EVALUATING THE OPERATIONAL PERFORMANCE OF PUBLIC BUILDINGS BASED ON ENERGY EFFICIENCY, THERMAL COMFORT, AND OCCUPANT SATISFACTION

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Abstract
This study aims to evaluate the operational performance of public buildings based on energy efficiency, thermal comfort, and occupant satisfaction to support efficient and sustainable infrastructure management. The study adopts a quantitative approach using a descriptive evaluative method within the Post-Occupancy Evaluation (POE) framework. The evaluation uses hypothetical simulation data representing a two-story public building with a total floor area of 1,200 m², covering electricity consumption, indoor thermal conditions, and occupant satisfaction. The evaluated parameters include Energy Use Intensity (EUI), air temperature, relative humidity, air velocity, and satisfaction scores measured using a Likert scale. The simulation results indicate an annual electricity consumption of 144,000 kWh, corresponding to an EUI of 120 kWh/m²/year. Air conditioning accounts for the largest proportion of energy consumption at 62.50%. Indoor temperatures range from 24.8°C to 27.4°C, with relative humidity between 56% and 67%. Based on a simulated sample of 120 hypothetical respondents, 68.33% report being satisfied or very satisfied, with an average satisfaction score of 3.67 out of 5. An energy-saving scenario of 8% reduces the estimated EUI to 110.40 kWh/m²/year. These findings illustrate the potential of an integrated evaluation approach to identify opportunities for improving energy efficiency while considering thermal comfort and occupant satisfaction. However, the hypothetical findings require validation through actual building measurements and occupant surveys before supporting operational recommendations.
Keywords: Public Buildings; Energy Efficiency; Thermal Comfort; Occupant Satisfaction; Operational Performance.

INTRODUCTION

Public buildings are essential components of infrastructure that play a significant role in supporting public services, government administrative activities, education, healthcare, and various other social functions. Public buildings are not only required to meet structural strength and safety requirements but must also provide comfortable, healthy, and productive indoor environments for their occupants. As the demand for public services continues to increase, building management requires greater attention to operational performance to ensure that all facilities can be utilized optimally throughout their service life. The International Energy Agency (IEA, 2025) reported that the building sector accounts for approximately 30% of global energy demand, with a proportion of building energy consumption associated with commercial activities and public services. This condition indicates that improving building operational performance is an essential component of energy management and sustainable infrastructure development.

The operational performance of public buildings can be understood as the ability of buildings to perform their intended functions effectively while considering energy consumption, indoor environmental quality, and the needs and perceptions of users. Operational performance evaluation is necessary because the success of a building is determined not only by the quality of its design and construction but also by its ability to maintain an adequate level of service throughout its operational life. Lighting systems, ventilation, air conditioning, electrical equipment operation, and space utilization patterns are among the factors that influence building operational quality. Zhao et al. (2024) explained that Post-Occupancy Evaluation (POE) is an important approach for assessing building environmental quality after occupancy by integrating energy efficiency, thermal comfort, and occupant satisfaction. Therefore, a comprehensive evaluation of operational performance is necessary to identify actual building conditions and establish a basis for improving facility management quality.

Energy efficiency is one of the primary indicators in evaluating the operational performance of public buildings because it is directly related to energy demand and building operating costs. Energy consumption in buildings generally originates from air-conditioning systems, lighting, electronic equipment, and various supporting facilities used by occupants. Uncontrolled energy consumption may increase operational expenses and reduce resource management effectiveness, particularly in buildings with high occupancy and intensive utilization. The IEA (2025) emphasized that improving building energy efficiency is a strategic measure for reducing energy demand while supporting emission

reductions in the building sector. However, energy efficiency cannot be achieved merely by reducing electricity consumption without considering occupant comfort and service requirements. Instead, energy efficiency should be accomplished through the optimization of building systems to control energy consumption without compromising the quality of the indoor environment required by occupants.

Energy efficiency challenges in public buildings become increasingly complex because space utilization characteristics, operating schedules, and occupancy levels may vary according to service activities. Administrative offices, meeting rooms, waiting areas, and other public service facilities have different requirements for ventilation, lighting, and equipment operation. Consequently, energy consumption is not necessarily proportional to building floor area but is also influenced by the number of occupants, types of activities, climatic conditions, and facility operating systems. In Indonesia, the National Standardization Agency established SNI 6390:2020 concerning energy conservation in building air-conditioning systems as a technical reference for supporting more efficient energy utilization (Badan Standardisasi Nasional, 2020). The implementation of energy conservation principles should be accompanied by an evaluation of actual building operating conditions because operational characteristics may differ from the assumptions adopted during the design stage. Therefore, measuring energy consumption and assessing energy use intensity are essential for identifying opportunities to improve the operational efficiency of public buildings.

In addition to energy efficiency, thermal comfort is an important aspect that determines indoor environmental quality and occupants' acceptance of building conditions. Thermal comfort relates to an individual's perception of feeling hot or cold while performing activities within an indoor environment. This condition is influenced by various environmental factors, including air temperature, relative humidity, air velocity, and mean radiant temperature, as well as personal factors such as activity level and clothing characteristics. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2023), through ANSI/ASHRAE Standard 55, explained that thermal comfort results from interactions between environmental conditions and individual characteristics that must be considered simultaneously. Therefore, thermal comfort assessment should not rely solely on indoor temperature measurements but should also incorporate an understanding of environmental conditions and the perceptions of building occupants.

Thermal comfort is closely related to energy efficiency because most efforts to regulate indoor temperature involve the operation of air-conditioning or ventilation systems. Excessive air-conditioning operation may increase energy consumption, whereas reducing cooling intensity without considering thermal conditions may cause occupant discomfort. This relationship highlights the need to establish a balance between energy conservation and the provision of indoor environments suitable for human activities. ASHRAE (2023) described thermal comfort evaluation approaches using conventional and adaptive methods that consider environmental conditions and human responses. Applying these approaches to public buildings is particularly important because variations in occupancy levels, operating schedules, and room characteristics may influence thermal comfort requirements. Therefore, energy efficiency strategies should be developed based on actual operating conditions and occupant characteristics rather than solely through restrictions on energy consumption.

User satisfaction is another important indicator in evaluating the operational performance of public buildings because it reflects the extent to which building facilities and environmental conditions meet occupants' needs. User satisfaction assessments may include perceptions of indoor temperature, air circulation, lighting, cleanliness, noise levels, accessibility and usability of facilities, and overall building service quality. Individuals who occupy indoor spaces for extended periods may have different experiences from those who use the facilities only temporarily. Kasi and Kaliluthin (2024) developed a post-occupancy evaluation approach that connects building performance attributes, facility utilization, and occupant satisfaction in assessing building quality. Although their research focused on residential buildings, the user perception-based assessment approach provides a relevant conceptual foundation for evaluating public buildings. This indicates that measurements of physical building conditions should be complemented by subjective assessments to ensure that evaluation results more comprehensively represent actual user experiences.

In building management practices, differences may arise between technical measurement results and the levels of comfort and satisfaction perceived by occupants. A room with a temperature that satisfies certain technical criteria may not necessarily be considered comfortable by all users because thermal perception is influenced by individual activities, clothing, habits, and adaptive capacity. Similarly, buildings with relatively low energy consumption may not necessarily demonstrate satisfactory operational performance if energy savings are achieved by compromising essential indoor environmental requirements. Zhao et al. (2024) emphasized the importance of incorporating user feedback into post-occupancy evaluation to understand thermal comfort conditions and the relationship between environmental quality and energy efficiency. Their study also identified inconsistencies in data collection methods and the interpretation of post-occupancy evaluation results across previous studies. Therefore, integrating technical measurements with user perception surveys is necessary to achieve a more objective and comprehensive assessment of building operational performance.

Previous studies have contributed to the development of building performance evaluation approaches based on environmental characteristics and user experiences. Dewi et al. (2023) conducted a post-occupancy evaluation of a multifunctional auditorium using zoning and activity-based approaches to assess indoor thermal conditions, noise levels, and lighting performance. Their study highlighted the importance of considering differences in activities and space utilization when evaluating building performance. Meanwhile, Zhao et al. (2024), through a systematic review of post-occupancy evaluation studies, emphasized the importance of integrating thermal comfort, energy consumption, and

occupant feedback to improve building quality. Kasi and Kaliluthin (2024) also highlighted an evaluation approach based on building attributes and occupant perceptions. These studies demonstrate that building performance assessment has evolved from evaluating physical parameters toward more comprehensive approaches that incorporate user experiences, activity characteristics, and the effectiveness of indoor environmental management.

Although previous studies have examined energy efficiency, thermal comfort, and user satisfaction, integrating these three indicators into a comprehensive operational evaluation framework still requires further development according to the characteristics of the buildings being investigated. Studies involving multifunctional auditoriums, for example, have emphasized environmental conditions based on activities and spatial zoning, whereas research on residential buildings has focused more extensively on post-occupancy conditions and occupant experiences. Public buildings have different characteristics because they may accommodate employees, facility managers, and members of the general public with varying occupancy durations and service requirements. These differences may simultaneously influence energy consumption, thermal conditions, and user satisfaction levels. Therefore, an evaluation approach capable of integrating these three aspects through measurable indicators appropriate to the operational characteristics of public buildings is required. This need provides the basis for developing research that not only identifies energy consumption levels but also examines whether such energy utilization produces adequate thermal conditions and satisfactory user experiences.

Based on these considerations, the research gap addressed in this study is the need for an integrated assessment of public building operational performance by connecting energy efficiency, thermal comfort, and user satisfaction within a unified evaluation framework. The proposed novelty of this study lies in developing a multicriteria evaluation approach that combines technical indicators, including energy use intensity and thermal environmental parameters, with perceptual indicators representing user satisfaction levels. Through this approach, the relationship between energy consumption and indoor environmental quality can be analyzed alongside the actual experiences of building occupants. Integrating these three indicators is expected to provide a more comprehensive understanding of building operational conditions and identify areas requiring priority improvements. Furthermore, this approach has the potential to establish a more practical evaluation framework for public building management, particularly in determining energy efficiency strategies that maintain service quality and occupant comfort.

Based on the aforementioned background, this study aims to evaluate the operational performance of public buildings based on three primary aspects: energy efficiency, thermal comfort, and user satisfaction. The evaluation focuses on identifying building energy consumption characteristics, analyzing indoor temperature, humidity, and other relevant thermal parameters, and measuring user satisfaction with indoor environmental quality. Subsequently, the results of these three assessments are analyzed to determine the relationships among energy consumption, thermal comfort conditions, and user perceptions in supporting effective building operations. This study is expected to contribute academically to the development of building performance evaluation methods that integrate technical indicators and user perceptions while providing practical recommendations for facility managers to improve operational efficiency, enhance indoor environmental comfort, and support sustainable public service delivery.

RESEARCH METHODOLOGY

3.1 Research Design and Approach

This study was designed using a quantitative approach with a descriptive-evaluative method through Post-Occupancy Evaluation (POE) to assess the operational performance of public buildings based on energy efficiency, thermal comfort, and user satisfaction. The quantitative approach was employed to obtain measurable insights into the relationships among energy consumption characteristics, thermal environmental conditions, and users' perceptions of building facility quality. The descriptive-evaluative method was applied to identify operational performance levels by comparing technical measurements and user assessments with predetermined evaluation criteria. The POE approach was selected because it enables the evaluation of buildings after they have been occupied, allowing the findings to reflect the extent to which actual building performance meets users' needs. This study integrates energy consumption measurements, observations of thermal conditions, and questionnaire surveys to obtain complementary information. Such integration is expected to produce a more comprehensive evaluation than assessments focusing separately on energy consumption or environmental comfort.

3.2 Research Object and Location

The research object consists of public buildings that are operational and actively used for community services, administrative activities, education, or other public functions. The selection of research objects is conducted purposively by considering the representativeness of building functions, the intensity of space utilization, the availability of energy consumption data, and access to building users. The research scope focuses on areas with relatively high utilization rates, such as offices, service areas, meeting rooms, and waiting areas, as these spaces exhibit different operational characteristics and comfort requirements. Observations consider building floor area, number of stories, building orientation, air-conditioning systems, lighting systems, occupancy levels, and operating hours. These characteristics serve as the basis for interpreting differences in energy consumption and thermal conditions across building areas. The research location and observation period are determined based on the actual buildings selected for investigation to ensure systematic data collection and to allow the evaluation results to reflect operational conditions during the study period.

3.3 Types and Sources of Data

The research data consist of primary and secondary data used to evaluate three main aspects of public building operational performance. Primary data are planned to be obtained through thermal environmental measurements, observations of facility utilization, and questionnaires completed by building users. Thermal measurements include air temperature, relative humidity, and air velocity, while user assessments cover perceptions of temperature comfort, air circulation, lighting, and overall satisfaction with indoor environmental conditions. Secondary data include electricity consumption records, building floor area, air-conditioning equipment specifications, lighting system characteristics, operating schedules, and available technical building documents. Electricity consumption data may be obtained from energy meter readings or electricity bills covering the designated observation period. All collected data are subsequently categorized according to energy efficiency, thermal comfort, and user satisfaction indicators to establish a measurable and comparable basis for evaluating building operational performance.

3.4 Data Collection Techniques

Data collection is designed to involve direct observation, indoor environmental measurements, energy consumption documentation, and questionnaire surveys administered to building users. Direct observations are conducted to identify space utilization patterns, types of electrical equipment, air-conditioning operating conditions, and the characteristics of user activities during service hours. Air temperature and relative humidity may be measured using a thermo-hygrometer, while air velocity is measured using an anemometer at observation points selected according to room functions and characteristics. Measurements are conducted at several intervals during operating hours to identify possible variations in thermal conditions associated with occupancy levels and building activities. Energy consumption data are obtained through electricity usage records and an inventory of equipment contributing to energy demand. Questionnaires are then distributed to respondents who use the building during the observation period to obtain assessments of comfort levels and satisfaction with environmental conditions. Combining these data collection techniques is intended to reduce dependence on a single information source and strengthen the interpretation of evaluation results.

3.5 Building Energy Efficiency Analysis

Energy efficiency analysis is conducted by evaluating building electricity consumption based on the amount of energy used during a specified period and the corresponding floor area. The primary indicator is Energy Use Intensity (EUI), known in Indonesian as Intensitas Konsumsi Energi (IKE), which represents the amount of energy consumed per unit of building floor area over the same period. EUI is determined by dividing total electricity consumption, expressed in kilowatt-hours (kWh), by the building floor area, expressed in square meters (m^2). When energy consumption is assessed annually, the resulting value is expressed in kWh/m^2/year. This indicator enables a more proportional assessment of energy consumption relative to building size. The calculated results are subsequently analyzed by considering operational characteristics, occupancy schedules, air-conditioning systems, lighting arrangements, and electrical equipment usage. Interpretation takes into account building functions and relevant benchmarking criteria to ensure that energy efficiency is not evaluated solely based on absolute energy consumption. The analysis also aims to identify operational components that may contribute to unnecessary energy consumption and could therefore become priorities for efficiency improvements.

3.6 Thermal Comfort Analysis

Thermal comfort analysis is conducted to evaluate indoor environmental conditions based on physical measurements and building users' perceptions. The main observed parameters include air temperature in degrees Celsius (°C), relative humidity expressed as a percentage (%), and air velocity in meters per second (m/s). Measurements are conducted at representative points within occupied areas, considering the location of air-conditioning equipment, ventilation openings, and the intensity of space utilization. The collected data are analyzed using mean, minimum, and maximum values, as well as variations in thermal conditions throughout the observation period. Thermal comfort evaluation refers to the principles of ANSI/ASHRAE Standard 55-2023, which considers both environmental factors and individual characteristics in determining acceptable thermal comfort conditions. Where supporting data are available, the analysis may be extended using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) methods, considering mean radiant temperature, activity levels, and occupants' clothing characteristics. In spaces that meet the applicability requirements of the adaptive approach, thermal comfort may also be assessed using an adaptive thermal comfort model. The measurement results are subsequently compared with users' comfort responses to determine the correspondence between physical indoor conditions and perceived thermal experiences.

3.7 Building User Satisfaction Analysis

User satisfaction analysis is conducted through questionnaire surveys designed to measure respondents' perceptions of indoor environmental quality and building facilities. Respondents are selected based on their involvement in building utilization, including employees, facility managers, and members of the public accessing building services. Respondent selection considers duration of space utilization, types of activities, and representation of user groups to ensure that the collected data provide a proportional understanding of satisfaction levels. The research instrument employs a five-point Likert scale, ranging from very dissatisfied, assigned a score of 1, to very satisfied, assigned a score of 5. The assessment

indicators include temperature comfort, air circulation quality, lighting, noise levels, ease of facility use, and overall satisfaction with the building environment. Scores for each indicator are calculated based on the average responses and subsequently analyzed descriptively to identify aspects receiving the highest and lowest evaluations. Before implementation, the questionnaire instrument should be examined for content relevance, clarity of questions, and internal consistency reliability to ensure that the results can be interpreted appropriately. The analysis is intended to identify operational aspects that most strongly influence user satisfaction and determine priorities for improving building facility quality.

3.8 Analysis of the Relationships Among Energy Efficiency, Thermal Comfort, and User Satisfaction

The relationships among research variables are analyzed to evaluate the associations between energy consumption, thermal conditions, and building users' perceptions. Energy Use Intensity (EUI) serves as an energy efficiency indicator at the building level or within zones equipped with separate energy monitoring systems, while air temperature, relative humidity, and air velocity represent thermal environmental conditions. User satisfaction levels are obtained from processed questionnaire scores corresponding to the established evaluation indicators. The relationship between thermal conditions and satisfaction may be examined using Pearson correlation analysis when the data satisfy the relevant statistical assumptions, whereas Spearman correlation analysis may be applied when the data characteristics are more appropriate for a nonparametric approach. Analyzing the relationship between energy consumption and user satisfaction requires consistency in observational units, such as corresponding rooms, zones, or time periods. When energy consumption data are available only as a single total value for the entire building, direct statistical correlations with individual questionnaire responses are not performed because the units of analysis differ. Under such circumstances, findings from the three evaluation aspects are interpreted descriptively and comparatively to identify the balance between energy consumption and the quality of indoor environmental services.

3.9 Evaluation of Building Operational Performance

Building operational performance is evaluated by integrating the findings from energy efficiency, thermal comfort, and user satisfaction analyses based on predetermined indicators. Energy performance evaluation focuses on electricity consumption levels and their suitability for the building's operational characteristics. Thermal comfort assessment is conducted based on environmental measurement results and the extent to which users perceive indoor conditions as acceptable. Meanwhile, user satisfaction is evaluated through perceptions of environmental quality and facilities supporting public service activities. These three aspects are compared to identify operational conditions that adequately meet users' needs and components requiring improvement. The evaluation does not prioritize minimum energy consumption alone because energy savings achieved at the expense of occupant comfort may reduce overall building service quality. Conversely, high comfort levels must also be assessed in relation to the energy required to maintain such conditions. Therefore, operational performance evaluation aims to identify an appropriate balance among efficient resource utilization, the fulfillment of thermal comfort requirements, and the quality of user experiences within public buildings.

3.10 Data Processing and Interpretation Techniques

Data obtained from environmental measurements, energy consumption records, and questionnaire surveys are processed using descriptive and comparative statistical analysis. Initial data processing involves checking data completeness, categorizing observations according to location and measurement period, and organizing indicators based on the research variables. Air temperature, relative humidity, and air velocity measurements are analyzed to determine average values and the ranges of environmental variations, while energy consumption is evaluated according to the observation period and building floor area. Questionnaire responses are processed to obtain response distributions, average scores, and descriptions of respondents' satisfaction levels. The analytical findings are subsequently presented in tables and graphs to illustrate operational characteristics and relationships among the investigated aspects. Data interpretation is conducted by comparing the findings with predetermined evaluation criteria while considering the characteristics of building utilization. Research conclusions are formulated by integrating technical measurement results and user assessments, allowing the resulting recommendations to focus on reducing unnecessary energy consumption, improving thermal comfort, and enhancing user satisfaction in public buildings.

RESULTS AND DISCUSSION

4.1. General Characteristics of the Public Building

The object of evaluation in this simulation was a public building assumed to function as a facility for administrative services and community activities. The building was assumed to have a total floor area of 1,200 m² distributed over two stories, with primary activities including administrative services, office operations, meetings, and public services. The building was equipped with air-conditioning systems, artificial lighting, and various electronic devices used during operating hours. Space utilization characteristics and occupant activity levels were considered important factors in determining evaluation indicators because different spaces exhibit varying energy demands and comfort requirements.

The operational evaluation focused on four functional areas: public service areas, administrative offices, meeting rooms, and waiting areas. These areas were selected because they have different activity patterns and indoor environmental

requirements. Administrative offices were assumed to be occupied continuously by employees, public service areas experienced frequent occupant turnover, meeting rooms were used periodically with fluctuating occupancy levels, and waiting areas exhibited irregular visitor arrival patterns. These differences were assumed to influence energy consumption, thermal environmental conditions, and user satisfaction.

Table 1. Characteristics of the public building in the simulation model

Parameter	Simulated Value
Building function	Public administrative services
Number of stories	2
Total floor area	1,200 m²
Operating hours	08:00–16:00 WIB
Operating days	Monday–Friday
Air-conditioning system	Air conditioning and ventilation
Lighting system	LED lighting
Energy analysis period	12 months
Number of simulated respondents	120
Observed space categories	4

Source: Research model assumptions, 2026.

Based on these characteristics, the evaluation distinguished between energy consumption analysis at the building level and thermal comfort and user satisfaction assessments at the functional space level. This distinction was necessary because electricity consumption could be recorded for the building as a whole, whereas thermal conditions and user satisfaction could vary among different areas. Through this approach, the evaluation could identify operational aspects requiring attention in facility management.

4.2. Building Energy Efficiency Analysis

Building energy efficiency was evaluated based on annual electricity consumption using the Energy Use Intensity (EUI) indicator. This indicator represents the amount of electrical energy consumed per unit of building floor area, allowing comparisons of energy consumption intensity among buildings of different sizes, provided that consistent measurement boundaries are applied.

In the simulation model, annual electricity consumption was assumed to be 144,000 kWh, while the total floor area was 1,200 m². Dividing annual energy consumption by the building floor area produced an EUI of 120 kWh/m²/year. This value represented the assumed energy consumption characteristics of the simulated building and did not establish that the building met any particular energy efficiency classification. Determining energy efficiency performance requires appropriate benchmarks that consider building function, operating hours, floor area definitions, climatic conditions, and air-conditioning systems.

Table 2. Simulated electricity consumption of the public building

Period	Energy Consumption (kWh)	Annual Percentage
First quarter	35,000	24.31%
Second quarter	36,000	25.00%
Third quarter	38,000	26.39%
Fourth quarter	35,000	24.31%
Total	144,000	100%

Source: Hypothetical simulation data, 2026. Percentages are rounded to two decimal places.

The results indicated that the highest electricity consumption occurred during the third quarter, reaching 38,000 kWh, while the lowest consumption was recorded during the first and fourth quarters, each accounting for 35,000 kWh. These differences illustrated variations in energy consumption throughout the operational period. In actual buildings, such variations may be influenced by weather conditions, occupancy levels, activity intensity, and equipment operating duration. However, these contributing factors cannot be established solely from aggregated energy consumption data and would require additional operational information.

For a more detailed illustration of energy consumption components, the total electricity consumption was divided into three categories: air conditioning, lighting, and electronic equipment. This allocation was based on assumed energy consumption proportions rather than actual submetering measurements.

Table 3. Assumed energy consumption distribution by operational component

Component	Energy Consumption (kWh/year)	Proportion
Air-conditioning systems	90,000	62.50%

Lighting	30,000	20.83%
Electronic equipment	24,000	16.67%
Total	144,000	100%

Source: Assumed energy distribution in the simulation model, 2026.

The simulated distribution indicated that air-conditioning systems accounted for the largest proportion of electricity consumption, representing 62.50% of the total. This suggested that improving air-conditioning system operation could become a priority in assessing potential energy efficiency improvements. Adjusting temperature settings, optimizing operating schedules, inspecting equipment conditions, and maintaining ventilation systems are among the measures that could be evaluated to control energy consumption.

From a technical perspective, SNI 6390:2020 establishes provisions for energy conservation in building air-conditioning systems, including minimum equipment efficiency requirements and system operation and maintenance considerations. Therefore, energy conservation strategies for air-conditioning systems should consider both equipment efficiency and occupant comfort rather than simply reducing cooling operating hours.

4.3. Evaluation of Building Thermal Comfort

Thermal comfort was evaluated by analyzing air temperature, relative humidity, and air velocity across four functional space categories. In the simulation model, environmental conditions were represented by assumed average values corresponding to observations during building operating hours. These parameters were used to identify differences in thermal conditions among spaces and assess potential requirements for improving air-conditioning and ventilation performance.

Table 4. Simulated thermal environmental characteristics of the public building

Functional Space	Air Temperature (°C)	Relative Humidity (%)	Air Velocity (m/s)
Public service area	24.8	56	0.15
Administrative office	25.6	59	0.13
Meeting room	27.4	67	0.08
Waiting area	26.8	64	0.10

Source: Hypothetical simulation data, 2026.

The simulation results indicated that the lowest air temperature occurred in the public service area at 24.8°C, whereas the highest temperature occurred in the meeting room at 27.4°C. The meeting room also exhibited the highest relative humidity at 67%, accompanied by an air velocity of 0.08 m/s. These conditions could indicate the need to examine air distribution, cooling capacity, occupancy levels, and ventilation operation if similar patterns were observed in an actual building.

In interpreting these findings, thermal comfort cannot be determined solely from air temperature and relative humidity measurements. ANSI/ASHRAE Standard 55-2023 explains that thermal environments are influenced by air temperature, mean radiant temperature, humidity, air velocity, and personal factors such as activity level and clothing insulation. The standard provides conventional and adaptive approaches for evaluating thermal comfort according to environmental characteristics and occupant conditions.

Consequently, the differences presented in Table 4 describe variations in environmental conditions rather than direct evidence of compliance or noncompliance with ASHRAE thermal comfort requirements. A more comprehensive assessment would require information on mean radiant temperature, occupant activity levels, clothing characteristics, and the application of appropriate Predicted Mean Vote–Predicted Percentage of Dissatisfied (PMV–PPD) or adaptive thermal comfort methods.

Within the context of public building operations, meeting rooms and waiting areas could be prioritized for further investigation because they exhibited relatively higher temperatures and lower air velocities than the other areas. Nevertheless, before modifying air-conditioning systems, facility managers should verify the underlying causes through equipment inspections, ventilation assessments, space utilization observations, and occupant feedback.

4.4. Analysis of Building User Satisfaction

User satisfaction represents an indicator of individuals' acceptance of environmental conditions and facilities during building occupancy. In this simulation, satisfaction was evaluated using hypothetical responses from 120 participants representing employees and public service users. The assumed questionnaire employed a five-point Likert scale consisting of very dissatisfied, dissatisfied, neutral, satisfied, and very satisfied.

The assessment was designed to identify perceptions of temperature comfort, air circulation, lighting, noise conditions, and facility quality. The following analysis focused on overall satisfaction as a perceptual indicator of building operational performance.

Table 5. Simulated distribution of building user satisfaction

Satisfaction Category	Number of Respondents	Percentage
Very satisfied	20	16.67%
Satisfied	62	51.67%
Neutral	20	16.67%
Dissatisfied	14	11.67%
Very dissatisfied	4	3.33%
Total	120	100%

Source: Hypothetical respondent data, 2026.

The simulated results showed that 82 of the 120 respondents, equivalent to 68.33%, were classified as satisfied or very satisfied. Meanwhile, 18 respondents, or 15.00%, expressed dissatisfaction or strong dissatisfaction, while 20 respondents, representing 16.67%, provided neutral assessments. This distribution suggested that most hypothetical users expressed positive perceptions of building operational conditions, although a proportion of respondents indicated dissatisfaction.

The mean satisfaction score was calculated by applying the corresponding Likert-scale weights to the response distribution. The resulting average was 3.67 on a five-point scale. This value indicated a generally positive satisfaction tendency within the hypothetical model but could not be interpreted as the actual satisfaction level of occupants in an existing public building.

User satisfaction assessments play an important role in complementing technical building measurements. Zhao et al. (2024) explained that post-occupancy evaluation can integrate occupant feedback with thermal comfort information and energy performance data to provide a more comprehensive understanding of building conditions after occupancy. Their review also emphasized the importance of consistent data collection and interpretation methods to improve comparability among evaluation results.

Accordingly, satisfaction assessment in this study was not intended to replace technical measurements but rather to provide complementary information regarding how building occupants perceive and experience indoor environmental conditions.

4.5. Relationship Between Thermal Conditions and User Satisfaction

The relationship between thermal conditions and user satisfaction was evaluated by comparing the environmental characteristics of each functional space category with the percentage of respondents reporting satisfaction or high satisfaction. The 120 hypothetical respondents were distributed equally among four functional space categories, with 30 respondents assigned to each area.

Table 6. Simulated relationship between thermal conditions and user satisfaction by functional space

Functional Space	Temperature (°C)	Respondents	Satisfied/Very Satisfied	Satisfaction Rate
Public service area	24.8	30	25	83.33%
Administrative office	25.6	30	23	76.67%
Meeting room	27.4	30	16	53.33%
Waiting area	26.8	30	18	60.00%
Total	—	120	82	68.33%

Source: Hypothetical simulation data, 2026. Satisfaction rates combine the satisfied and very satisfied categories.

The results indicated that the public service area, with an assumed air temperature of 24.8°C, exhibited the highest satisfaction rate at 83.33%. Conversely, the meeting room, which had the highest assumed temperature of 27.4°C, demonstrated the lowest satisfaction rate at 53.33%. Satisfaction levels in the administrative office and waiting area fell between these two conditions.

Within the hypothetical scenario, spaces with higher air temperatures tended to exhibit lower proportions of satisfied users. Nevertheless, this pattern cannot be interpreted as evidence of a causal relationship. User satisfaction may also be influenced by occupancy levels, activity intensity, duration of space utilization, air circulation, noise, and facility quality.

Furthermore, the dataset represented only four functional space categories, which is insufficient to support strong statistical conclusions regarding the relationship between temperature and satisfaction across public buildings. Reliable correlation analysis would require repeated measurements, paired observations linking environmental conditions with individual responses, and appropriate control of relevant variables.

These illustrative findings highlight the importance of post-occupancy evaluation approaches that integrate physical environmental measurements with user responses. Zhao et al. (2024) emphasized the value of user-centered approaches in assessing thermal comfort and energy efficiency, allowing building operational improvements to address both actual environmental conditions and occupants' needs.

4.6. Integrated Evaluation of Public Building Operational Performance

The integrated evaluation combined the results of energy consumption analysis, thermal environmental assessment, and user satisfaction measurements. This approach was adopted to provide a more comprehensive representation of building operational performance because each indicator contributes different information. Energy consumption reflects resource utilization, thermal measurements describe physical environmental conditions, and satisfaction levels represent users' perceptions of building environmental quality.

Table 7. Summary of simulated public building operational performance

Indicator	Simulation Result	Interpretation
Annual energy consumption	144,000 kWh	Basis for energy assessment
Energy Use Intensity	120 kWh/m²/year	Requires comparable benchmarks
Air-conditioning energy contribution	62.50%	Priority for potential energy savings assessment
Lowest indoor temperature	24.8°C	Public service area
Highest indoor temperature	27.4°C	Meeting room
Mean satisfaction score	3.67 out of 5	Generally positive perception
Satisfied/very satisfied users	68.33%	Majority of hypothetical respondents satisfied
Dissatisfied/very dissatisfied users	15.00%	Indicates potential improvement needs

Source: Summary of hypothetical simulation results, 2026.

The integrated findings demonstrated the importance of evaluating energy consumption, environmental comfort, and user satisfaction simultaneously. Air-conditioning systems accounted for the largest proportion of assumed electricity consumption, while meeting rooms and waiting areas exhibited relatively higher temperatures than other spaces. At the same time, these areas showed lower satisfaction levels in the hypothetical scenario. These findings illustrated that energy consumption reductions should not be pursued without considering occupants' comfort requirements.

Potential operational improvements could focus on optimizing air-conditioning systems according to room characteristics, utilization schedules, and occupancy levels. In frequently occupied areas, facility managers could evaluate cooling capacity, air distribution, filter conditions, and ventilation effectiveness. Meanwhile, in spaces with intermittent occupancy, adjusting equipment operating schedules could reduce unnecessary energy consumption. However, the magnitude of achievable energy savings would need to be established through energy audits, additional measurements, or appropriate technical simulations.

4.7. Discussion of Potential Energy Efficiency Improvements

The potential for improving energy efficiency was evaluated through hypothetical scenarios involving reductions in electricity consumption while maintaining the building's public service functions. To provide a quantitative illustration, this study considered energy savings of 5%, 8%, and 10% relative to the initial annual electricity consumption of 144,000 kWh. These savings percentages were assumed evaluation targets rather than measured outcomes of implemented energy conservation measures.

Table 8. Simulated energy savings scenarios

Scenario	Energy Savings (kWh/year)	Annual Consumption After Savings (kWh/year)	EUI (kWh/m²/year)	Scenario	Energy Savings (kWh/year)	Annual Consumption After Savings (kWh/year)
Reference condition	0	144,000	120.00	Reference condition	0	144,000
5% savings	7,200	136,800	114.00	5% savings	7,200	136,800
8% savings	11,520	132,480	110.40	8% savings	11,520	132,480
10% savings	14,400	129,600	108.00	10% savings	14,400	129,600

Source: Hypothetical scenario calculations, 2026.

The simulation showed that an assumed energy reduction of 8% would decrease annual electricity consumption from 144,000 kWh to 132,480 kWh. Consequently, the EUI would decline from 120 kWh/m²/year to 110.40 kWh/m²/year. This result illustrated the mathematical relationship between reduced electricity consumption and lower energy use intensity when the building floor area remains constant.

However, potential energy savings must be evaluated alongside thermal comfort and user satisfaction. Reduced electricity consumption cannot automatically be considered an overall improvement in operational performance if the conservation measures cause indoor temperatures to become unsuitable for occupants' needs. Therefore, energy management strategies should focus on improving system efficiency, maintaining equipment, optimizing operating schedules, and enhancing space utilization. These principles are consistent with the energy conservation considerations for building air-conditioning systems addressed in SNI 6390:2020.

4.8. Implications of the Research Findings for Public Building Management

The hypothetical findings illustrated the importance of evaluating public building operations by integrating energy consumption indicators, indoor environmental conditions, and user perceptions. Assessments focusing exclusively on reducing electricity consumption may overlook occupant comfort, while efforts to improve comfort solely by increasing air-conditioning use may result in higher energy demand and operating costs. Therefore, balancing energy efficiency and indoor environmental quality is essential when developing sustainable building management strategies.

Within public facility management, Post-Occupancy Evaluation provides a framework for identifying operational problems, determining maintenance requirements, and prioritizing facility improvements. The evaluation combines measurable energy consumption and thermal environmental data with information regarding users' experiences. Zhao et al. (2024) emphasized that structured post-occupancy evaluation can help establish connections between building performance and occupant feedback while supporting strategies to improve indoor environmental quality.

The findings also highlighted the importance of selecting evaluation indicators appropriate to the characteristics of each building. EUI values should be interpreted according to building function and operational conditions, while thermal comfort assessments require consideration of multiple physical and personal parameters. User satisfaction provides an important complementary indicator but cannot replace technical performance assessments. Accordingly, operational performance evaluation becomes more meaningful when all three aspects are examined within an integrated framework.

Based on the overall hypothetical results, potential improvements in public building performance could focus on air-conditioning system management, aligning facility operation with occupancy and activity patterns, and periodically evaluating occupant comfort and satisfaction. Although the present study did not provide empirical evidence regarding the effectiveness of these measures, the proposed framework could serve as a foundation for developing more structured field investigations.

4.9. Research Limitations

This study has several limitations because the data were derived from hypothetical simulations rather than direct measurements conducted in operational public buildings. Electricity consumption values, thermal environmental parameters, and user satisfaction distributions were established to illustrate the application of the evaluation methodology. Therefore, the findings cannot be generalized to actual building conditions.

Furthermore, the thermal comfort analysis did not include all parameters necessary to calculate Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), while the energy efficiency assessment did not incorporate benchmarking data from buildings with comparable functions and operational characteristics. The relationship between thermal conditions and user satisfaction was also limited to descriptive interpretation because the analysis was not supported by paired individual observations or inferential statistical testing.

Future research should incorporate actual energy consumption records collected over an adequate observation period, repeated measurements of thermal environmental conditions, and user satisfaction surveys employing instruments with established validity and reliability. Such improvements would allow the relationships among the three dimensions of operational performance to be evaluated more accurately and would provide a stronger empirical foundation for developing technically justified building management recommendations.

CONCLUSIONS

Based on the evaluation of public building operational performance conducted using the Post-Occupancy Evaluation (POE) approach, it can be concluded that energy efficiency, thermal comfort, and user satisfaction are three interrelated aspects that determine the quality of building operations. The hypothetical simulation results indicated that a building with a total floor area of 1,200 m² had an annual electricity consumption of 144,000 kWh, corresponding to an Energy Use Intensity (EUI) of 120 kWh/m²/year. Air-conditioning systems represented the largest energy-consuming component, accounting for 62.50% of total electricity consumption. These findings suggested that optimizing air-conditioning systems could be one of the primary strategies for improving building energy efficiency. Under the assumed 8% energy-saving scenario, annual electricity consumption could potentially be reduced to 132,480 kWh, resulting in an EUI of 110.40 kWh/m²/year. However, determining the actual level of energy efficiency would require comparisons with appropriate standards or benchmarks that reflect the building's operational characteristics.

Regarding thermal comfort, the simulated indoor air temperatures ranged from 24.8°C to 27.4°C, with relative humidity levels ranging from 56% to 67%. The public service area exhibited the lowest air temperature, while the meeting room recorded the highest temperature. The hypothetical user satisfaction results indicated that 68.33% of respondents were classified as satisfied or very satisfied, with an average satisfaction score of 3.67 on a five-point scale. Comparisons among

different functional areas revealed a tendency for spaces with higher temperatures to have lower user satisfaction percentages. Nevertheless, this relationship remained descriptive and could not be interpreted as evidence of causality because thermal comfort and user satisfaction are also influenced by other environmental factors and individual characteristics.

Overall, the simulation results demonstrated that improving the operational performance of public buildings requires an integrated approach that balances energy conservation, thermal comfort requirements, and user satisfaction. Optimizing air-conditioning system operations, adjusting equipment operating schedules, maintaining building facilities, and periodically evaluating indoor environmental conditions could be considered potential strategies for enhancing building operational quality. This study provides an evaluation framework that may serve as a foundation for developing more efficient, comfortable, and sustainable public building management practices. However, because all data used in this study were hypothetical, the findings cannot be generalized to actual building conditions. Further research is necessary using direct measurements of energy consumption and thermal environmental conditions, along with actual user satisfaction surveys, to obtain more accurate, verified, and scientifically reliable results.

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