KMÜ Sosyal ve Ekonomik Araştırmalar Dergisi (KMUSEKAD)
KMU Journal of Social and Economic Research
Yıl/Year: 2025, 27(50): 1421-1438

Geliş/Received: 20.10.2024
Kabul/Accepted: 26.11.2025
Doi: 10.18493/kmusekad.1570580

SYSTEMATIC REVIEW OF STUDIES ON ENERGY EFFICIENCY IN HOSPITALS

Mustafa KAYA[1]

Abstract

As a result of the introduction of a new technological development into our lives every day, the use of energy consumption is increasing. Considering that most of the electricity still used is produced from fossil fuels, it is a fact that we should not forget that we need to save on energy consumption. Health institutions are institutions where intensive technology is used and uninterrupted service is provided. For this reason, it is one of the areas where energy-saving studies should be implemented as a priority. Conducting studies on this subject and implementing practices in line with the results of the study will provide energy savings. It is more important to carry out these studies in countries dependent on foreign energy. For this reason, in this study, it is aimed to make a systematic review of the studies conducted in Türkiye or at least one of the authors is Turkish and the studies on energy efficiency in hospitals. This study summarizes which studies have been conducted on this topic, the areas of focus, the methods used and the results of the studies. It is thought that this study will provide information to researchers working on the subject.

Anahtar Kelimeler: Energy Efficiency, Energy Saving, Hospitals, Systematic Review
JEL Sınıflandırması: I18; Q43; O38

HASTANELERDE ENERJİ VERİMLİLİĞİ ÜZERİNE YAPILAN ÇALIŞMALARIN SİSTEMATİK İNCELEMESİ

Öz

Her geçen gün yeni bir teknolojik gelişmenin hayatımıza girmesi sonucunda enerji tüketimi de artmaktadır. Halen kullanılan elektriğin büyük bir kısmının fosil yakıtlardan üretildiği düşünüldüğünde enerji tüketiminde tasarruf etmemiz gerektiği unutmamamız gereken bir gerçektir. Sağlık kurumları, yoğun teknolojinin kullanıldığı ve kesintisiz hizmetin verildiği kurumlardır. Bu nedenle enerji tasarrufu çalışmalarının öncelikli olarak uygulanması gereken alanlardan biridir. Bu konuda çalışmalar yapılması ve çalışma sonuçları doğrultusunda uygulamaların hayata geçirilmesi enerji tasarrufu sağlamada etkili olacaktır. Enerjide dışa bağımlı ülkelerde bu çalışmaların yapılması ise daha büyük önem taşımaktadır. Bu nedenle bu çalışmada Türkiye'de yapılan veya yazarlarından en az biri Türk olan ve hastanelerde enerji verimliliği konusunda yapılan çalışmaların sistematik bir derlemesinin yapılması amaçlanmıştır. Bu çalışma, bu konuda hangi çalışmaların yapıldığını, odaklanılan alanları, kullanılan yöntemleri ve çalışmaların sonuçlarını özetlemektedir. Bu çalışmanın konu üzerinde çalışan araştırmacılara bilgi sağlayacağı düşünülmektedir.

Keywords: Enerji Verimliliği, Enerji Tasarrufu, Hastaneler, Sistematik İnceleme
JEL Classification: I18; Q43; O38

[1] Dr. Öğr. Üyesi, Kırıkkale Üniversitesi, Sağlık Bilimleri Fakültesi, Sağlık Yönetimi Bölümü, e-mail: mustafa_519@hotmail.com, Orcid ID: https://orcid.org/my-orcid?orcid=0000-0002-2005-5370

1. INTRODUCTION

The evolution in production and consumption has shifted from labor intensive to technology intensive in the provision of products and services. Production, which was previously carried out using manpower or mechanical power, is now carried out with less power with the help of technological possibilities. However, this technological development has increased the demand for energy day by day. On the other hand, the increase in human population and the decrease in fossil fuels used in energy production have made energy saving and energy efficiency mandatory. Considering the diminishing energy resources, economic difficulties and the release of harmful gases into nature, energy conservation and efficiency are the most important options (Gillingham et al., 2009:12). Although energy conservation and energy efficiency are defined in different ways, they are generally defined as the absolute reduction in energy demand measured in energy units, and energy efficiency as the improvement (increase) in the efficiency with which energy is used to provide a specific product or service per unit of energy. It may be possible to provide the same level of energy service or output with a lower energy consumption, and therefore efforts in this regard should be sustained (Linares and Labandeira, 2010:573). The benefits of energy conservation are generally as follows (Heur, 2008; Teke and Timur, 2013:59; EPA, 2006: 14):

- Reduces maintenance and operating costs.
- Reduced costs reflect positively on consumers.
- Greenhouse gases and air pollution are reduced.
- Foreign dependence on energy decreases.
- Competitiveness of businesses increases.

The scarcity of resources makes it necessary to save energy in all areas. Prioritizing the areas to be implemented during savings planning makes the steps taken in energy efficiency effective and strong. Variables affecting energy consumption such as energy consumption, working hours, and size of the application area should be taken into consideration when implementing energy savings at the national or international level. Hospitals are institutions that provide 24/7 uninterrupted service and consume high energy (U.S. Department of Energy, 2009). Depending on the energy demand, they also have a significant share in CO2 emission pollution caused mostly by fossil fuel-based consumption (Söğüt, 2023:1). A European study showed that hospitals account for 10% of total energy use and about 5% of CO2 emissions (European Commission, 2020; Pichler et al., 2019:1), making them one of the highest energy consumers among all non-residential buildings (Alexis and Liakos, 2013:488). Considering their working hours and energy consumption, hospitals are among the top institutions where energy savings can be implemented and energy efficiency can be achieved.

The health system, which is one of the most critical elements for the development and welfare of the society, has become a huge sector today. Although the budget allocated by countries for health expenditures varies according to their level of development, this ratio covers a significant portion of the total budget (Nour et al., 2020:1). The increase in the number of hospitals and the increasing need for energy in hospitals equipped with new technology have recently increased the importance of efficiency practices in hospitals and the number of practices implemented. Exterior insulation, isolation of heating and cooling system pipes, opening the front of radiators, replacing inefficient motors, using high efficiency heat pumps in heating-cooling, meeting hot water with solar thermal systems, cogeneration and trigeneration applications, smart and economical lighting are among the applications that can be

used in all buildings. In addition to these, ensuring the pressure relations of the pressure chambers in the hospital in a proper way and preferring oil-free compressors in hospitals, using filtered air conditioning systems that prevent contamination, and arranging intensive care units as single rooms are practices that increase energy efficiency (Mousavi et al., 2014:316 ; Yılmazoğlu, 2016:39; Yılmazoğlu, 2022:60).

Many circulars on energy saving or energy efficiency have been issued in Türkiye in recent years. These circulars, which specifically address public buildings, include the improvement of practices and deficiencies that lead to energy waste and increase consumption in buildings. The latest of these circulars, the Presidential Circular No. 2023/15 dated 04/11/2023, obliges buildings with a total annual energy consumption of 250 TOE or more or a total construction area of 10,000 m2 or more to have an energy manager. It also includes 25 articles such as preventing heat losses, switching to energy efficient lighting systems, sheathing of buildings and electric vehicles to be purchased from now on (Official Gazette, 2023). Steps have also been taken towards energy efficiency in health services. In 2012, the Energy Efficiency in Health (SEVER) Project was launched to increase energy efficiency in health services in Türkiye, and it was aimed to make LEED, the international green building certification system, mandatory for all hospitals with a capacity of 200 beds or more and to initiate the "Green Hospital" era in Türkiye (Ministry of Health, 2013).

In countries like Türkiye, which are dependent on foreign energy, energy saving and energy efficiency are of greater importance. For this reason, this study aims to conduct a systematic review of studies on energy efficiency in hospitals conducted in Türkiye or where at least one of the authors is Turkish.

The articles identified by searching the databases were listed by the researcher with their names. Study titles and abstracts were checked and duplicate articles were identified. Then, the titles and abstracts of the remaining articles were checked again and the studies on energy efficiency in hospitals written in Turkish or English were included in the research. As a result of the screening, 20 studies (Figure 1) that were found to meet the relevant criteria were included in the scope of the review (Annex 1). The scans were reviewed three times by the author to ensure critical quality assessment and then reviewed and verified for accuracy by two investigators. The studies included in this study were coded into a database created by the researcher using Microsoft Office Excel according to the determined categories. The articles obtained as a result of the scanning were numbered to facilitate the use of later researchers and presented as author, year, purpose of the study, method of analysis, source of the data used and conclusion. Thus, both the strength of evidence of the study was increased and its confirmation was facilitated.

2. METHOD

This study used a systematic review method for data collection, analysis, interpretation and reporting. This method allows gathering evidence to answer a predefined research question, identifying all primary research relevant to the research question, critically evaluating that research, and synthesizing the results (Gough et al., 2012). The study was conducted and reported in accordance with the most preferred PRISMA flow diagram for Systematic Reviews and Meta-Analyses. This study used a systematic review method for data collection, analysis, interpretation and reporting. This method allows gathering evidence to answer a predefined research question, identifying all primary research relevant to the research question, critically evaluating that research, and synthesizing the results (Gough et al., 2012). The study was conducted and reported in accordance with the most preferred PRISMA flow diagram for Systematic reviews and Meta-Analyses (Moher et al., 2009:3). Three different

databases were searched in the study. The databases, keywords used in the search and inclusion criteria are shown in Table 1.

Table 1. Search Criteria, Indexes/Databases and Keywords

Databases	Web of Science Core Collection, Scopus, Pubmed
Keywords	"Hospital" and "Energy Efficience" and "Turkey" or "Hospital" and "Energy Efficience" and "Türkiye"
Inclusion Criteria	To have been published between 2014-2023
	Published in a peer-reviewed journal
	English or Turkish
	Study on energy efficiency in hospitals
	Research article
	Availability of the full text
	The field of study is Türkiye or at least one of the authors is Turkish.

The review flowchart, which determines the studies to be included in the research and is created according to the PRISMA guidelines, is shown in Figure 1.

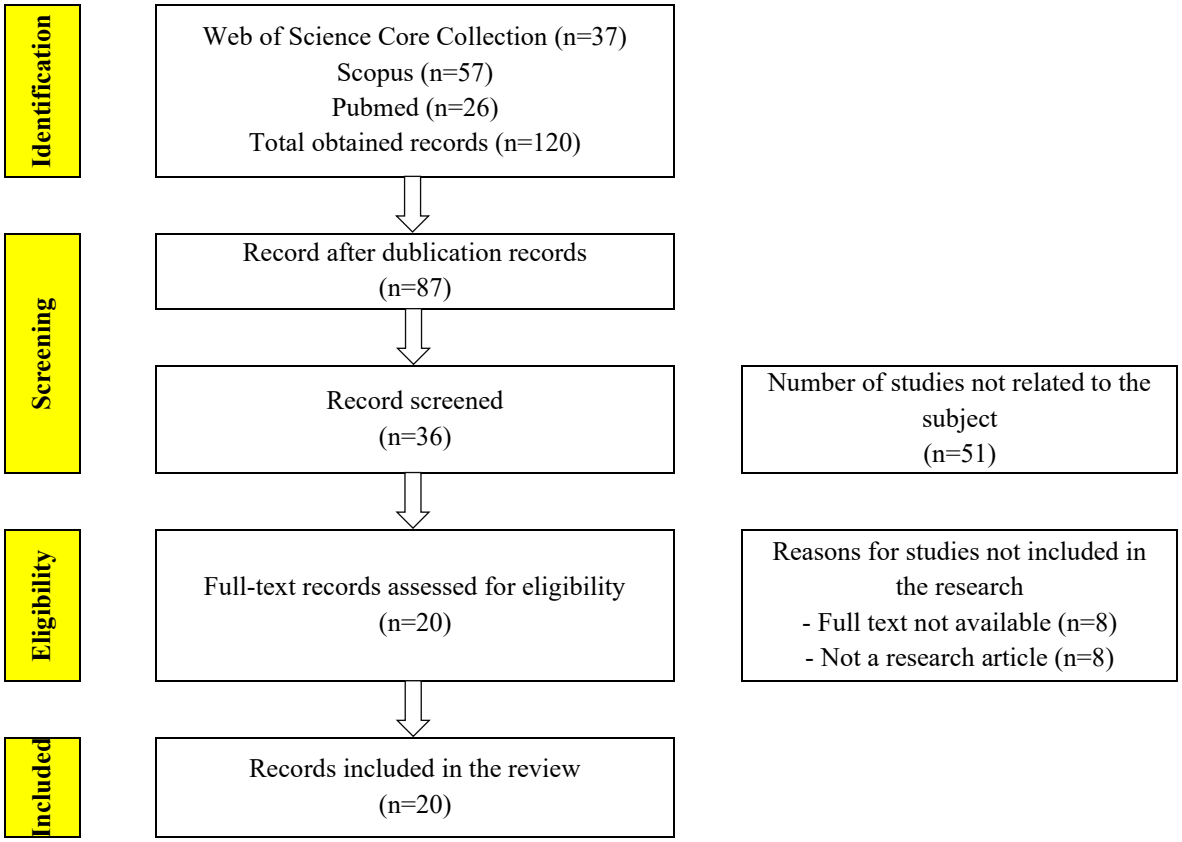


Figure 1. Study Selection Flowchart According to PRISMA Guidelines

Since the study aimed to reach the main articles on energy efficiency in hospitals in Türkiye, the simplest possible search form was used and for this reason, the keywords "energy efficiency", "hospitals" and "Turkey or Türkiye" were used. The articles identified by searching the databases were

listed by the researcher with their names. Study titles and abstracts were checked and duplicate articles were identified. Then, the titles and abstracts of the remaining articles were checked again and the studies on energy efficiency in hospitals written in Turkish or English were included in the research. As a result of the screening, 20 studies (Figure 1) that were found to meet the relevant criteria were included in the scope of the review (Annex 1). The scans were reviewed three times by the author to ensure critical quality assessment and then reviewed and verified by Critical Appraisal Skills Programme (CASP) qualitative checklist tool for accuracy by two investigators. The studies included in this study were coded into a database created by the researcher using Microsoft Office Excel according to the determined categories. The articles obtained as a result of the scanning were numbered to facilitate the use of later researchers and presented as author, year, purpose of the study, method of analysis, source of the data used and conclusion. Thus, both the strength of evidence of the study was increased and its confirmation was facilitated.

3. RESULTS

3.1. Descriptive Results

The studies obtained as a result of the review are summarized in Annex 1 according to author, year, purpose of the study, method of the study, data used and results variables. Then, the 20 studies included in the study were grouped and evaluated according to the titles of purpose, method and data used.

Among the studies, 40.0% of the studies were on energy management (energy consumption of different applications, country comparisons, heating/cooling); 40.0% were on energy saving for building or design (material used, position of the building facade in relation to the sun, number of windows, natural lighting); and 20.0% were on energy consumption in medical devices used in hospitals (autoclave device, pneumatic systems).

The most commonly used method in the studies was observational field research (28.5%). Other methods used include machine learning, data envelopment analysis, regression analysis, multi-criteria decision making, artificial neural networks, modeling and energy/exergy analysis. Comparisons with recognized standards were also used.

The data used in the 20 studies were also reviewed. 65.0% of the studies used primary data; 20.0% used secondary data. In 3 studies (15.0%), constructed scenario data were used. Researchers using primary data obtained the data from the device or the whole hospital they examined. Researchers using secondary data analyzed using previously published data.

3.2. Interpretive Results

As a result of the in-depth analysis, it was seen that the vast majority of the studies worked on existing buildings/structures or devices. These studies investigated how to make the current situation more energy efficient.

Researchers working on devices have addressed the working systems or physical structures of the devices. For example, in two of the studies, the heat loss of the autoclave device, which is frequently used in hospitals, and the reuse of this heat were investigated. In another study on the pneumatic system used for transportation in hospitals, it was aimed to develop the most efficient pneumatic system model that reduces energy consumption.

Studies focusing on the building/structure have dealt with the lighting, heating, cooling and losses that occur in buildings. In the studies dealing with lighting, the materials used for lighting, the

number and size of windows to utilize natural light, the position of the building in relation to the sun, the facade and the architectural structure of the building were examined. Studies on heating and cooling systems in buildings examined the type of energy used in heating and cooling, the availability of renewable energy sources in heating and cooling systems, the best choice according to climate and region, and regional comparisons. Studies on energy losses in buildings have examined the materials used in building construction, the state of the building's sheathing, the state of solarization in order to utilize natural heat, the facade systems in the building and the facades of the building positioned according to the sun.

Some of the studies obtained as a result of the scanning worked on a scenario they determined instead of the existing structure/design or device and tried to achieve the most energy efficient results in the issues they addressed in the scenario.

The main results obtained from the reviewed studies using different objectives, methods and data sets are as follows:

- Energy savings can be achieved through energy efficiency in buildings utilizing daylight.

- The use of renewable energy sources in lighting increases energy savings and reduces emissions.

- Improvements to the autoclave device can reduce heat loss and energy savings can be achieved by reusing the leaked heat.

- LEED certified buildings save billions of dollars in energy costs and reduce carbon emissions.

- Lack of insulation in the walls increases carbon dioxide emissions by 10%.

- The materials selected when creating the units of hospitals and the location of the relevant units within the hospital can increase energy efficiency.

- Energy efficiency is the most important variable of energy performance management.

- The cogeneration system has a static payback period of 2.41 years and a dynamic payback period of 2.85 years; the trigeneration system has a static payback period of 3.13 years and a dynamic payback period of 3.86 years.

- The most energy consuming devices are laboratory equipment, ventilation equipment and imaging devices that exhaust indoor air.

4. CONCLUSION

Energy efficiency is one of the important agenda items of today. The fact that energy is not unlimited and the demand is increasing day by day keeps the issue on the agenda and studies and applications are carried out on the subject. In order for the applications to be carried out in practice to become more efficient, they need to be examined and analysed by scientists. In the reviewed literature, it has been observed that studies on energy efficiency in hospitals are not very numerous. Increasing these studies plays an important role in proving the effectiveness of the applications and increasing their efficiency. Studies such as systematic review and meta-analysis, in which these studies are examined collectively in line with certain criteria, serve as a guiding guide for researchers and readers by summarising the literature on the subject.

Prior to this study, it was observed that there were a limited number of studies on energy efficiency in hospitals in Türkiye. Tiftik (2022:419) also mentioned energy efficiency in his study on sustainability in health enterprises. In his systematic review of the national literature, four of the nine

studies he discussed consist of studies on energy efficiency. Aygün et al. (2025:123), who analysed the studies on the relationship between health and energy in the international literature by content analysis method, reached 118 studies published between 2017-2021. It was concluded that 81.36% of the studies focusing on issues such as energy efficiency, energy poverty and energy use were practical studies. None of the studies in the international literature were published in Türkiye and only one of the 118 studies included a researcher from Türkiye.

A systematic review of studies on energy efficiency in healthcare organizations is thought to provide useful information in the field of energy efficiency, which is one of the important issues of today. The fact that Türkiye is the application area of the study on the subject in the international literature or that at least one of the authors of the study is a researcher from Türkiye distinguishes this study from other studies. In this study, it has been compiled which points the researchers working on energy efficiency have focused on in hospitals, what are the things that reduce energy efficiency, how they can be intervened, and what implemantations can be made to increase efficiency.

Most of the studies reviewed focused on energy losses and energy efficiency improvements for existing hospitals or existing devices or systems used in hospitals. Considering the high cost of buildings, devices and systems, it can be said that the focus of the studies is very accurate. It has been observed that small touches to be made to the buildings, devices or systems used (installation of newly created apparatus to devices, prevention of factors causing losses, sensors, thermal insulation, etc.) increase energy efficiency and reduce carbon emissions. Upgrading and utilizing end-of-life buildings, devices and systems is also important to support the circular economy.

Another issue addressed in the studies is making fundamental changes in buildings. Changes in the building structure, redesign of heating and cooling systems, replacement of the devices used with newly developed devices are some of these changes. These changes are costly, time-consuming and may prevent business for a while in institutions that need to provide uninterrupted service. However, these changes are also supported, taking into account the lifespan of the buildings or devices, once it is determined through analysis that they will increase energy efficiency in the long term.

The last area of the studies is scenarios that will guide future investments. In these studies, different scenarios have been analyzed for different situations and recommendations have been made according to both region and climate.

In today's world where energy is becoming a bigger and bigger problem, it is recommended that the results of scientific studies on this subject should be taken into consideration, and studies on energy efficiency should be supported and increased. Both the results of the previous review studies and the results of this study show that the number of studies on energy efficiency in health institutions in Türkiye is low. Considering that Türkiye is largely dependent on foreign energy, it is necessary to emphasise once again the inadequacy of this number. It is thought that studies to increase energy efficiency should be increased in institutions, especially hospitals, which provide 24-hour uninterrupted service and consume intensive energy.

Ethical Statement

In the writing and publication processes of the study titled “Systematic Review of Studies on Energy Efficiency in Hospitals” research and publication ethics have been strictly adhered to, and no data manipulation has been conducted. Ethics committee approval was not required for this study.

Contribution Rate Statement

The author of the study has contributed to all stages of the study, from writing to drafting, and has approved the final version after reviewing it.

Conflict Statement

This study did not lead to any individual or institutional/organizational conflict of interest.

REFERENCES

Alexis, G.K., and Liakos, P. (2013) A Case Study of A Cogeneration System for A Hospital in Greece. Economic and Environmental Impacts. *Applied Thermal Engineering*, 54(2), 488-496.

As, M., and Bilir, T. (2023). Enhancing Energy Efficiency and Cost-Effectiveness While Reducing CO2 Emissions in A Hospital Building. *Journal of Building Engineering*, 78, 107792.

As, M., and Bilir, T. (2024). Machine Learning Algorithms For Energy Efficiency: Mitigating Carbon Dioxide Emissions and Optimizing Costs in A Hospital İnfrastructure. *Energy and Buildings*, 318, 114494.

Aycam, İ., and Yazici, A. (2017). Evaluation of Operating Room Units within The Context Of Green Design Criteria. *Gazi University Journal of Science*, 30(1), 1-15.

Aygün, S., Onaran, S., and Altun, U. (2025). Evaluation of Studies on Health and Energy Relationship with Content Analysis Method. *Çukurova University Journal of Institute of Social Sciences*, 34(1), 118-133.

Çakmak Barsbay, M. (2020). Energy Efficiency Analysis in Public Hospitals: An Application Based on Radial and Non-Radial Data Envelopment Analysis Models. *Pamukkale University Journal of Engineering Sciences*, 27(1), 35-42.

Çakmak, B., and Yol, Ş. (2019). Medical Device Energy Consumption Analysis. In Proceedings of the 2019 Medical Technologies Congress (TIPTEKNO) (pp. 1-4).

EPA, US Environmental Protection Agency. Energy Efficiency: Reduce Energy Bills, Protect The Environment. National Action Plan for Energy Efficiency. P:1–4. https://www.epa.gov/sites/default/files/2015-08/documents/vision.pdf

European Commission (2020). EU Buildings Datamapper, Share of Non-Residential in Total Building Floor Area. https://ec.europa.eu/energy/en/eu-buildings-datamapper (06.10.2024).

Gillingham, K., Newell, R. G., and Palmer, K. (2009). Energy Efficiency Economics and Policy. *Annu. Rev. Resour. Econ.*, 1(1), 597-620.

Gough, D., Oliver, S., and Thomas, J. (2012). *An Introduction to Systematic Reviews*. London: SAGE Publications Ltd.

Heur, R.V. (2008). Power Quality Utilization Guide: Hospitals Energy Efficiency. European Copper Institute. *Leonardo Energ*, 1–24.

Himmetoğlu, S., Delice, Y., Aydoğan, E. K., and Uzal, B. (2022). Green Building Envelope Designs in Different Climate and Seismic Zones: Multi-Objective ANN-Based Genetic Algorithm. *Sustainable Energy Technologies and Assessments*, 53, 102505.

Karakasli, E., Oztop, H. F., and Hepbasli, A. (2016). Performance Assessment of A Polyclinic Heating and Cooling System in A Hospital Building. *International Journal of Exergy*, 21(1), 70-86.

Kilkis, B. I. (2014). An Exergy-Based Algorithm for Optimizing CHP Systems in Health Facilities. *ASHRAE Transactions*, 120(1).

Koç, A., and Ulusam Seçkiner, S. (2024). Measuring Energy-Based Environmental Efficiency of Buildings Using Data Envelopment Analysis Models-A Hospital Application Case. *International Journal of Energy Sector Management*, 18(4), 812-833.

Kuzgunkaya, E. H. (2019). Energy Performance Assessment in Terms of Primary Energy and Exergy Analyses of The Nursing Home and Rehabilitation Center. *Energy & Environment*, 30(8), 1506-1520.

Linares, P., and Labandeira, X. (2010). Energy Efficiency: Economics and Policy. *Journal of economic Surveys*, 24(3), 573-592.

MacNaughton, P., Cao, X., Buonocore, J., Cedeno-Laurent, J., Spengler, J., Bernstein, A., and Allen, J. (2018). Energy Savings, Emission Reductions, and Health Co-Benefits of The Green Building Movement. *J. Expo. Sci. Environ. Epidemiol,* 28(4), 307-318.

Ministry of Health (2013). Energy Efficiency in Health Project, https://www.saglik.gov.tr/TR-11482/enerji-verimliligi.html (06.10.2024).

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., and The PRISMA Group. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med 2009*, 6:e1000097.

Mousavi, S., Kara, S., and Kornfeld, B. (2014). Energy Efficiency of Compressed Air Systems. *Procedia CIRP*, 15, 313-318

Nour, M., Sindi, H., Abozinadah, E., Öztürk, Ş., and Polat, K. (2020). A Healthcare Evaluation System Based on Automated Weighted Indicators With Cross-Indicators Based Learning Approach in Terms of Energy Management and Cybersecurity. *International Journal of Medical Informatics*, 144, 104300.

Othan, O., and Omar, M. A. (2023). Thermo-Economic Study of Two Different Combined Heat-Power System for A Hospital. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 38(3), 1467-1480.

Official Gazette (2023). Circular on Energy Saving in Public Buildings, 4.11.2023, Official Gazette No. 32359. https://www.resmigazete.gov.tr/eskiler/2023/11/20231104-5.pdf (06.10.2024).

Pooyanfar, M., and Topal, H. (2018). Assessing Effectıveness of Integrated Building Design Parameters on Energy Performance and Emissions in Health Care Facilities By Means of Building Energy Modelling. *Journal of Thermal Science and Technology*, 38(2), 151-165.

Sahin, M. E. (2022). Autoclave Device Exergy and Energy Analysis in Hospital Sterilization Units. *Thermal Science*, 26(4 Part A), 2955-2961.

Solak, G., Kıyak, İ., and Spor, A. (2019). Artificial Intelligence Supported Healthy Unit Hybrid Lighting Control. In Proceedings of 2019 International Conference on Applied Automation and Industrial Diagnostics (ICAAID) (Vol. 1, pp. 1-5). IEEE.

Söğüt, M.Z. (2023). Criteria of Environmental Sustainability for Hospitals; Energy Efficiency and Management. In Proceedings of 15th National Installation Engineering Congress // 26-29 April 2023 / Izmir.

Şahin, M. E., and Elbir, A. (2024). Energy Analysis of The Absorption Cooling Cycle From The Waste Heat of The Hospital Sterilization Unit. *Environmental Progress & Sustainable Energy*, 43(2), e14305.

Takgil, B., and Kara, R. (2024). Proposing A Novel Mathematical Model for Hospital Pneumatic System. *An International Journal of Optimization and Control: Theories & Applications (IJOCTA)*, 14(2), 113-122.

Teke, A., and Timur, O. (2013). Lighting Systems at The Hospitals: An Overview. *Majlesi J Energy Manage 2013*;2:39–51.

Teke, A., Timur, O., and Bayındır, K. Ç. (2016). Development and Testing of An Energy Saving Tool–Suitability Analysis with Case Study. *International Journal of Electrical Power & Energy Systems*, 77, 59-69.

Tiftik, C. (2022). Sustainability in Health Sector Organisations: A Systematic Review Study. *Düzce University Journal of Social Sciences*, 12(1), 404-426.

The U.S. Department of Energy (DOE) (2009). Join the Hospita Energy Alliance, https://www1.eere.energy.gov/buildings/publications/pdfs/alliances/hospital_energy_alliance_fact_sheet.pdf, (06.10.2024).

Yılmazoğlu M.Z. (2016). Hastanelerde Enerji Yönetimi, *TTMD Dergisi*, 102, 38-46

Yılmazoglu, Z. (2022). Different Energy Efficiency Practices for Hospitals Compared to Other Buildings. *Engineer and Machine,* 63(706), 55-66.

Yüksel, S., Eti, S., Dinçer, H., Gökalp, Y., Yavuz, D., Mikhaylov, A., and Pinter, G. (2024). Prioritizing The Indicators of Energy Performance Management: A Novel Fuzzy Decision-Making Approach for G7 Service Industries. *Environmental Research Communications*, 6(1), 015003.

Extended Abstract

Systematic Review of Studies on Energy Efficiency in Hospitals

Aim: This study aimed to conduct a systematic review of studies on energy efficiency in hospitals. The fact that the studies were conducted in Türkiye or that at least one of the authors is Turkish is one of the aspects that make the study different. **Method:** Systematic review method was used in the study. This method allows for a comprehensive examination of the studies obtained as a result of reviewing the literature according to the determined topics and criteria, and for defining and grouping them according to certain headings. Web of Science, SCOPUS and PubMed databases were examined to obtain studies on the identified topic. Then, relevant studies were identified. Which of these studies will be included in the study was made according to the criteria (To have been published between 2014-2023, published in a peer-reviewed journal, English or Turkish, study on energy efficiency in hospitals, research article, availability of the full text, the field of study is Türkiye or at least one of the authors is Turkish) determined before the research. The PRISMA flow diagram was utilized while sifting through the studies. As a result of the PRISMA flow diagram, the remaining studies were examined and tabulated and presented.

Results: As a result of the search conducted by entering the relevant criteria in the determined databases, a total of 120 studies, 37 in WoS, 57 in SCOPUS and 26 in PubMed, were reached. Duplicate studies were eliminated to prevent dublication and 87 studies remained as a result of the elimination. After examining the remaining studies, 51 studies that were not relevant to the subject were identified and these studies were excluded from the scope of the study. After the third stage of PRISMA, 36 studies remained. From these studies, 8 studies whose full text could not be accessed and 8 studies that were not reserch articles were also excluded, leaving 20 articles that met the research criteria. The 20 studies identified as a result of PRISMA were examined in detail and the author/authors, year, purpose of the study, method of analysis, data collection method and conclusions of these studies were summarized in tables. It has been found that utilizing daylight, using energy-efficient light bulbs and insulating materials in walls saves energy and reduces carbon emissions. Reducing heat losses in devices that process heat and reusing the leaked heat, and determining the correct location of the relevant units in the hospital also provide energy efficiency. Other results include that LEED-certified buildings save billions of dollars in energy costs; the most energy-consuming devices are laboratory equipment, ventilation equipment and imaging devices that exhaust indoor air; energy efficiency is the most important variable of energy performance management.

Conclusion: The study deals with studies on energy efficiency in hospitals conducted in Türkiye or where at least one of the authors is Turkish. It is thought that a systematic review of studies on energy efficiency in healthcare organizations will provide useful information in the field of energy efficiency, which is one of the important issues of today. In this study, it is compiled which points the researchers focus on in hospitals, what are the things that reduce energy efficiency, how they can be intervened and what practices can be done to increase efficiency. In general, the studies have indicated improvements that can be made to existing devices and buildings to increase energy efficiency and the rules to be considered in new buildings. These improvements and recommendations need to be implemented in order to save energy. Especially in energy-dependent countries, institutions that provide 24/7 uninterrupted service such as hospitals should be implemented without wasting any time. In addition to these results, it is thought that studies on the subject are insufficient for Türkiye, which is still an energy-poor country, and it is recommended to increase research.

Annex 1. Summary of articles evaluating energy efficiency in hospitals.

No	Author/Year	Purpose of the Study	Analysis Method	Data Collection Method	Conclusion
1	Kılkış, 2014	It aimed to present a basic optimization algorithm with two objectives: minimizing CO2 emissions and shortening the payback period of the investment when planning hospital constructions.	Multivariate Optimization	Scenario	Working on four scenarios, the author concluded that the optimization study can significantly improve exergy efficiency, fuel savings and reduce CO2 emissions by up to 50%.
2	Karakaşlı et al., 2016.	In this study, it is aimed to evaluate the heating and cooling performance of a hospital building heated by a natural gas boiler system using energy and exergy analysis methods.	Energy and Exergy Performance Analysis	A Hospital in Elazığ Province	The overall energy and exergy efficiencies of the heating and cooling system were found to be 13.4% and 1.35% respectively and recommendations were made to improve them.
3	Teke et al., 2016.	It is aimed to track and analyze electricity bills, recommend the best electricity tariff, control active and reactive power ratios, increase energy efficiency, and enable consumers to compare alternatives.	Delphi Programming	A University Hospital	It demonstrates the performance of the developed tool for optimization of commercial and industrial plants under different power consumption and load demand scenarios.
4	Ayçam and Yazıcı, 2017.	It is aimed to determine the studies that can be done on compliance with green building criteria in operating rooms with complex design features	Case Study According to Green Hospital Criteria	Private Memorial Hospital, Private Acıbadem Hospital, Private Bayındır	The operating rooms of five hospitals, which were built according to the mandatory rules, were compared in terms of energy efficiency, and the

		compared to other units of hospitals.		Hospital, Private Medicana International Hospital and Private TOBB ETÜ Hospital	green building criteria that each hospital met and failed to meet were determined. It is also stated that the materials selected while creating the operating rooms and the location of the relevant units within the hospital can increase energy efficiency.
5	Pooyanfar and Topal, 2018.	It is aimed to find possible solutions to reduce the energy consumption of hospital buildings in order to reduce energy and thus service costs.	Energy Modeling	Isparta State Hospital	It has been seen that it is possible to achieve significant savings and emissions can be reduced by about half if appropriate design and applications are realized for architectural, mechanical and lighting systems in hospital buildings and renewable energy sources are used.
6	MacNaughton et al., 2018.	It aimed to examine the co-benefits to health through reductions in energy use and associated reductions in air pollution according to LEED energy certification in six countries.	Harvard's Co-BE Calculator	Green Building Information Gateway	LEED certified buildings have been found to save 7.5 billion dollars in energy costs and reduce many harmful gases. This equates to $5.8 billion (lower bound = $2.3 billion, upper bound = $9.1 billion) in climate and health co-benefits between 2000 and 2016 in the

					six countries studied.
7	Nour et al., 2020.	Using hospital performance indicators in terms of energy management and cyber security, they aimed to automatically generate a performance score that can represent each individual that makes up the community.	Machine Learning	A ready-made dataset on health systems	120 countries' health systems were assessed for performance. The results show that the results of the proposed framework are highly compatible with today's expectations and are more applicable than other studies.
8	Solak et al., 2019.	A smart lighting system has been designed for the examination and observation rooms of a health institution using artificial intelligence to make maximum use of natural lighting.	Artificial Neural Networks	Scenario	It is concluded that the daylight-assisted system has positive effects on both patients and healthcare workers using these areas and provides energy savings with high energy efficiency.
9	Şahin. 2022.	It is aimed to determine the energy efficiency measurements for the autoclave device in the Sterilization Unit and to make recommendations.	Observational Field Research (Thermal Camera)	Isparta State Hospital	Since the exergy efficiency of the autoclave is 89.75% and the average exergy loss is 0.117655 kW, this efficiency value should be increased; also the total heat loss of the autoclave is calculated as 10%.
10	Şahin and Elbir, 2024.	In a sterilization unit, it is aimed to achieve a cooling load by adding an integrated sub-cycle to the waste steam heat of the autoclave device.	Observational Field Research	Süleyman Demirel University Sterilization Unit	Provided that the cooling temperature is 7 C, the generator temperature of 95 C and the cooling load of 130.9 W are generated by 531.7 W of waste heat

					taken by the absorption cooling system. Accordingly, an efficiency of COP 0.246 was achieved. Energy analysis of the absorption refrigeration cycle can improve the energy efficiency of the autoclave and save energy. It is also concluded that the cooling load achieved will be conserved in medical materials that need to be kept cold.
11	Hancıoğlu Kuzgunkaya, 2019.	It is aimed to analyze Narlıdere Nursing Home and Rehabilitation Center using actual energy consumption data obtained from various energy audits.	Observational Field Research	Izmir Narlidere Nursing Home and Rehabilitation Center	Low energy efficiency was observed throughout the organization, particularly in the heating and cooling system, and the use of renewable energy sources was recommended.
12	As and Bilir, 2023.	It is aimed to increase energy efficiency and cost effectiveness while reducing CO2 emissions in a hospital building.	Revit Modeling	A Private Hospital in Aksaray Province	The lack of insulation in the walls was found to cause a 10.09% increase in CO2 emissions and the importance of insulation was emphasized. It was also concluded that the wall/window ratio also increases CO2 emissions.
13	Çakmak and Yol, 2019.	The study aimed to raise awareness among medical	Observational Field Research	Medicalpark İzmir Hospital	Energy consumption amounts of all medical devices in

		device suppliers about optimizing energy while maintaining quality in the delivery of healthcare services.			the hospital and energy consumption by units were calculated, and the most energy consuming devices were found to be laboratory devices, ventilation equipment and imaging devices that exhaust indoor air. It was concluded that although bedside monitors and ECG devices have low energy consumption, they have a large share in consumption due to their large number.
14	Çakmak Barsbay, 2020.	It is intended to contribute to energy efficiency initiatives by demonstrating the need for the use of innovative managerial practices and metric tools.	Data Envelopment Analysis	20 Public Hospitals in Regions with Similar Climate Characteristics in Türkiye	According to both the radial and non-radial model, nine public hospitals were found to be efficient. Recommendations are also made for the inefficient hospitals.
15	Himmetoğlu et al., 2022.	It is aimed to present a multi-purpose green building approach that takes into account variables such as CO2 emissions, heating/cooling energy consumption and material cost in terms of life cycle cost analysis of the most appropriate green building designs for buildings in different climates	Simulation, Artificial Neural Network, Genetic Algorithm	Türkiye City Hospitals Projects	As a result of the research, a green building recommendation application was developed according to different regions and climate characteristics and it was concluded that the application made calculations with 99% accuracy.

		and earthquake zones.			
16	Othan and Omar, 2023.	It is aimed to investigate the applicability of cogeneration and trigeneration systems in a university hospital.	Observational Field Research-Thermo Economic Analysis	Kafkas University Health Research and Application Hospital	It has been determined that both systems will benefit hospitals in regions with Kars climate characteristics, but due to the high initial investment costs in trigeneration systems, it may be more advantageous to implement a cogeneration system for the hospital under study.
17	As and Bilir, 2024.	It is aimed to reduce carbon dioxide emissions and optimize costs in the hospital building.	Machine Learning	Scenario	Considering many characteristics of Bursa and Aksaray provinces, 1440 scenarios were developed. The model proved its effectiveness in accurately predicting CO2 emissions and closely predicting energy consumption, total and life cycle cost, while also proving to be adaptable to provinces with similar climate characteristics.
18	Koç and Ulusam Seçkiner, 2024.	It is aimed to examine the environmental efficiency of a hospital building based on energy exchange using energy-related and	Data Envelopment Analysis	A Hospital	It shows that energy-based environmental efficiency reaches its highest level in winter months, while summer months have the lowest efficiency values due to

		non-energy-related variables.			increased electricity consumption due to high cooling needs. It is concluded that the month with the highest efficiency in all periods is January with an average efficiency score of 0.936 and the lowest month is August with an average efficiency score of 0.406.
19	Yüksel et al., 2024.	The study aims to evaluate the main indicators of energy performance management systems and to identify the most effective indicators and ensure that resources are used for them.	Fuzzy Multi-criteria Decision Making Methods	Data for G7 Countries	A new model for priority analysis for hospitals is proposed, energy efficiency is found to be the most important variable of energy performance management, and it is concluded that France is the most successful G7 economy in terms of energy performance management.
20	Takgil and Kara, 2024.	It is aimed to develop a new mathematical model that can be used to make more energy efficient hospital pneumatic systems.	Multivariate Nonlinear Regression	Duzce University Hospital	It is concluded that the proposed mathematical model provides up to 43% more efficient transportation than the current system tested.