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Assessing energy consumption and operational carbon emission: A case study of office building in Hanoi

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KEYWORDS

Office building
Energy consumption
Operational carbon emission
Plug loads
Cooling demand

ABSTRACT

This study investigated the energy consumption characteristics and associated operational carbon emissions of a specific office building located in Hanoi during the period from Sep 2024 to May 2025. Monthly electricity consumption, technical and operational data were collected through site surveys and engineering drawings. The analysis revealed that energy consumption was strongly influenced by seasonal climatic conditions, with cooling loads driving the increased electricity demand during the warmer months (September – November, 2024 and April – May, 2025). Plug loads were identified as the largest contributor to the total energy consumption of the office building during the study period, followed by air-conditioning systems, outdoor lighting systems, ventilation systems, indoor lighting systems, elevators, and domestic water pumps. The monthly CO_2 emission estimations showed a strong relationship with the monthly electricity consumption, resulting in the elevated operational carbon emission levels during high cooling demand periods. The findings implied that the targeted energy-saving measures such as enhanced operational management and improvements in air-conditioning systems could collectively reduce energy consumption and CO_2 emissions of the office building. This case study contributes valuable insights for building owners and managers, designers, and policy makers aiming to improve the energy and environmental performance of office buildings.

1. Introduction

The building sector has emerged as one of the largest consumers of energy and a major contributor to global greenhouse gas emissions [1]. In rapidly developing countries such as Vietnam, the economic growth, expansion of urban areas and the increasing demand for modern office spaces have significantly intensified energy use in the construction industry, especially in the building sector, which now accounts for approximately 37–40 % of the country's total final energy consumption [2]. The proliferation of high-rise office buildings - often designed with extensive glazing and heavy reliance on air conditioning, has resulted in elevated electricity consumption and correspondingly high operational CO_2 emissions. As a result, office buildings are expected to become as one of critical focal points in national efforts to reduce energy consumption and mitigate CO_2 emissions in the building sector. At the same time, Vietnam remains heavily dependent on fossil fuels for electricity generation, with coal and natural gas still supplying over 60 % of the grid. Consequently, the carbon intensity of electricity consumed in office buildings is substantially higher than in many temperate countries, amplifying the environmental impact of seemingly moderate energy use intensities.

Vietnam's commitments under the Paris Agreement targeting net-zero emissions by 2050 [3] and its updated Nationally Determined Contributions highlight the urgent need for improved energy efficiency and carbon reduction across all sectors. Within this context, the building sector, particularly office buildings in major cities such as Hanoi, Da Nang and Ho Chi Minh City, presents substantial opportunities for energy savings through both technical and operational interventions. However, efforts to design effective energy-saving strategies require accurate assessments of actual energy-use patterns and emission profiles of existing office buildings.

Despite growing concern, empirical research on energy consumption and CO_2 emissions in office buildings in Vietnam remains limited. Therefore, conducting detailed assessments of energy use and associated carbon emissions in office buildings is essential for generating context-specific insights and supporting evidence-based policy and management decisions. This study aims to analyze the energy consumption and associated operational carbon (CO_2) emissions of an office building in Hanoi City, identify the major end-use contributors to the total energy consumption, and propose potential measures for energy efficiency and CO_2 emission reduction. The findings are expected to provide practical implications for building managers, policymakers, and researchers working toward sustainable development in Vietnam's building sector.

2. Research Methods

The research method was designed to evaluate the energy consumption patterns and quantify the associated CO_2 emissions of a

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selected office building. The framework consists of four main stages: (i) data collection, (ii) energy consumption analysis, (iii) operational carbon emission estimation, and (iv) interpretation of results to identify improvement opportunities.

2.1. Studied Building Description

This research adopts a single-case study approach to investigate energy consumption and operational carbon (CO_2) emissions in a real office building. The selected building, a 45-storey office building located in Hanoi City, has a total gross floor area of 117,000 m^2. The building is served by a central air-conditioning system with water-cooled chillers. The building uses high-performance LED lights, with light sensors that automatically adjust lighting intensity based on natural light. The building management system (BMS) is applied to control and manage all systems in the building including chillers and cooling towers of air conditioning, lighting, pumps, ventilation fans, elevators, etc.

2.2. Data Collection

Data was collected from both primary and secondary sources to ensure accuracy and representativeness.

- Electricity consumption data: Monthly electricity consumption data of the selected office building during the period from Sep 2024 to May 2025 were collected to establish the building's monthly energy profile.
- Operational data: Information on daily operating hours, occupancy levels, and equipment usage schedules were obtained from the building's management system and utility bills.
- Technical specifications: Information on air-conditioning and ventilation systems, lighting, pumps, elevators, and plug loads was gathered through site surveys and engineering drawings.

All data were cross-checked to ensure completeness and consistency before analysis.

2.3. Energy Consumption Analysis

Monthly energy use was allocated to major systems including air-conditioning, ventilation, indoor and outdoor lighting, pumps, elevators, and plug loads based on measurements, equipment capacity, and operational schedules.

2.4. Operational Carbon Emission Estimation

Monthly operational carbon (CO_2) emissions were calculated using the following equation:

CO_2 emissions (tons) = Electricity consumption (kWh) × Electricity grid emission factor (tons CO_2/kWh)

Where: Electricity grid emission factor of Vietnam in 2022 (0,6766 tCO_2/MWh) was adopted from official national sources.

2.5. Interpretation and Reporting

Results from the energy and emission analyses were synthesized to identify major contributors to total energy consumption and operational carbon emissions. Key findings were used to propose energy-saving measures and emission-reduction strategies.

3. Results and Discussion

3.1. Overview of Monthly Energy Consumption

The monthly energy consumption of the studied office building (Figure 1) showed significant seasonal fluctuations, with the higher consumption occurring during the warmer months (September – November, 2024 and April – May, 2025). These monthly trends coincide with those of the air-conditioning systems (Figure 2), confirming that air-conditioning systems represented the dominant driver of energy use in the studied office building. Conversely, energy consumption during the cooler months (December, 2024 and Jan - March, 2025) decreased significantly, indicating the reduced use of air-conditioning system during this period. The data suggested a clear dependence on climatic conditions, suggesting that improvements in thermal performance and cooling efficiency could contribute meaningfully to reducing overall energy consumption of the studied office building. While the monthly trend of the plug loads somewhat similar to those of the air-conditioning systems, the monthly energy consumption of elevators, ventilation systems, and outdoor and indoor lighting systems remain relatively stable month-to-month.

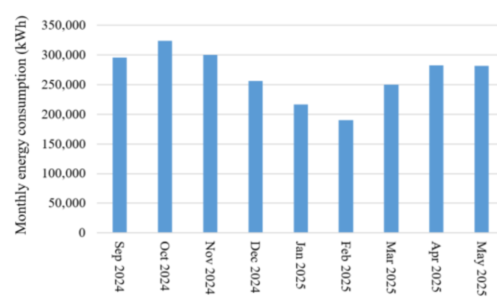

Figure 1. The monthly energy consumption of the studied office building.

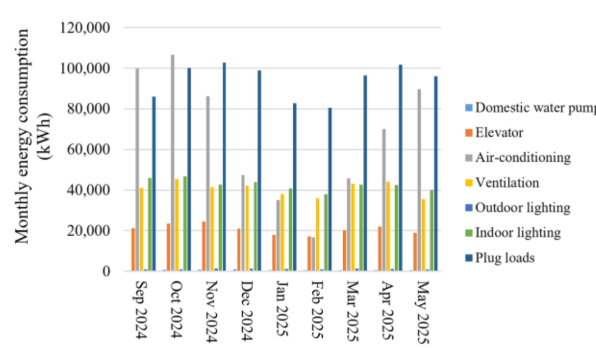

Figure 2. The monthly energy consumption of major end uses.

3.2. End-Use Energy Breakdown

Figure 3 illustrates the estimated distribution of energy consumption among major end uses. The plug loads accounted for the largest share at 26.4 % of the total energy use. The notable contribution of plug loads reflects extended occupancy hours and increasing reliance on electronic devices in modern office buildings. This suggests that implementing automated plug load controls, awareness programs, and shutdown protocols could reduce plug load consumption. The second largest share of the total energy use was the air-conditioning systems which responsible for 25.1 % of the total energy use. One of the main reasons for the air-conditioning systems not being the largest contributor to the total energy use of the studied office building was the hottest months (June - August) with the highest cooling demand were not included in this study. The other reason could be the use of BMS to control and manage the chillers and cooling towers of air-conditioning systems that could enhance the energy efficiency of the air-conditioning systems in the studied office building. Meanwhile, the outdoor lighting systems were the third largest contributor to the total energy use (16.1 %), followed by the ventilation systems (15.3 %), the indoor lighting systems (9.1 %), and elevators (7.8 %). The domestic water pumps represented the lowest share (0.2 %) of the total energy use.

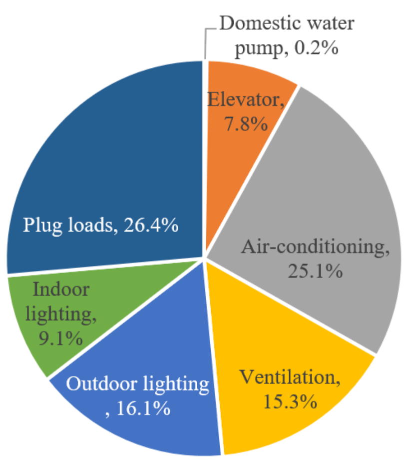

Figure 3. The estimated distribution of energy consumption among major end uses.

3.3. Monthly Operational Carbon Emissions

Using the national grid emission factor, the monthly operational carbon (CO_2) emissions from electricity consumption were calculated and expressed in Figure 4. The monthly CO_2 emissions followed the same pattern as the monthly energy consumption, with the highest emissions recorded during the warmer months (September – November, 2024 and April – May, 2025). During the study period, the peak monthly CO_2 emissions reached 219.4 tons CO_2 in October 2024 while the lowest recorded value was 128.5 tons CO_2 in February 2025. These results underscore the strong correlation between cooling demand and CO_2 emission levels.

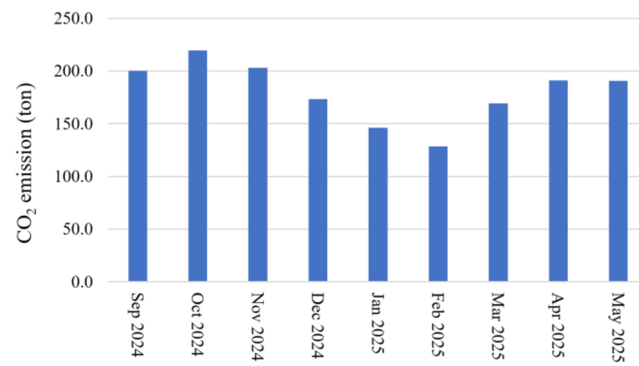

Figure 4. The monthly operational carbon emission from electricity consumption.

When considering the monthly operational carbon emissions among major end uses, the air-conditioning systems have the higher CO_2 emissions during the warmer months (September – November, 2024 and April – May, 2025) as shown in Figure 5. The other studies [4, 5] also showed the similar results. Whereas, the monthly operational carbon emissions of elevators, ventilation, outdoor and indoor lighting systems remain relatively stable month-to-month.

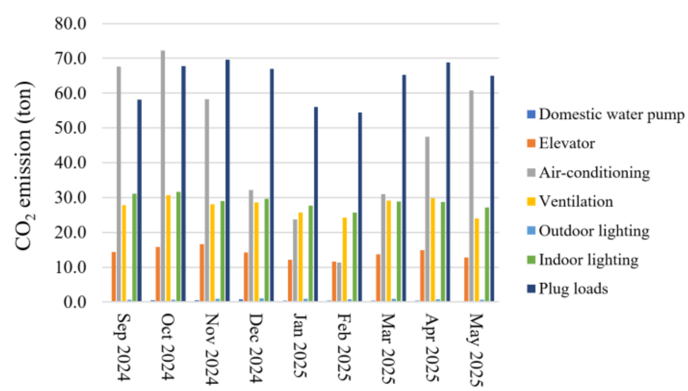

Figure 5. The monthly operational carbon emission among major end uses.

The estimated distribution of operational carbon emission among major end uses was shown in Figure 6. The plug loads represented the largest contributor (35.3 %) to the total CO_2 emission during the study period which corresponding to the largest energy consumption. The second largest contributor to the total CO_2 emission was the air-conditioning systems (25 %), followed by the indoor lighting systems (16 %), the ventilation systems (15.3 %), elevators (7.8 %), and the outdoor lighting systems (0.4 %). The smallest contributor to the total CO_2 emission was the domestic water pumps (0.2 %).

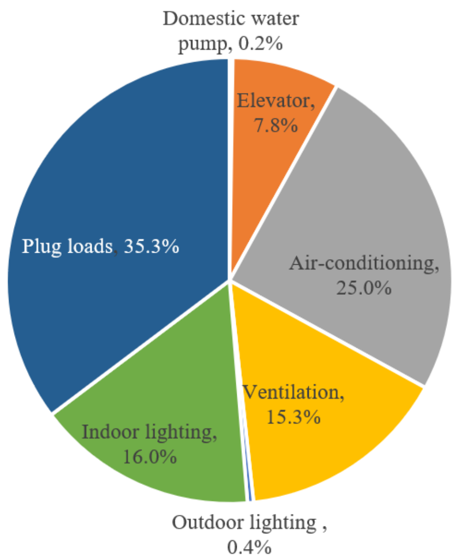

Figure 6. The estimated distribution of operational carbon emission among major end uses.

4. Conclusions

This study investigated the energy consumption characteristics and associated CO_2 emissions of a specific office building, providing an assessment of its operational performance. The analysis revealed that energy consumption is strongly influenced by seasonal climatic conditions, with cooling loads driving the increased electricity demand during the warmer months. Plug loads were identified as the dominant energy consumers for the office building during the study period, followed by air-conditioning systems, outdoor lighting systems, ventilation systems, indoor lighting systems, elevators, and domestic water pumps. CO_2 emission estimations showed a strong relationship with electricity use, resulting in elevated emission levels during high cooling demand periods. The findings implied that the targeted energy-saving measures such as enhanced operational management and improvements in air-conditioning systems could collectively reduce energy consumption and CO_2 emissions significantly. Implementing such measures would not only enhance building efficiency but also support broader sustainability and carbon emission reduction goals.

Overall, the research underscores the importance of building-specific energy analysis as a foundation for informed decision-making in energy management. Future work should focus on real-time monitoring, dynamic modeling, and evaluation of retrofit scenarios to further refine energy-saving strategies. This case study also contributes valuable insights for building owners and managers, designers, and policy makers aiming to improve the energy and environmental performance of office buildings.

Acknowledgments

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