reduce the risk of infection and manage patient body temperature during extended procedures. In contrast, higher temperatures such as 24-26°C are determined for gynecology surgeries where patient exposure is minimized, and thermal comfort is prioritized. These varying requirements necessitate highly flexible and responsive HVAC systems that can maintain precise environmental conditions tailored to surgical needs [18]. However, in practical applications, it is seen that the indoor temperature is mostly left to the preference of the physician performing the surgery. This situation causes temperature settings to change according to personal preferences and energy consumption in air conditioning systems to fluctuate. When examined specifically for state hospitals, it is seen that there is no comprehensive infrastructure that instantly measures indoor conditions and manages the systems according to this data. In current air conditioning systems, the air flow rate into the air ducts is fixed at a certain temperature value; therefore, the air temperatures in operating rooms are generally kept at very low levels. Operating rooms are among the areas where temperature and humidity values in hospitals must be controlled most precisely. In order to change the air flow temperatures and rates in operating rooms according to the need, instant measurements must be made.

2. Material and Method

In this study, the energy performance of an operating room was investigated, and the aim was to reduce energy consumption by making changes to the ventilation system operation. Real-time data from the operating room were used in the study, and the targeted energy savings were calculated analytically.

2.1. Night mode scenario

The capacity utilization rate in operating rooms was investigated. At the studied hospital, by 20:00, the capacity utilization rate in operating rooms drops to 1.9%. In this study, the periods when the operating room utilization rate falls below 2% are defined as "night mode." 99.4% of surgeries are completed between 08:00 and 20:00. Night mode is the hours between 20:00 and 08:00. After midnight, no surgeries are performed except for emergencies, which account for only 0.6% of the total surgeries.

2.2. Cooling load

The energy required for heating and cooling residential buildings can be estimated using the degree-hour method. This approach calculates degree-hour values based on a total of 8,760 hours per year (one full calendar year). Specifically, the cooling degree-hours (°C–hours) can be determined using the following equation [19]:

$$CDH = \sum_{j=1}^{t}(T_{out} - T_{base})_j \tag{1}$$

where T_{out} is the outdoor temperature at hour j, and T_{base} is the base temperature below which cooling is not required. Depending on the outside temperature and the cooling requirements of the operating room, the cooling unit attempts to maintain a consistent supply air temperature. It was observed that this supply air temperature stabilizes at 18.5 °C. For calculation purposes, a base temperature (T_{base}) of 18.5 °C is used. Outdoor temperature data for İzmir were obtained from the Türkiye General Directorate of Meteorology for the year 2024. These temperature records are essential for accurately assessing the thermal load and potential energy savings in the hospital's HVAC system. The data will be used to simulate real-world operating conditions and support climate-based energy optimization strategies. The annual cooling energy demand can be calculated using the following equation:

$$Q_{cooling} = N \cdot CDH + Q_{personnel} + Q_{patient} + Q_{equapment} \tag{2}$$

Here, $Q_{personnel}$, $Q_{patient}$, and $Q_{equipment}$ denote the heat gains from employees, patients, and equipment, respectively.

Thermal gains can be expressed in two main groups as gains consisting mainly of devices and gains from people. Thermal gains can be investigated in two parts as employees and patients. The average number of employees per unit closed area is predicted as 0.1 personnel/m^2. It was observed that there were an average of six healthcare professionals in the operating room where the examination was conducted, depending on the type of surgery. This number includes surgeons, anesthesiologists, nurses, and support staff, and may vary based on the complexity and requirements of each surgical procedure. The presence of healthcare personnel plays a role in determining internal heat gain and ventilation needs within the operating room environment. During the study, it was determined that each healthcare personnel emitted approximately 240 W of thermal heat. Thermal gains from personnel can be calculated using Eq. 3, which takes into account the number of individuals and their average metabolic heat output. This parameter is essential for estimating the internal heat load in the operating room, which directly affects the HVAC system's cooling demand.

$$Q_{employee} = \left[\frac{0.1 \text{ personnel}}{m^2}\right] . \left[\frac{240W}{\text{personnel}}\right] = 24\text{W}/m^2$$ (3)

During the study, it was determined that each patient emitted approximately 260 W of thermal heat. This value represents the average metabolic heat contribution from patients during surgical procedures. It is an important parameter when calculating internal heat loads and designing effective cooling strategies in operating rooms.

$$Q_{patient} = \left[\frac{0.00167 \, patient}{m^2}\right] . \left[\frac{260W}{patient}\right] = 0.43 \text{ W}/m^2$$ (4)

The average electrical load density of equipment ($Q_{equapment}$) in the operating room was taken as 171.7 W/m². This value includes the typical power consumption of medical and surgical equipment used during procedures.

The hourly cooling requirements for the operating room, calculated by considering these factors, are presented in Figure 1.

The total cooling load for the operating room was calculated as 41,813 kWh. To verify the accuracy of the calculated cooling load, the total electricity consumption of the HVAC system and the Energy Efficiency Ratio (EER) corresponding to the average outdoor temperature data were utilized. Using this method, the total cooling load was determined to be 43,905 kWh. This calculated value differed from the initially predicted cooling load by approximately 5%, indicating a reasonable margin of validation between the theoretical and empirical approaches.

2.3. Operating Room

An operating room with a ceiling height of 3.5 meters and an area of 60 m² was examined. The cooling unit's hourly volumetric airflow rates ranged between a maximum of 6,050 m³/h and a minimum of 4,400 m³/h, with a nominal flow rate of 5,500 m³/h for the selected air conditioning device. The detailed technical specifications of the air conditioning unit used in the examined operating room are provided in Table 1.

Table 1. Technical Specifications of the Air Conditioning Unit for the Operating Room

Installed Power (kW)	15.63
Cooling Capacity (kW)	28.5
Energy Efficiency Ratio (EER)	3.19

The calculated air change rate for the operating room is 26.2 ACH (Air Changes per Hour). While the volumetric flow rate can be adjusted by up to 10%, it is generally preferred to maintain a fixed volumetric airflow rate to ensure consistent ventilation and maintain the required environmental conditions in the operating rooms.

The total electricity consumption for the operating room during the cooling season was calculated as 7,088.4 kWh. By reducing the airflow rate by 50% during non-use hours (20:00 to 08:00) in the cooling season, a theoretical energy saving potential of 803.3 kWh per operating room was identified (see Fig. 2). The analysis presented in Fig. 2 assumes a 50% reduction in airflow.

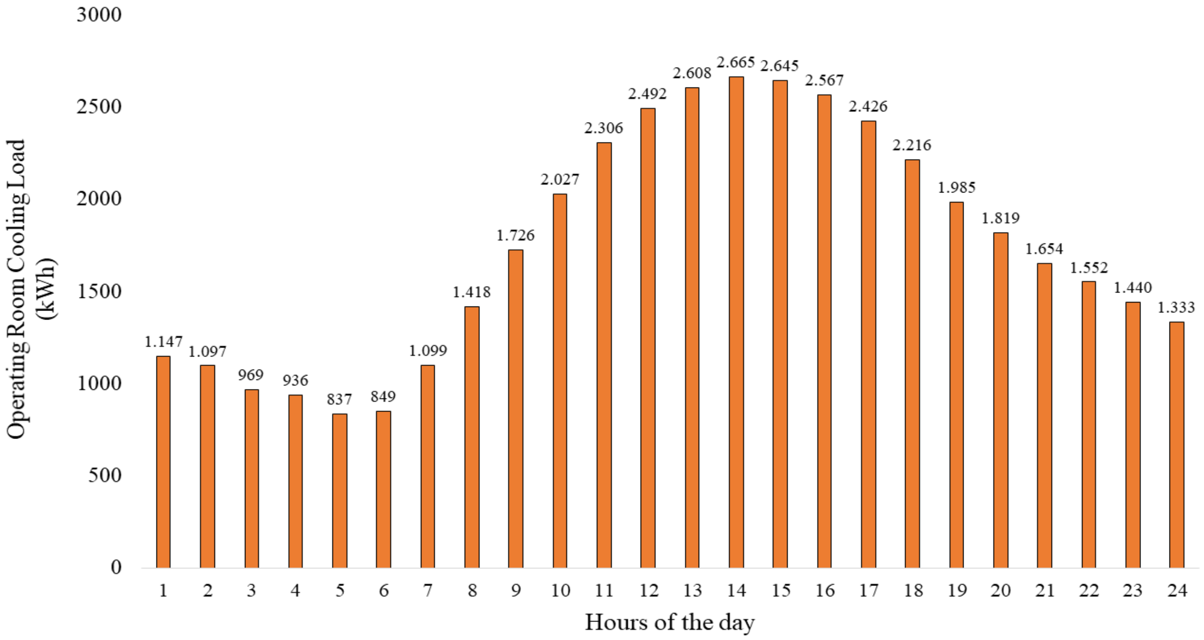

Fig.1. Hourly operating room cooling load

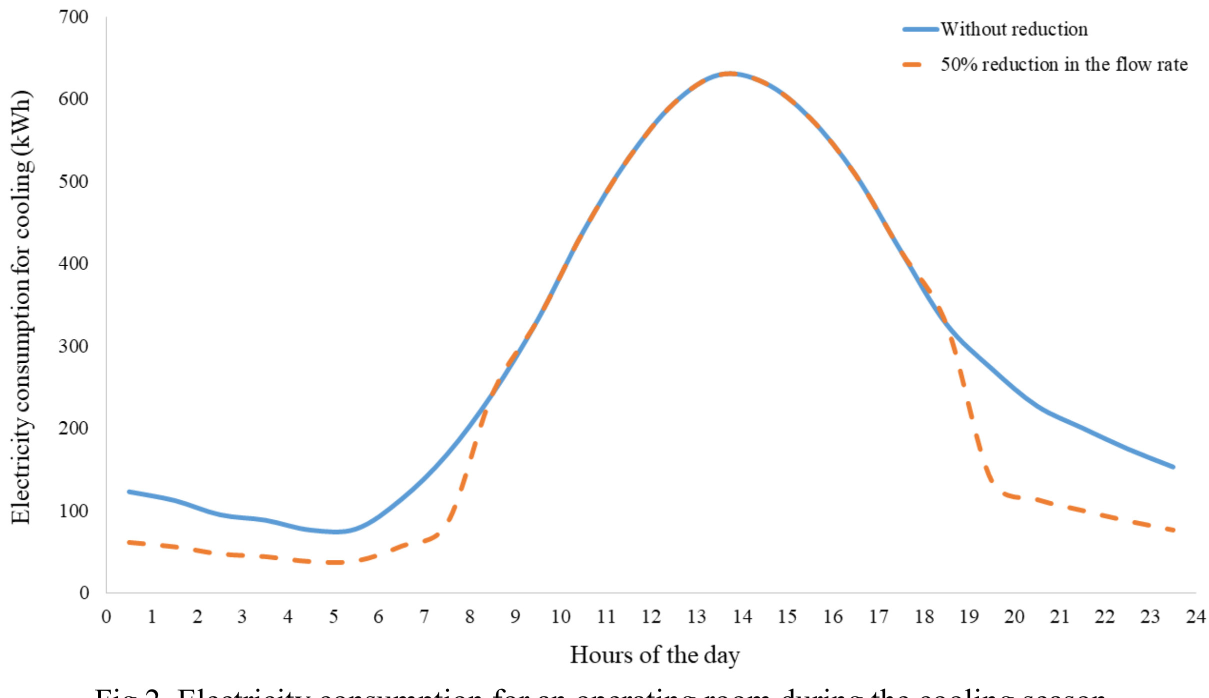

Fig.2. Electricity consumption for an operating room during the cooling season

This assumption is based on the modeling we have conducted as part of the study. The model incorporates various parameters including thermal loads, ventilation requirements, and pressure stability to ensure the feasibility of the proposed airflow reduction.

This theoretical framework serves as a basis for estimating potential energy savings while maintaining operational and safety standards within the operating room.

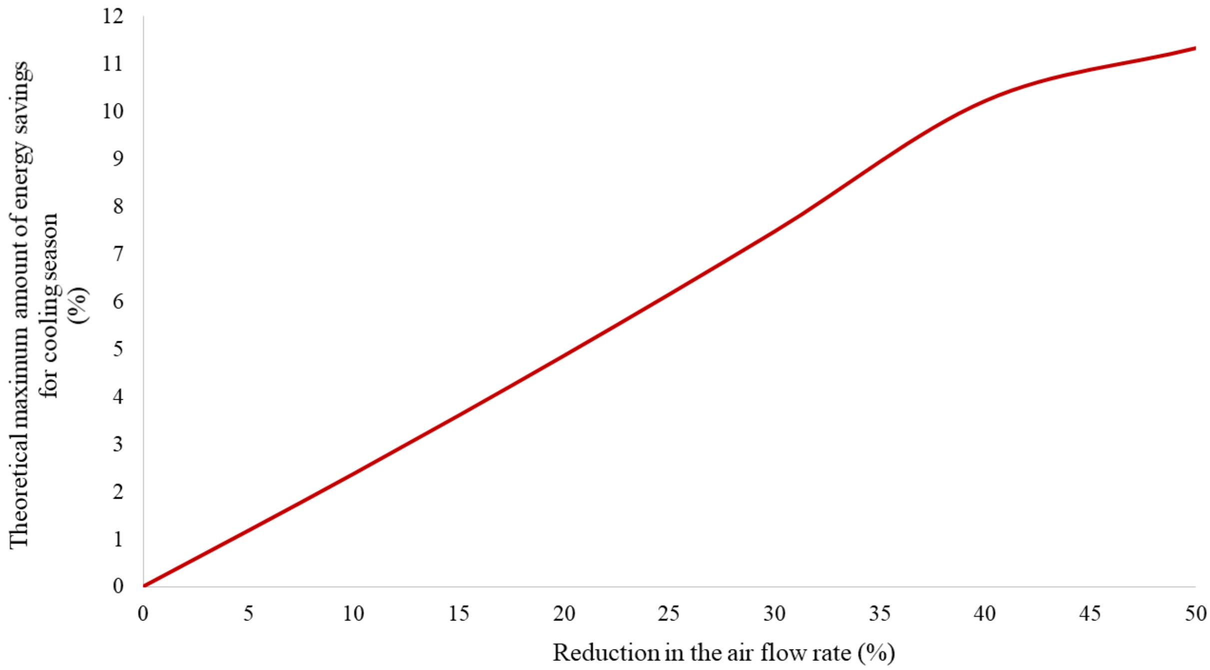

Fig. 3. The theoretical maximum energy savings in operating rooms for night mode ventilation based on different airflow reduction rates.

This relatively modest saving is due to lower outside temperatures and decreased cooling demand at night. At the hospital level, the annual electricity consumption is 1,239 MWh/year, with 255,182 kWh (20.6% of total) attributed to cooling operating rooms. Considering there are 36 active operating rooms in the hospital, the cumulative theoretical maximum energy saving potential reaches 28,918 kWh annually.

Importantly, achieving this saving potential would require only the implementation of automated ventilation control systems, making it a cost-effective and feasible energy efficiency measure

The level of energy savings from operating room cooling can be estimated for any desired airflow reduction rate between 0% and 50% by referring to Figure 3. Implementing night mode ventilation control during the cooling season results in an 11.3% electricity savings for operating room air conditioning. This corresponds to an overall 2.33% reduction in annual hospital electricity consumption.

3. Results and discussion

In this study, the theoretical energy gain that can be achieved for surgeries performed at temperatures between 18 and 19 °C has been calculated. When considering surgeries performed at temperatures ranging from 15 to 26 °C, the potential for energy savings will vary for each operating room depending on its specific temperature conditions. This study focused on a single operating room. In our next phase of research, all operating rooms will be considered, and a comprehensive calculation will be conducted to determine which surgery type corresponds to which temperature range and the associated percentage distribution. Future studies will also aim to determine an average operating room temperature based on the number and types of surgeries performed. Energy savings calculations will then be updated accordingly within this context.

Additionally, this study only assessed data from the province of Izmir. In our subsequent research, different climate zones across Türkiye will be evaluated to determine the energy savings potential for each zone. This will provide a comprehensive overview of the potential savings throughout the country.

We will investigate the thermal comfort conditions in the operating room by using the mood state correction factor proposed by Özkurt et al. [21]. Psychological factors significantly influence thermal sensation and, consequently, HVAC usage behavior. In hospital settings, psychological adaptation—or the changes experienced by individuals during their stay—is a critical consideration. Accounting for these effects is essential when evaluating thermal comfort and optimizing environmental control strategies in healthcare facilities.

According to the Hospital Air Conditioning System Design and Control Principles [20], in accordance with ASHRAE standards, the total ACH in operating rooms in Türkiye should be 25. This standard ensures proper ventilation, infection control, and thermal comfort in critical healthcare environments such as operating rooms. Maintaining this air change rate is essential for meeting hygiene and safety requirements in surgical settings. Future research should focus on the extent to which airflow rates can be further reduced without compromising pressure conditions during non-use periods. Moreover, there is a need to investigate energy-saving opportunities in operating rooms that remain unused during daytime hours, as cooling demand is highest during this period.

Even in night mode, the formation of negative pressure inside the operating room must be strictly prevented. To maintain a minimum positive pressure of 10 Pa within the room, the reduced airflow rate should be carefully determined for each hospital through real-time measurements. Since the architectural layout, HVAC configuration, and usage patterns may vary, different airflow reduction rates will be necessary for each operating room. Therefore, recommending a single, fixed airflow value would not be appropriate from a healthcare safety perspective. Customized analysis and adjustment for each operating room are essential to ensure both energy savings and compliance with hygiene and pressure control standards.

Implementing night mode ventilation control in operating rooms, especially in city hospitals in Türkiye, would be a beneficial step toward reducing energy consumption. With data obtained from such implementations, this strategy could be mandated in the design and construction of future zero energy healthcare facilities, contributing significantly to environmental sustainability and operational cost savings.

There is no additional cost for implementing night mode in systems equipped with inverter-controlled motors. In such systems, only the time intervals need to be configured via the automation system, and the motor speeds can be reduced accordingly. However, for electric motor systems that do not have inverter control, an upgrade to inverter-controlled operation is required. The investment necessary for this conversion will be evaluated, and the payback period will be calculated in detail in future studies. This analysis is essential for understanding the financial feasibility and energy-saving potential of implementing night mode across different types of HVAC systems.

4. Conclusion

Hospitals are among the highest energy-consuming buildings, and generating their own energy from renewable sources offers substantial economic and environmental benefits. The increasing number of successful zero-energy hospital implementations worldwide demonstrates the feasibility of this concept. The following main concluding remarks are drawn from the present study:

- Cooling energy consumption can be reduced by 13.4 kWh/m² by lowering the airflow rate during non-use hours (night mode) in operating rooms. It was calculated that up to 803.3 kWh of energy can be saved annually in an operating room by reducing the airflow rate during non-use hours (night mode), while maintaining the required pressure relationships.
- Implementing a 50% reduction in airflow rate results in an 11.3% electricity savings during the cooling period for operating room air conditioning.
- The measured air change rate was approximately 26.2 ACH, which aligns well with the American ASHRAE standard of 25 ACH for operating rooms.
- Currently, only 22.7% of the total air conditioning electricity consumption in operating rooms occurs during night mode hours (20:00–08:00), while the remaining 77.3% is consumed during daytime. Notably, although daytime cooling accounts for 65.7% of the total cooling demand, it represents a disproportionate 77.3% of the electricity consumption. This is primarily due to the reduced efficiency of cooling units at higher outdoor temperatures during the day, whereas they operate more efficiently at night, resulting in lower electricity usage.
- Applying night mode operation can improve overall hospital electricity consumption by approximately 2.33%.

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