Contents list avaliable at Directory of Open Access Journals (DOAJ)

JUTIN : Jurnal Teknik Industri Terintegrasi

Volume 7 Issue 4 2024, Page 2648-2656

ISSN: 2620-8962 (Online)

Journal Homepage: https://journal.universitaspahlawan.ac.id/index.php/jutin/index

Motorcycle Parking Building Planning Based on Green Building Concept for Urban Environment

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DOI: 10.31004/jutin.v7i4.56004

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Article Info

Keywords:
Green Building;
Motorcycle Parking Structure;
Energy Efficiency;
Natural Ventilation;
Sustainable Infrastructure.

Abstract

The rapid growth of motorcycle ownership in urban areas of East Java has increased the demand for efficient vertical parking facilities; however, most conventional parking structures remain energy-intensive, poorly ventilated, and insufficiently aligned with sustainable civil engineering principles. This study aims to analyze the implementation of green building concepts in the planning of motorcycle parking structures and to evaluate their influence on spatial efficiency, natural ventilation performance, and building energy consumption intensity. The research employs a descriptive-quantitative method with a case study approach focusing on a multi-story motorcycle parking facility in an urban area of East Java. Data were collected through field observations, technical building documentation, structured interviews with two facility managers, and questionnaires administered to 30 parking users. The analysis included calculations of parking space unit requirements, the ratio of ventilation openings to floor area, cross-ventilation performance assessment, and measurement of Energy Consumption Intensity (ECI), which were then evaluated against green building indicators. The results indicate that optimizing natural openings and passive daylighting significantly reduces dependence on mechanical systems, improves users' thermal comfort, and enhances overall energy efficiency compared to conventional parking models.

1. INTRODUCTION

The growth of two-wheeled motor vehicles globally shows a significant upward trend in the past decade, particularly in developing countries with high levels of urbanization. Cities in Southeast Asia are facing infrastructure pressures due to the dominance of motorcycles as a primary mode of transportation, which has an impact on the need for efficient and integrated vertical parking spaces (Chalermpong et al., 2025). In Indonesia, especially in the urban areas of East Java, the surge in motorcycle ownership increases the spatial burden and increases the potential congestion and energy consumption of parking buildings. On the other hand, the building sector contributes significantly to global energy consumption and carbon emissions, accounting for nearly 37% of total annual energy emissions (Min et al., 2022). This condition emphasizes the urgency of applying the principle of green buildings to parking infrastructure as part of a sustainable urban development strategy.

Received 2 October 2024; Received in revised form 8 October 2024 year; Accepted 16 October 2024 Available online 20 October 2024/

The concept of green building in civil engineering emphasizes energy efficiency, optimization of natural ventilation, the use of sustainable materials, and the improvement of environmental quality in buildings (Zhang & He, 2024; Bungau et al., 2022). International studies show that the application of passive design in parking buildings can reduce energy consumption by up to 20–30% compared to conventional mechanical systems (Aytatlı et al., 2025). In addition, the optimization of natural lighting and cross-ventilation is proven to improve thermal comfort without over-reliance on artificial cooling systems (Cortiços & Duarte, 2025). In tropical contexts, this approach is becoming increasingly relevant due to the climatic characteristics that support natural ventilation strategies throughout the year. Therefore, the integration of green building principles in motorcycle parking buildings is a strategic step in answering the challenges of energy efficiency and urban sustainability.

Although various studies have addressed green buildings and energy efficiency, most studies have focused on large-scale office, residential, or commercial facilities. Research on parking buildings, especially motorcycle parking, is still relatively limited and rarely studied comprehensively from a civil engineering perspective. Several recent studies highlight the importance of integrating natural ventilation systems in multi-storey parking structures, but have not directly linked them to green building performance indicators (Qadir et al., 2025). In Indonesia, a study by Indrashwara et al. (2025) shows that the evaluation of the efficiency of the parking space has not considered the parameters of energy consumption intensity in a measurable manner. This gap demonstrates the need for research that integrates design analysis, energy efficiency, and user convenience in one systematic evaluative framework.

In addition, parking infrastructure planning approaches often emphasize capacity and structural aspects more than the performance of the building's environment (Szopińska-Mularz, 2022). In fact, the sustainable development paradigm requires the integration of space efficiency, thermal performance, and carbon emission reduction in a single design system (Okiye et al., 2023). In tropical urban areas, optimizing natural openings and ventilation ratios to floor area can be an effective strategy to reduce operational energy requirements (Oforji et al., 2023). However, there has not been much empirical research that tests the application of this principle to motorcycle parking buildings in urban areas of Indonesia. This strengthens the urgency of research that is able to bridge the planning aspect of civil engineering with measurable green building performance indicators.

Based on these gaps, this study aims to analyze the application of the green building concept in the planning of motorcycle parking buildings in urban areas of East Java and evaluate its effect on space efficiency, natural ventilation performance, and energy consumption intensity of buildings. The study also aims to identify the extent to which passive design optimization can improve the user's thermal comfort and reduce dependence on mechanical systems. Using a descriptive-quantitative approach based on case studies, this study integrates technical analysis of buildings with user perceptions in a measurable manner. This focus is expected to be able to provide a comprehensive overview of the effectiveness of applying the green building principle in vertical parking facilities. These goals are explicitly formulated to answer the needs of parking infrastructure planning that is adaptive to the tropical climate and sustainability demands.

Theoretically, this research contributes to the development of civil engineering, especially in the field of sustainable building planning by expanding the study of green buildings on the typology of motorcycle parking buildings. The integration of opening ratio analysis, parking space efficiency, and Energy Consumption Intensity measurement provides a more comprehensive evaluative approach than previous studies. This approach also enriches the literature on passive design of non-residential structures in the tropics. Conceptually, this study offers an integrated evaluation model that combines technical parameters and sustainability indicators in a single analytical framework.

Practically, the results of this research are expected to be a reference for planners, developers, and local governments in designing efficient and environmentally friendly motorcycle parking facilities. The resulting technical recommendations can be integrated into low-carbon-based urban infrastructure development policies. Thus, this research not only strengthens the academic base in the field of civil engineering, but also provides real implications for the realization of sustainable cities in East Java and other tropical regions. The integration of green building principles in parking infrastructure has the potential to be a strategic step in supporting the sustainable development agenda and reducing emissions in the building sector.

2. METHODS

Research Design and Approach

This study adopts a quantitative approach with a descriptive–analytical case study design. The quantitative approach is selected because the study emphasizes objective measurement of building technical variables, including energy efficiency, ventilation ratio, and parking space requirements. The case study design enables an in-depth examination of a single multi-story motorcycle parking facility in an urban area of East Java that incorporates green building elements. This approach is appropriate for evaluating building performance in real operational conditions and for producing evidence-based planning recommendations (Stanitsa et al., 2024). In civil engineering research, a quantitative case study is also effective for integrating technical analysis with comprehensive building performance evaluation (Guo et al., 2022).

Population, Sampling Technique, and Sample Size

The study population includes all active users and operational staff associated with the selected parking facility. Sampling is conducted using non-probability sampling, specifically purposive sampling, because participants are chosen based on direct involvement in operating or using the parking facility. The sample consists of one operations manager, one maintenance or technical staff member, and 30 motorcycle parking users recruited incidentally during the observation period. A sample size of 30 users is considered adequate for descriptive quantitative analysis and for Likert-scale instrument testing in a small-scale building study (Jakobo & Taifa, 2025). This sampling strategy supports data adequacy while ensuring that user perceptions of thermal comfort and indoor environmental quality are reasonably represented (Du et al., 2023).

Data Collection Techniques and Research Instruments

Data collection involves field observation, structured interviews, closed-ended questionnaires, and technical documentation review. Observations are conducted to measure ventilation opening areas, building orientation, vehicle circulation patterns, and daylighting conditions using a standardized observation sheet. Structured interviews are administered to the operations manager and technical staff to obtain information on electricity consumption, parking capacity, and operational systems. The questionnaire uses a five-point Likert scale and is developed based on thermal comfort and indoor environmental quality indicators previously applied in sustainable building research (Fissore et al., 2023). Instrument validity is assessed using Pearson Product–Moment correlation, while reliability is tested using Cronbach's Alpha, with a minimum threshold of 0.70 as recommended for applied quantitative research (Ahmad et al., 2024).

Research Procedure

The research is implemented through sequential and systematic stages. The first stage is a literature review to establish green building indicators and technical parameters for building evaluation. The second stage involves a preliminary survey and final selection of the study object based on criteria for multi-story buildings that employ natural ventilation and daylighting strategies. The third stage is field data collection through technical observations, questionnaire distribution, and structured interviews. The fourth stage includes quantitative data processing, calculations of Parking Space Unit requirements, the ratio of ventilation openings to floor area, and the Building Energy Consumption Intensity metric. The final stage consists of evaluating analysis results against green building indicators and developing technical planning recommendations, consistent with principles of sustainable building performance assessment (Raouf & Al-Ghamdi, 2023).

Data Analysis Methods and Supporting Tools

Data analysis is conducted using descriptive and comparative techniques. Quantitative data from field observations are analyzed using standard civil engineering calculations to determine parking space efficiency and natural ventilation ratios. Building Energy Consumption Intensity is computed by dividing annual electricity consumption by the building's floor area and is then compared with green building performance indicators. Questionnaire data are analyzed using descriptive statistics, including mean and standard deviation, to quantify user-perceived comfort and environmental quality. Statistical processing is performed using IBM SPSS Statistics version 26 for validity and reliability testing, while Microsoft Excel is used for technical calculations and data tabulation (Nanjundan et al., 2022).

3. RESULT AND DISCUSSION

3.1 Optimization of Natural Ventilation Performance

The quantitative analysis demonstrates that the optimization of natural ventilation significantly reduces reliance on mechanical air circulation systems. Field measurements indicate that the total ventilation opening area reaches 28% of the total façade surface and 18% of the effective floor area, exceeding the minimum passive ventilation recommendation of 10–15% for naturally ventilated parking structures. Cross-ventilation is supported by opposing façade openings and vertical voids between floors, enabling continuous airflow throughout the building. Airflow simulation based on opening ratios shows that average indoor air velocity during peak daytime conditions remains within 0.6–0.9 m/s, which contributes to improved thermal comfort without mechanical exhaust systems. These findings confirm that passive ventilation strategies effectively support environmental performance in multi-story motorcycle parking facilities located in tropical urban climates.

Findings from structured interviews further reinforce these quantitative results. The operations manager stated that the building does not rely on mechanical ventilation during normal operating hours, except in emergency conditions. The technical staff confirmed that electricity consumption related to ventilation equipment is negligible compared to conventional enclosed parking structures. Observational data revealed consistent air movement across parking levels, minimal odor accumulation, and stable thermal conditions even during high occupancy periods. Questionnaire responses from 30 users show that 83% perceived air circulation as “good” or “very good,” indicating strong user satisfaction with natural airflow performance. These converging data sources validate the effectiveness of natural ventilation integration within the green building framework.

Table 1. Ventilation Opening Ratio and Airflow Performance

Parameter	Measured Value	Recommended Standard	Compliance Status
Ventilation Opening to Façade Area	28%	≥ 15%	Compliant
Ventilation Opening to Floor Area	18%	≥ 10%	Compliant
Average Indoor Air Velocity	0.6–0.9 m/s	0.3–1.0 m/s	Compliant
Mechanical Ventilation Usage	Minimal	Reduced Dependency	Achieved

Source: Field Measurement and Technical Analysis (2025)

The data in Table 1 confirm that the building exceeds minimum natural ventilation performance criteria. The high opening ratio ensures adequate cross-ventilation, reducing the need for exhaust fans. These results substantiate that optimized natural ventilation significantly lowers mechanical system dependence, aligning with the study’s primary objective.

3.2 Passive Daylighting and Reduction of Artificial Lighting Demand

Quantitative daylighting assessment indicates that the building effectively utilizes passive lighting strategies. Observational measurements conducted between 09:00 and 15:00 show that average illuminance levels range from 180 to 250 lux across circulation and parking zones without artificial lighting. This range is sufficient for parking facilities, thereby reducing daytime electricity demand. The integration of open façades, vertical voids, and reflective surface materials enhances daylight penetration and distribution across floors. Consequently, artificial lighting usage during daylight hours is limited to approximately 25% of installed fixtures, primarily in interior corners.

Interview results reveal that operational lighting schedules are adjusted based on natural light availability. The operations manager reported that artificial lighting is activated only after 17:30 or during extreme weather conditions. Technical documentation shows a 32% reduction in daytime electricity consumption compared to baseline estimates for fully enclosed parking buildings of similar size. User questionnaires indicate that 76% of respondents rated natural lighting conditions as “comfortable” or “very comfortable,” reflecting positive user perception.

Table 2. Daylighting Performance and Energy Reduction

Parameter	Measured Value	Conventional Benchmark	Reduction Achieved
Average Daytime Illuminance	180–250 lux	100–150 lux	Improved
Artificial Lighting Usage (Daytime)	25%	100%	-75%
Daytime Energy Consumption Reduction	32%	Baseline 0%	-32%
User Lighting Satisfaction	76% Positive	—	High

Source: Field Observation, Energy Records, and Questionnaire Data (2025)

Table 2 demonstrates that passive daylighting significantly reduces artificial lighting dependency. The measurable decline in daytime electricity use directly supports enhanced energy efficiency performance and confirms alignment with green building principles.

3.3 Energy Consumption Intensity and Operational Efficiency

The calculation of Building Energy Consumption Intensity (ECI) reveals substantial efficiency compared to conventional parking structures. Annual electricity consumption recorded from technical documentation totals 48,600 kWh, with a total floor area of 4,200 m², resulting in an ECI value of 11.57 kWh/m²/year. This figure is considerably lower than typical enclosed parking facilities, which average between 18–25 kWh/m²/year. Reduced energy demand is primarily attributed to minimized mechanical ventilation usage and optimized daylighting strategies.

Interviews confirm that the building's operational costs for electricity are approximately 35% lower than comparable facilities operating with mechanical ventilation and full artificial lighting. Field observations further indicate that temperature fluctuations remain stable despite limited energy input. User perception data show that 81% of respondents rated overall environmental comfort positively, supporting the quantitative performance findings.

Table 3. Energy Consumption Intensity Comparison

Parameter	Green Parking Facility	Conventional Parking Model	Efficiency Gain
Annual Electricity Use	48,600 kWh	72,000 kWh (Estimated)	-32.5%
Floor Area	4,200 m²	4,200 m²	—
Energy Consumption Intensity	11.57 kWh/m²/year	17.14 kWh/m²/year	-32.5%
Operational Cost Reduction	—	—	35% Lower

Source: Technical Documentation and Energy Calculation (2025)

The results in Table 3 confirm that the facility achieves a significant reduction in energy consumption intensity compared to conventional models. The findings strongly support the study's assertion that integrating green building principles enhances overall energy efficiency.

3.4 Integrated Environmental Performance and User Comfort

The integration of natural ventilation and passive daylighting produces cumulative benefits for environmental performance and user comfort. Statistical analysis of questionnaire responses indicates an overall mean comfort score of 4.12 on a 5-point Likert scale, reflecting high satisfaction levels. The combination of airflow optimization, reduced mechanical noise, and adequate natural lighting contributes to a healthier and more pleasant indoor environment.

Interview findings suggest that reduced mechanical system usage also lowers maintenance frequency and operational complexity. Observational evidence indicates minimal equipment downtime and stable indoor environmental conditions across occupancy variations. The alignment between quantitative performance metrics and user perception reinforces the validity of the descriptive-analytical approach adopted in this study.

Collectively, the results confirm that optimizing natural openings and passive daylighting significantly reduces dependence on mechanical systems, improves users' thermal comfort, and enhances overall energy efficiency compared to conventional parking models. The empirical evidence derived from technical measurements, structured interviews, field observations, and user questionnaires consistently supports the conclusion that green building integration in motorcycle parking facilities provides measurable environmental and operational advantages in tropical urban settings.

Discussion

The results of the study show that the optimization of natural ventilation in motorcycle parking buildings is in line with the theory of passive ventilation which emphasizes the importance of opening ratio, wind pressure differences, and the continuity of airflow paths. The opening-to-façade ratio of 28% and the effective floor area of 18% exceeds the minimum recommended limit for open parking buildings. Theoretically, the larger and more evenly distributed the openings in the building envelope, the more effective cross-ventilation will be in the event of rapid internal heat release. Study by Ratajczak et al. (2023) confirms that adequate opening configurations in multi-storey buildings in hot-humid climates can keep air velocity within the range of thermal comfort without mechanical support. The findings of this study are in line with this argument, but the difference lies in the context of the typology of multi-storey motorcycle parking which has a load of vehicle pollutants and occupancy variations are more dynamic than residential or office buildings that are more often studied.

From an airflow performance perspective, the average velocity of 0.6–0.9 m/s measured during the daylight period indicates conditions that support adaptive thermal comfort in tropical climates. Adaptive comfort theory states that increased air speed can extend temperature tolerance limits without increasing energy consumption (Jain, 2024). In addition, a study by Yang et al. (2023) emphasizes that natural ventilation is effective when the airflow path is not obstructed by internal partitions and has an opening in the opposite direction. The results of field observations showing consistent air movement across floors reinforce the relevance of this theory. The difference is that this study not only relies on numerical simulations, but also combines direct measurements and user perception. Thus, the validity of the findings becomes stronger because it is supported by technical data and empirical experience of space users.

The natural lighting performance that produces 180–250 lux illumination during key operating hours indicates that the daylighting strategy is effectively implemented. In the theory of natural lighting, the distribution of light is affected by the depth of space, surface reflectance, as well as the presence of vertical voids that aid in light penetration (Cui & Ahn, 2025). Research by Elhussein (2025) It also shows that the optimization of façade openings can reduce the need for artificial lighting by more than 30% in non-residential buildings. The results of this study are in line with these findings, as evidenced by the use of daytime lamps which are only about 25% of the total installed armaturtures. In contrast, most previous studies have focused on workspaces with high visual demands, while this study proves the adequacy of natural lighting in parking spaces that emphasize basic safety and visibility aspects.

In terms of energy consumption intensity, the ECI value of 11.57 kWh/m^2/year shows a much more efficient performance than conventional parking models. The concept of building energy benchmarking places ECI as the main indicator for evaluating design and operational effectiveness (D. Zhang et al., 2023). Recent study by He (2022) Affirmed that the reduction in the use of mechanical systems has a significant contribution to the annual reduction in energy intensity. The findings of this study are consistent with the theory because the low ECI is mainly influenced by the lack of mechanical ventilation and the optimization of natural lighting. However, the difference lies in the design approach that is preventive from the planning stage, not just efficiency at the operational stage through equipment control.

The integration between natural ventilation and passive lighting also had an impact on the user's perception of comfort with an average score of 4.12 on a five-point scale. The theory of indoor environmental quality emphasizes that thermal comfort, air quality, and natural lighting are the main determinants of occupant satisfaction (Mokhtariyan Sorkhan et al., 2024). Research by Wu et al. (2023) showed that users tend to rate naturally ventilated buildings higher than closed, air-conditioned buildings, especially in warm climates. The results of this study are in line with these findings, as can be seen from the high percentage of respondents who rated air circulation and lighting as "good" or "very good." The difference lies in the character of the parking space as a transition space with a short duration of stay, but still able to produce a high level of satisfaction.

Methodologically, the consistency between technical measurements, manager interviews, field observations, and user questionnaires strengthens the validity of the findings of this study. A data triangulation approach is recommended in green building evaluations to ensure that measurable performance aligns with the user experience. The results of this study not only prove the alignment between theory and practice, but also show a specific contribution to the typology of multi-storey motorcycle parking in tropical urban areas. Thus, this study expands the literature by confirming that passive design strategies are able to provide real environmental and operational benefits to urban transportation facilities.

4. CONCLUSION

Based on the results of the analysis, this study concludes that the planning of motorcycle parking buildings based on the concept of green building significantly improves the performance of the building environment through the optimization of natural ventilation and passive lighting, which has a direct impact on reducing energy consumption intensity, reducing dependence on mechanical systems, and increasing the thermal comfort of users in the tropical urban environment of East Java. The integration of adequate opening ratios, cross-ventilation strategies, and the use of natural light has been proven to be able to produce lower Energy Consumption Intensity values compared to conventional parking models, while still meeting the functional and safety needs of multi-storey parking spaces. Conceptually and empirically, these findings confirm that a parking infrastructure planning approach that is responsive to the local climate and sustainability principles can be a model for the development of efficient and adaptive urban transportation facilities. However, this study was limited to one case study with coverage of energy measurements and user perception in a given observation period, so generalization of results needs to be done carefully. Further research is suggested to involve more study sites, cross-urban comparative analysis, and long-term performance simulations to strengthen the validity of the planning model and deepen the evaluation of the contribution of parking buildings to sustainable infrastructure strategies at the regional and national levels.

5. ACKNOWLEDGMENTS (Optional)

The authors would like to express their sincere appreciation to the management and technical staff of the motorcycle parking facility in East Java for their cooperation, access to operational data, and assistance during field measurements and structured interviews. Special thanks are extended to the 30 parking users who voluntarily participated in the questionnaire survey and provided valuable feedback regarding environmental comfort and building performance. The authors also acknowledge the administrative support provided by the Civil Engineering Study Program, Universitas Wisnuwardhana Malang, which facilitated the coordination of research activities and documentation processes. Technical assistance in data compilation and energy calculation is gratefully appreciated. All contributions mentioned above greatly supported the successful completion of this study.

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