UDC 621.311:004.85+004.7
DOI https://doi.org/10.32782/IT/2024-2-23

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To cite this article: Shepeliev, D., Boiko, O. (2024). Analiz enerhospozhyvannia komertsiinykh budivel u pomirnomu klimati [Analysis of energy consumption in commercial buildings in a moderate climate]. *Information Technology: Computer Science, Software Engineering and Cyber Security*, 2, 176–181, doi: https://doi.org/10.32782/IT/2024-2-23

ANALYSIS OF ENERGY CONSUMPTION IN COMMERCIAL BUILDINGS IN A MODERATE CLIMATE

*This study provides a comprehensive analysis of energy consumption patterns in various commercial buildings located in regions with a moderate climate, characterized by cold, often frigid winters and hot, humid summers. **The aim** of this work is to identify operational energy consumption trends across different building types, including offices, healthcare facilities, educational institutions, hotels, and restaurants, to create future energy management and decision-making systems. **The methodology** of the research employs a comparative analysis approach, examining energy usage across diverse building types. Data was normalized to kilowatt-hours per square foot to facilitate direct comparisons. The analysis considered seasonal variations, incorporating data on external temperature, occupancy patterns, and operational hours. **Scientific novelty.** The originality of this study lies in its detailed integration of various building types. By focusing on a specific geographic area, this research provides tailored insights into how local climate conditions affect energy use. The study also innovates by translating its findings into practical recommendations for developing machine learning models that can optimize energy usage. **Conclusions.** The analysis revealed that larger buildings, such as hospitals and large offices, exhibit higher energy usage compared to smaller buildings, due to their extensive facilities and continuous operation. Seasonal trends show significant variations, with peaks during winter and summer due to heating and cooling demands. The study concludes that understanding these patterns is crucial for effective energy management and sustainability efforts. By identifying key parameters influencing energy consumption, this research supports the development of predictive models that can enhance energy efficiency in commercial buildings. The findings offer valuable insights for stakeholders, including building managers, policymakers, and researchers, aiming to reduce energy consumption and improve sustainability in energy management.*

Key words: *energy management, energy consumption patterns, energy comparative analysis, energy savings, occupancy patterns, energy demands.*

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Бібліографічний опис статті: Шепелєв, Д., Бойко, О. (2024). Аналіз енергоспоживання комерційних будівель у помірному кліматі. *Information Technology: Computer Science, Software Engineering and Cyber Security,* 2, 176–181, doi: https://doi.org/10.32782/IT/2024-2-23

АНАЛІЗ ЕНЕРГОСПОЖИВАННЯ КОМЕРЦІЙНИХ БУДІВЕЛЬ У ПОМІРНОМУ КЛІМАТІ

Дослідження надає всебічний аналіз споживання енергії у різних комерційних будівлях, розташованих у регіонах із помірним кліматом, що характеризується холодними, часто морозними зимами та гарячими, вологими літами. ***Мета роботи*** *полягає в ідентифікації тенденцій споживання енергії в різних типах будівель, включаючи офіси, медичні заклади, освітні установи, готелі та ресторани, з метою створення систем управління енергією та прийняття рішень.* ***Методологія*** *дослідження полягає у вивченні споживання енергії в різних типах будівель. Дані були нормалізовані до кіловат-годин на квадратний фут, щоб полегшити порівняння. Аналіз враховував сезонні варіації, включаючи дані про зовнішню температуру, моделі поведінки користувачів та години роботи.* ***Новикова новизна.*** *Оригінальність цього дослідження полягає в детальному дослідженні різних типів будівель. Зосереджуючись на конкретному географічному регіоні, це дослідження надає уявлення про те, як місцеві кліматичні умови впливають на використання енергії. У дослідження також наведені практичні рекомендації щодо розробки моделей машинного навчання, які можуть оптимізувати використання енергії.* ***Висновки.*** *Аналіз показав, що більші будівлі, такі як лікарні та великі офіси, споживають більше енергії порівняно з меншими будівлями через їхнє велике устаткування та безперервну роботу. Сезонні тенденції демонструють значні варіації, з піками в зимовий та літній періоди через потреби в опаленні та охолодженні. Розуміння цих моделей споживання є важливим для ефективного управління енергією та сталого розвитку. Дослідження визначає ключові змінні, що впливають на споживання енергії, які можуть бути використані для розробки моделей машинного навчання. Моделі машинного навчання з використанням цих змінних можуть покращити енергоефективність у комерційних будівлях. Висновки надають цінну інформацію для зацікавлених сторін, включаючи менеджерів будівель, політиків та дослідників, які прагнуть зменшити споживання енергії та оптимізувати використання енергії.*

Ключові слова: *управління енергією, залежності споживання енергії, порівняльний аналіз енергоспоживання, енергозбереження, залежності використання приміщень, потреби в енергії.*

Introduction. In the contemporary discourse on sustainability, the significance of energy efficiency and sustainable development cannot be overstated. Particularly in the realm of commercial buildings, where the dependence on energy is notably substantial, the ability to predict energy consumption accurately is paramount. This capability facilitates more effective management of consumption and resources, a crucial factor given that buildings account for over 30% of primary energy usage globally (Chen et al., 2021, p. 1-10). The behavior of occupants, a major determinant of a building's energy efficiency, along with other factors, necessitates a nuanced analysis of consumption patterns (Jia et al., 2017, p. 525–540). These patterns are essential for developing predictive models capable of generating precise forecasts with minimal data while maintaining data privacy.

There are two predominant methodologies for forecasting energy consumption in buildings: physical and data-driven modeling (Amasyali & El-Gohary, 2018, p. 1192–1205). Physical modeling demands an exhaustive description of all system parameters, posing challenges in scalability and speed of implementation. In contrast, data-driven approaches offer a more expedient and less resource-intensive alternative, although they require robust datasets that respect confidentiality constraints–particularly pertinent in commercial settings where financial and operational data sensitivity is paramount.

Research on energy usage in moderate climates is crucial for several key reasons, especially given the substantial proportion of the global population living in these regions. About 1.6 billion people live at 12–18°C compared to about 2.2 billion at 24–28°C (Klinger & Ryan, 2022, p. 1-10).

The analytical process involves examining various factors (Sadaghat et al., 2024, p. 1-10), such as electricity, heat, and water consumption, alongside external influences like climatic conditions, operational hours, and building types. Through such analysis, it is possible to discern patterns, identify seasonal variations, and understand other dynamics that impact energy use. These insights inform the selection of key parameters for predictive models, including building dimensions, technology types used for heating and air conditioning, operational schedules, and even specific business activities within the premises.

The implications of this research extend across multiple stakeholders, encompassing the business community, academic researchers, government bodies, and public organizations. For the scientific community, this study offers a framework to explore the multifaceted influences on energy efficiency within commercial buildings and develop innovative methodologies for measuring and managing energy consumption.

Purpose. The purpose of this study is to conduct a comparative analysis of energy usage across various types of commercial buildings in moderate climate with cold, often frigid winters and hot, humid summers to determine variables for machine learning models. By examining the patterns of energy consumption, this research aims to highlight operational and structural factors that contribute to energy efficiency, or lack thereof, within different commercial contexts. This paper evaluates a spectrum of building types including office spaces of varying sizes, healthcare facilities ranging from hospitals to outpatient clinics, educational institutions from primary to secondary schools, hospitality services from large to small hotels, and food service establishments from full-service to quick-service restaurants.

Furthermore, the study investigates the energy usage disparities within similar categories of buildings, offering a comparative analysis that brings to light the influence of building size and type on energy consumption. This includes an exploration into how small offices compare to medium and large ones, how energy demands differ between outpatient facilities and hospitals, and the energy profiles of primary schools versus secondary schools. The analysis extends to the hospitality sector, comparing large hotels to their smaller counterparts, and examines the energy consumption differences between full-service and quick-service restaurants, as well as retail strip malls and standalone retail outlets.

Methodology. Data for the state of Minnesota was chosen for it's extremes.

The dataset was aggregated from the U.S. Department of Energy's Programs, Offices, and National Laboratories for the State of Minnesota (National Renewable Energy Laboratory, 2018).

The database includes datasets per each of the building type: full-service restaurant, quick-service restaurant, hospital, outpatient, large hotel, small hotel, large office, medium office, small office, large office, primary school, secondary school, retail standalone, retail stripmall, warehouse. The dataset contains data for the year of 2019. In order to research the utilization of energy per unit area, it was decided to normalize kilowatt-hours (kWh) by the unit of area, which, in the dataset, is represented in square feet.

The following dataset columns were used for each dataset.

Findings. The analysis of energy consumption trends across various building types reveals distinct patterns and seasonal variations in energy consumption. Overall, the energy consumption fluctuates throughout the year, reflecting the influence of seasonal changes in weather conditions and building operations.

Within the office category, significant variations in energy consumption patterns are observed among small, medium, and large offices. Large offices tend to have higher average energy consumption, exceeding medium offices by 16.73% per square area and small offices by 51.01%. Medium-sized offices typically show a 29.36% higher average consumption per square area compared to small offices. This disparity can be attributed to several factors, including larger floor areas, higher occupant densities, and more extensive heating, ventilation, and air conditioning (HVAC) systems. Medium-sized offices exhibit moderate energy consumption values, reflecting a balance between size and operational efficiency. Small offices, on the other hand, demonstrate relatively lower energy consumption values, suggesting more efficient energy usage per square area due to smaller floor areas and potentially less intensive operational needs.

The comparison between outpatient facilities and hospitals reveals notable differences in energy consumption, reflecting distinct operational characteristics and service requirements. Hospitals typically exhibit higher energy consumption values than outpatient facilities due to their 24/7 operation, extensive medical equipment usage, and larger building sizes. The continuous need for lighting, HVAC, and medical equipment contributes to higher energy consumption in hospitals compared to outpatient facilities, which operate during limited hours and provide fewer specialized services. Hospitals typically exhibit significantly higher average energy consumption, surpassing outpatient buildings by 70.6% per square area.

Primary and secondary schools display contrasting energy usage patterns, with secondary schools generally exhibiting higher energy consumption values than primary schools. The higher energy consumption in secondary schools may be attributed to larger building sizes, increased energy demand for specialized facilities such as

Table 1

The research utilized the columns of the dataset for analysis

Dataset Column	Explanation
in.sqft	The floor area that this model represents in the U.S. building stock.
out.electricity.total.energy_consumption.kwh	Building annual total site electricity energy consumption
timestamp	Timestamp of the collected data. Timestamps are 15 minute intervals.

laboratories and gymnasiums, and longer operating hours for extracurricular activities and sports events. In contrast, primary schools typically have smaller footprints and simpler operational needs, resulting in lower energy consumption values. Secondary schools typically show higher average energy consumption compared to primary school buildings, by 8.2% per square area.

The analysis of energy consumption in large hotels versus small hotels reveals differences influenced by factors such as amenities, occupancy rates, and operational scale. Large hotels tend to have higher energy consumption values compared to small hotels due to their larger size, extensive facilities (e.g., conference rooms, swimming pools, fitness centers), and higher occupancy rates. The constant demand for heating, cooling, lighting, and other services in large hotels contributes to their higher energy consumption per square area compared to smaller establishments. Large hotels generally demonstrate a substantially higher average energy consumption in comparison to smaller hotel establishments, by an increase of 72.4% per square area.

The evaluation of energy consumption between full-service and quick-service restaurants highlights differences in energy consumption associated with service models and operational practices. Full-service restaurants typically have higher energy consumption values compared to quick-service restaurants. The need for ambient lighting, heating, cooling, and kitchen operations throughout the day may contribute to higher energy consumption in full-service restaurants. Quick service restaurants typically exhibit a significantly higher average energy consumption compared to full-service restaurants, by 228.29% per square area.

The comparison of energy consumption for retail strip malls against standalone retail buildings reveals contrasting energy consumption patterns influenced by shared versus individual energy systems. Retail malls may have less energy consumption values compared to standalone retail buildings due to shared energy systems, common area lighting, and centralized HVAC systems serving multiple tenants. In contrast, standalone retail buildings typically have higher energy consumption values as they operate independently with individual HVAC systems and lighting controls tailored to their specific needs. Stand-alone retail establishments typically exhibit a slightly higher average energy consumption compared to retail strip malls, by 0.8% per square area. Even when energy consumption values do not show a significant difference in consumption values per square area, the patterns remain distinct.

Originality. This research encompasses a wide range of building types, including offices, hospitals, schools, hotels, restaurants, and retail spaces. By comparing different types of buildings, the study encourages cross-sector learning, where strategies that are effective in one type of building might be adapted and applied in another. These findings underscore the importance of understanding the unique characteristics and operational dynamics of different building types in analyzing energy consumption patterns and implementing targeted energy efficiency measures. The originality of this study is prominently highlighted by how it translates findings into practical recommendations for energy management and the development of machine learning models. This approach not only advances theoretical knowledge but also provides actionable insights that can be directly applied to improve building energy efficiency in various settings.

Discussion. The observed energy consumption patterns suggest that building size and operational complexity are key determinants of energy consumption. Larger buildings and those with more diverse usage tend to have higher energy consumption. Seasonal trends indicate that heating is a major driver of energy consumption in commercial buildings, with all building types showing increased energy consumption during the colder months.

The higher energy demands in hospitals and large hotels underscore the need for targeted energy efficiency measures in buildings with continuous operation. The comparatively lower energy consumption in smaller offices and outpatient facilities suggests that smaller scale operations could serve as models for energy-saving practices.

Limitations of this study include the lack of data on specific energy conservation measures in place and the potential impact of building age and retrofitting on energy consumption. Future research could explore these factors in detail, as well as the influence of occupancy behavior on energy consumption patterns.

Practical Value. The results may be utilized to determine variables for machine learning models that aim for high precision in predicting and optimizing energy usage. It is crucial to consider variables directly derived from the study of energy usage patterns observed through data from different buildings. The list of variables may include the following:

- Building Type: Specific types such as office, hospital, school, hotel, restaurant, or retail, as energy patterns significantly vary across types.

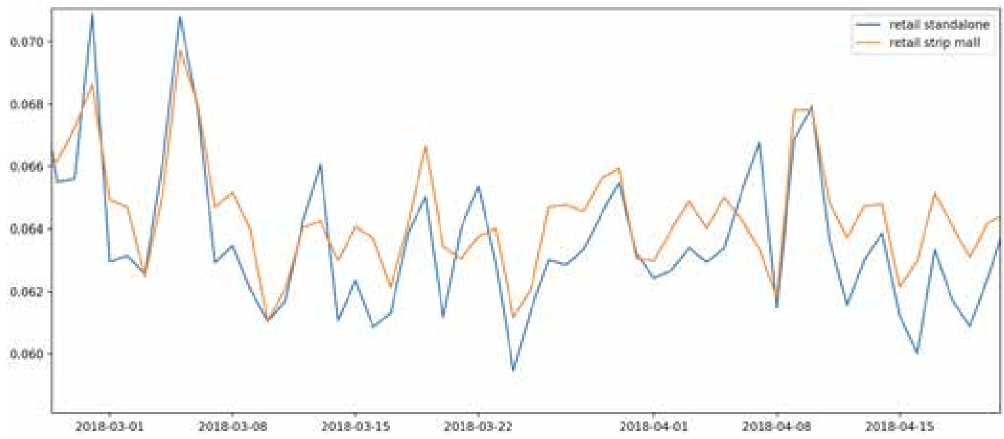

Fig. 1. The chart visually demonstrates the distinct difference in the data

- Building Size: The size of the building can impact energy use, with larger buildings possibly having different efficiency scales.
- Location: Geographic information which can influence energy needs based on climate.
- Energy Consumption History: Historical data on energy usage that helps in trend analysis and modeling.
- HVAC System Characteristics: Details about heating, ventilation, and air conditioning systems, which are critical for understanding what drives energy consumption.
- Insulation Quality: Information on the building's insulation which affects heating and cooling efficiency.
- Operational Hours: For commercial buildings like restaurants and retail stores, the hours of operation can significantly impact energy usage.
- Window-to-Wall Ratio: This ratio influences natural light usage and thermal efficiency in buildings.

Conclusion. The evidence collected suggests a clear correlation between building function and size with energy consumption, which has significant implications for energy management. Larger facilities, particularly those offering round-the-clock services like hospitals and large hotels, exhibit higher energy consumption, presenting unique challenges and opportunities for energy conservation efforts. Educational institutions, particularly secondary schools, also demonstrate a need for tailored energy-saving strategies, likely due to their larger physical footprints and extended usage for after-school activities.

For the commercial sector, the contrast in energy consumption between building types highlights the influence of operational practices on energy consumption. Small offices and outpatient facilities, with their lower energy consumption, exemplify the potential benefits of compact space usage and efficient operations.

The study's results align with the broader goals of sustainability and energy conservation, emphasizing the importance of energy-efficient design and operation in the face of changing climate conditions. By adopting best practices from building types with lower energy consumption, stakeholders can drive improvements in energy performance across all categories. Moreover, the findings suggest a significant potential for energy savings in commercial buildings, which could contribute to statewide efforts to reduce carbon emissions and combat climate change.

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