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Research Article

Exploring Energy Efficiency and User Attitudes toward Green Energy Implementation in University Buildings

Nurhasan Syah • Syaiful Haq * • Faisal Ashar • Yaumal Arbi

Department of Civil Engineering, Universitas Negeri Padang, Padang, West Sumatra, Indonesia

ABSTRACT

The global push for sustainable development has intensified the need to improve energy efficiency in higher education buildings, particularly in hot–humid tropical climates where cooling demand dominates electricity use. This study examines how occupant perceptions, environmental attitudes, and energy-related behaviors relate to measured building energy performance in a tropical university building, using a convergent parallel mixed-methods design. An ASHRAE Level 1–based energy audit (aligned with Indonesia's MEMR Regulation No. 13/2012) profiled electricity consumption by end-use systems and was complemented by a 38-item questionnaire and semi-structured interviews with students, lecturers, and administrative staff. The audit estimated total annual electricity consumption of 366,897.7 kWh/year, corresponding to an average Energy Use Intensity (EUI) of 17.34 kWh/m²/month, and associated emissions of 285,108.85 $kgCO_2eq$. Cooling/HVAC accounted for the largest share of electricity use (≈55%), followed by plug loads/equipment and lighting. Survey results indicated generally high pro-environmental attitudes; however, quantitative associations between aggregated floor-level perceptions/behaviors and electricity use were exploratory, given the limited number of analytic units (four floors/zones). Still, floor-level correlations consistently suggested negative relationships between behavioral variables and energy consumption, with expectations toward green-energy practices showing a particularly strong inverse association ($r = -0.968$). Qualitative findings highlighted practical operational and behavioral drivers such as temperature setpoints, schedule discipline, and equipment shutdown practices, pointing to actionable opportunities for demand reduction. Overall, the study contributes an integrated audit–behavior perspective to support occupant-centered interventions, green-campus policy alignment, and sustainability-oriented learning activities for long-term low-carbon campus development in hot–humid contexts.

KEYWORDS energy efficiency • energy use behavior • greenhouse gas • green energy • sustainable energy • tropical climate

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*CORRESPONDENCE
Syaiful Haq syaifulhaq@ft.unp.ac.id Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Padang, Jl. Prof. Dr. Hamka, Kampus Air Tawar Barat, Padang, West Sumatra 25132, Indonesia. https://orcid.org/0000-0001-6127-3748

1. INTRODUCTION

Buildings are among the world's largest energy consumers. The World Green Building Council reports that the construction sector accounts for approximately 30 – 45% of total global energy use, making it a major contributor to greenhouse gas emissions and climate change [1], [2]. In a typical high-rise building, energy consumption is dominated by heating, ventilation, and air conditioning (HVAC) systems, which often account for 40–55% of total energy use, followed by lighting systems contributing 20–25%, and the remaining 15–25% consumed by other electrical and mechanical equipment such as elevators, pumps, and electronic devices [3]. Consequently, improving energy efficiency in buildings has become a central strategy in global climate mitigation policies and sustainable development agendas [4].

Within this global context, commercial buildings, particularly office and university facilities, are recognized as among the most energy-intensive building categories [2], [5]. Academic buildings represent a distinctive subcategory of commercial buildings due to their dual role as centers of education and research. They must simultaneously ensure thermal comfort, visual quality, indoor air quality, and operational reliability to support learning, teaching, and research activities. At the same time, their intensive daily operations, covering cooling, lighting, laboratory equipment, and information technology systems, make them a substantial contributor to energy consumption and associated greenhouse gas (GHG) emissions [6]–[10]. This dual function creates a structural tension between educational performance and environmental sustainability, positioning academic buildings as a critical focus of building energy research.

In recent years, university campuses have increasingly been conceptualized as “living laboratories” for sustainability transitions, where energy-saving strategies can be tested, evaluated, and institutionalized. Campus buildings typically operate for extended hours, accommodate large and diverse user populations, and integrate technology-intensive facilities, resulting in consistently high energy demand [11]. A defining characteristic of campus buildings is their high level of functional complexity, as classrooms, laboratories, offices, meeting spaces, and data centers must operate simultaneously under varying occupancy patterns and usage schedules.

A common response to these challenges is the deployment of technology-driven energy management, such as Building Automation Systems (BAS) or Building Management Systems (BMS). Although such systems can be effective, evidence from developing-economy contexts highlights persistent barriers, including high upfront costs, maintenance burdens, interoperability with legacy systems, and limited operator capacity, which can prevent systems from performing as intended [12], [13]. As a result, occupant behavior becomes a crucial, often lower-cost, and immediately actionable pathway to reduce energy consumption, especially where operational practices (setpoints, switching behavior, scheduling discipline, equipment use) materially shape end-use loads and performance outcomes [14], [15].

Despite the growing body of literature on energy efficiency in educational buildings, clear gaps remain in the geographical/climatic coverage and in methodological approaches. First, empirical evidence on energy-related occupant behavior remains concentrated in developed, temperate/subtropical contexts (Europe, the U.S. and China). At the same time, hot–humid tropical regions such as Indonesia remain underrepresented [16]. This imbalance is critical because tropical educational buildings are typically cooling-dominated, with comfort expectations and adaptive practices that can differ from non-tropical settings [17]. At the same time, warming temperatures are expected to intensify further reliance on cooling and associated energy demand [18], [19].

Second, many occupant-behavior studies still rely heavily on simulations and simplified behavioral assumptions (fixed schedules/rules), which can limit realism and contribute to the gap between predicted and measured energy use [15], [20]. Reviews also highlight ongoing challenges in generalizability and the relative lack of field-measured validation for behavioral models [21]. This limitation is reflected in data availability: a recent global compilation identifies only 34 field-measured occupant-behavior datasets across 15 countries, indicating that robust empirical evidence remains scarce [22]. Consequently, there is still limited understanding of how psychosocial determinants (e.g., attitudes, norms, perceived control) translate into measured energy outcomes—supporting the need for integrated studies combining audit-grade performance measurement with theory-driven behavioral analysis in tropical campus buildings.

Rather than reiterating the now well-established argument that behavioral aspects are neglected in energy research, this study addresses a core research gap: the limited empirical integration of building energy audits with theory-driven behavioral analysis within a single framework, particularly in tropical campus environments. There remains a lack of studies that simultaneously measure actual building energy performance and systematically examine occupant behavior using established psychological theories, such as the Theory of Planned Behavior (TPB) and the Value–Belief–Norm (VBN) framework. Addressing this combined geographical, climatic, and methodological gap is increasingly urgent, as rising cooling demand in tropical regions places additional environmental and financial pressure on higher education institutions.

Accordingly, this study pursues three objectives: (1) to quantify the energy performance and associated greenhouse gas (GHG) emissions of a university building in a hot–humid tropical climate using empirical measurements and an ASHRAE Level 1 energy audit; (2)

to characterize occupants' environmental attitudes, perceptions, and energy-related behaviors through survey constructs grounded in the Theory of Planned Behavior (TPB) and the Value–Belief–Norm (VBN) framework; and (3) to test how these behavioral constructs relate to measured energy performance indicators within an integrated analytical model, complemented by qualitative evidence.

The study contributes to theory by evaluating TPB/VBN-based behavioral explanations in a tropical higher education building where cooling demand is the dominant load, thereby extending behavioral–energy research beyond commonly studied heating-driven contexts. In practice, it offers an integrated audit–behavior framework that can inform green campus programs and institutional energy management at minimal additional cost. Using the Faculty of Engineering Building at Universitas Negeri Padang, Indonesia as a case, the research addresses three questions: (RQ1) What is the building's end-use electricity profile and resulting EUI under a hot–humid tropical climate? (RQ2) How are attitudes, perceived norms, and behavioral intentions associated with reported energy-saving practices? (RQ3) How do interview accounts help interpret audit patterns and survey results?

2. LITERATURE REVIEW

Energy consumption in the building sector represents one of the most pressing global environmental challenges, accounting for approximately 30–45% of total energy use and a substantial share of greenhouse gas (GHG) emissions [2], [23], within this sector, institutional buildings particularly universities stand out as major energy consumers due to their high occupancy rates, diverse functions, and intensive use of mechanical and electrical systems [24]. The growing complexity of campus facilities, increasing digitalization, and extended operating hours have driven a steady rise in university energy demand worldwide [25], [26]. Unlike conventional commercial buildings, academic buildings combine high energy intensity with strong dependence on human-centered activities, making them a particularly sensitive case for examining the interaction between technical systems and occupant behavior.

2.1. Energy Consumption & Characteristics of Academic Buildings

Academic buildings differ fundamentally from conventional commercial buildings because they function as complex, mixed-use facilities that integrate classrooms, laboratories, offices, libraries, and other high-intensity spaces, resulting in diverse operational schedules and energy profiles. This functional complexity results in longer operating hours and significantly higher energy consumption than in other building types. Empirical studies indicate that universities typically consume three to five times more energy than primary and secondary schools and around 60% more than standard office buildings, primarily due to intensive HVAC use, laboratory equipment, and extended occupancy patterns [27]–[29]. In tropical developing countries, these challenges are further exacerbated by hot, humid climates, where cooling demand dominates building energy use and necessitates continuous air conditioning to maintain thermal comfort, thereby substantially increasing overall campus energy consumption [30], [31].

Empirical studies consistently report that HVAC systems account for 40–60% of total energy consumption in academic buildings, particularly in warm and hot climates [12]. However, while this dominance of HVAC loads is widely acknowledged, studies differ in their explanations for inefficiency. Some emphasize technological limitations (e.g., outdated systems or poor zoning), while others highlight operational practices and occupant behavior as decisive factors. This divergence suggests that technical characteristics alone cannot fully explain variations in energy performance across campuses.

Across the literature, a common pattern emerges: climate-driven cooling demand establishes a high baseline energy load, while institutional practices and user behavior influence deviations from that baseline. Given that up to 75% of total life-cycle emissions occur during the operational phase [32], this stage represents the most critical leverage point for intervention, particularly in existing university buildings where major retrofits are often constrained by budget and institutional inertia.

2.2. Determinant Factors of Energy Consumption: Technical and Behavioral Perspectives

Building energy performance is shaped by both technical and behavioral dimensions. From a technical perspective, factors such as building orientation, envelope design, insulation quality, HVAC efficiency, and lighting systems strongly influence Energy Use Intensity (EUI) [24]. Advanced technologies such as Variable Refrigerant Flow (VRF), Demand-Controlled Ventilation (DCV), and Building Management Systems (BMS) can significantly reduce energy use under controlled conditions [33]–[35].

From a behavioral perspective, occupants' awareness, attitudes, routines, and expectations play a critical role in shaping real energy outcomes. Several studies report that occupant behavior alone can account for 20–30% variation in total building energy consumption [23], [24]. However, the literature does not converge on a consistent magnitude of behavioral impact. While some studies identify strong, statistically significant effects, others report weak or inconsistent relationships, often attributing these discrepancies to differences in measurement methods.

A key limitation of many behavioral studies is their reliance on self-reported behavior or simulation-based assumptions that are not directly linked to measured energy data. As a result, the relationship between psychological constructs and actual energy performance indicators (such as EUI or GHG emissions) remains empirically underexplored. This methodological fragmentation highlights the need for integrative studies that simultaneously examine technical performance and behavior within a unified empirical framework.

2.3. Theoretical Framework: Mapping TPB and VBN to Energy Behavior

To systematically interpret behavioral influences on energy use, this study adopts the Theory of Planned Behavior (TPB) and the Value–Belief–Norm (VBN) Theory, two of the most widely applied frameworks in environmental behavior research [36],[37]. TPB posits that behavior is driven by attitudes, subjective norms, and perceived behavioral control, which together shape behavioral intention. VBN theory, in contrast, emphasizes that environmental values and beliefs activate personal moral norms that motivate pro-environmental action.

In this study, TPB and VBN are not treated as abstract concepts but are explicitly operationalized through measurable questionnaire indicators. TPB constructs are represented by: (1) Attitudes toward energy-saving practices (e.g., perceptions of importance and effectiveness); (2) Subjective norms within the academic community (e.g., perceived expectations from peers and management); (3) Perceived behavioral control over using air-conditioning, lighting, and electrical equipment. VBN constructs are operationalized through: (1) Environmental values related to sustainability and resource conservation; (2) Awareness of consequences of excessive energy consumption; (3) Personal norms regarding moral responsibility for saving energy. These constructs form the basis for hypothesis development, linking psychological variables to measured indicators of energy performance (EUI and GHG emissions). By explicitly mapping TPB and VBN components onto empirical indicators, this study reduces conceptual ambiguity and enables direct testing of behavioral theory against real building performance data.

2.4. Research Gap and Study Relevance

Although energy efficiency in academic buildings has been widely studied, most existing research remains concentrated in developed countries with temperate or subtropical climates, where heating demand dominates annual energy profiles [24]. In contrast, empirical evidence from hot–humid tropical regions, where cooling demand is continuous, passive, and highly energy-intensive, remains limited.

Beyond this geographical and climatic imbalance, a methodological gap is evident. Many behavioral studies rely on simulations or attitudinal surveys without integrating measured building performance data, while technical audits often neglect behavioral dimensions altogether. Moreover, few studies empirically test established behavioral theories, such as TPB and VBN, against objective energy metrics, particularly in developing-country campus contexts.

This study addresses these gaps by integrating empirical energy auditing with theory-driven behavioral analysis in a tropical university building. By combining measured EUI/GHG data with survey- and interview-based behavioral indicators, this research provides a more comprehensive, context-sensitive understanding of campus energy performance.

2.5. Conceptual Framework

Drawing from the synthesized literature, this study conceptualizes energy performance as the outcome of an interaction between technical and behavioral dimensions. The technical dimension is represented by Energy Use Intensity (EUI) and GHG emissions, reflecting baseline energy demand shaped by climate, building design, and systems. The behavioral dimension comprises occupant perceptions, attitudes, behaviors, and expectations, derived from TPB and VBN constructs.

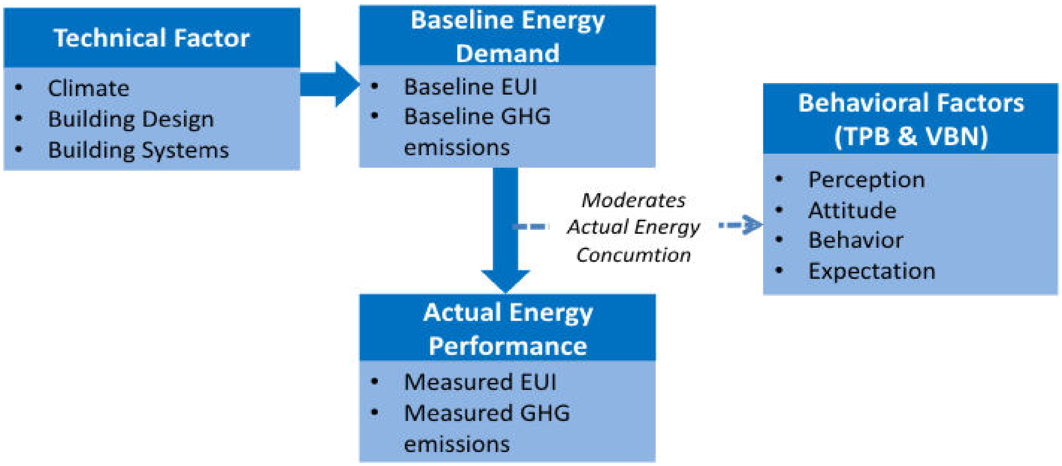

Figure 1. Conceptual Framework of Building Energy Performance

The conceptual framework explicitly proposes that: (1) technical characteristics establish baseline energy demand; (2) behavioral factors moderate actual consumption around this baseline; (3) higher pro-environmental engagement and expectation are associated with improved energy performance. This framework is visualized in a conceptual model (Figure 1) that links technical variables (EUI, GHG), behavioral variables (perception, attitude, behavior, expectation), and energy performance outcomes. The model guides hypothesis formulation and provides a coherent structure for integrating behavioral theory with empirical analyses of building performance.

Figure 1 presents the conceptual framework underlying this study. The model positions technical characteristics as determinants of baseline energy demand and behavioral factors as moderators of actual energy consumption, providing an analytical structure for examining the relationship between occupant behavior and measured energy performance indicators.

3. MATERIALS AND METHODS

3.1. Research Design

This study employed a convergent parallel mixed-methods design, integrating quantitative building energy performance measurements with occupant survey and interview data. Quantitative and qualitative datasets were collected concurrently, analyzed independently, and integrated through a convergence-based triangulation strategy.

Specifically, integration was conducted using a joint interpretation approach, where quantitative results (EUI, GHG emissions, and behavioral scores) were systematically compared with qualitative themes derived from interviews to identify convergence, complementarity, or divergence between measured energy performance and user behavior patterns. This design enhances internal validity by combining objective technical indicators with subjective behavioral insights [38].

3.2. Study Site

The research was conducted in the main administrative building of the Faculty of Engineering, Universitas Negeri Padang (UNP), Indonesia. The four-story building accommodates offices, classrooms, meeting rooms, computer laboratories, a library, a prayer room, and a multi-purpose hall, serving approximately 339 users. The building was selected as it represents a typical tropical campus facility in a developing-country context that has adopted partial energy-efficiency measures, including LED lighting, inverter-type HVAC units, and natural ventilation strategies.

An energy audit was conducted in accordance with the Indonesian Ministry of Energy and Mineral Resources Regulation No. 13/2012 and the ASHRAE Level 1 (Walk-through) framework [39],[40], including site observation, energy system inventory, and benchmarking. According to national standards, buildings consuming less than 8.5 kWh/m²/month (105 kWh/m²/year) are categorized as "Highly Efficient," while those exceeding 18.5 kWh/m²/month (222 kWh/m²/year) are considered "Inefficient."

3.3. Participants and Sampling Procedure

The study population comprised 339 occupants: 30 administrative staff, 24 lecturers, and 285 students. A minimum sample size of 184 respondents was initially estimated using Yamane's (1967) formula with a 5% margin of error. A total of 192 valid responses were obtained through proportionate stratified sampling (17 staff, 14 lecturers, and 161 students).

Although Yamane's formula was used for feasibility reasons, the authors acknowledge that this approach is considered conservative. Future studies are encouraged to use power analysis tools, such as G*Power, to enhance statistical rigor.

The dominance of student respondents reflects the building's actual occupancy profile. However, it is recognized as a methodological limitation, given the transient nature of student movement compared to staff with fixed workspaces.

3.4. Data Collection Procedures

3.4.1. Energy Performance Measurement

Energy performance data were collected using calibrated field instruments, including a lux meter, anemometer, sound level meter, and power quality analyzer, following national standards (SNI 03-6196-2000) and ASHRAE guidelines. Additionally, measurements of HVAC systems, lighting, and plug loads were conducted at 15-minute intervals over 7 consecutive days in July 2025, including both weekdays and weekends. Electricity consumption (kWh) was converted into Energy Use Intensity (EUI) and greenhouse gas (GHG) emissions using standard equations [7].

Greenhouse gas (GHG) emissions associated with electricity consumption were estimated in accordance with the Intergovernmental Panel on Climate Change (IPCC) guidelines. Emissions from carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were considered in the analysis. Country-specific electricity emission factors were applied, and total emissions were expressed in carbon dioxide equivalents (CO_2-eq) using the corresponding global warming potentials (GWPs) from the IPCC assessment reports. This approach ensures consistency and comparability with established international methodologies for GHG accounting.

3.4.2. Data Extrapolation Assumptions

Measured weekly energy consumption data were extrapolated to annual values using a linear scaling approach, assuming similar operational patterns throughout the academic year. July represents an active academic period rather than a semester break, thereby reflecting typical occupancy and operational conditions. The extrapolation accounted for the academic calendar by considering effective operational weeks and excluding extended holiday periods. The extrapolated annual energy consumption was then used to compute the monthly EUI value.

3.4.3. Questionnaire and Interview Data

Behavioral data were collected using a 38-item questionnaire covering four constructs: (1) perception of green energy, (2) environmental attitude, (3) energy-use behavior, and (4) expectations toward future energy practices. Items were adapted from the Theory of Planned Behavior (TPB) [36] and Value–Belief–Norm (VBN) Theory [37]. Content validity (Aiken's V > 0.80) and reliability (Cronbach's α > 0.80) confirmed the robustness of the instrument.

Semi-structured interviews were conducted with 10 purposively selected participants (R1–R10), representing students, lecturers, and administrative staff with varying tenure. Interviews lasted 20–30 minutes, were audio-recorded, transcribed verbatim, and thematically analyzed using an inductive–deductive approach aligned with the survey constructs.

3.5. Unit of Analysis and Data Integration

The unit of analysis in this study was the floor level (four zones). Survey responses were aggregated by floor to align with zonal energy metering data, enabling integration of behavioral indicators with measured energy performance. This aggregation approach was necessary due to the absence of desk-level sub-metering and ensures spatial consistency between datasets.

3.6. Data Analysis

Quantitative data were analyzed using Microsoft Excel, employing descriptive statistics to summarize energy consumption, EUI, and GHG emissions. Inferential analysis using Pearson correlation was conducted to explore associations between aggregated behavioral variables and energy performance indicators at the floor level (n = 4 zones).

Given the limited number of analytical units, correlation results are interpreted as exploratory and indicative of trends rather than conclusive statistical evidence. Reported results include correlation coefficients (r), p-values, and sample size (n) for transparency.

Qualitative findings were integrated during interpretation to contextualize quantitative patterns, particularly by comparing high-consumption zones (e.g., Floor 4) with low-consumption zones (e.g., Floor 1), thereby strengthening explanatory depth without over-reliance on statistically weak tests.

4. RESULTS

4.1. Energy Performance and End-Use Composition

An energy performance analysis was conducted for the main administrative building of the Faculty of Engineering at Universitas Negeri Padang, Indonesia. The four-storey building has a total floor area of 3,024 m², comprising parking and classrooms on the first floor (400 m²), academic and administrative offices on the second floor (896 m²), postgraduate classrooms and meeting rooms on the third floor (896 m²), and a library and multi-purpose hall on the fourth floor (832 m²). Across the four floors, total annual electricity consumption reached 366,898.19 kWh/year.

Figure 2. Sankey diagram end-use energy flows

Table 1. Annual energy consumption by system and floor (kWh/year)

Floor	HVAC	Lighting	Equipment	Total
1st Floor	20,340.00	3,290.56	9,851.00	33,481.56
2nd Floor	43,220.00	8,030.88	35,640.00	86,890.88

Floor	HVAC	Lighting	Equipment	Total
3rd Floor	55,420.00	8,170.00	39,630.00	103,220.00
4th Floor	84,449.20	5,832.56	53,024.00	143,305.76
Total	203,429.20	25,323.99	138,145.00	366,898.19

HVAC systems accounted for the largest share of consumption (55.40%), followed by electrical equipment (37.70%) and lighting systems (6.90%). The fourth floor recorded the highest annual energy consumption (143,305.76 kWh/year), while the first floor recorded the lowest (33,481.56 kWh/year). This large disparity indicates substantial variation in operational energy demand across floors with different functional characteristics, particularly between high-volume shared spaces (library and multi-purpose hall) and lower-intensity areas such as parking and classrooms.

4.2. Greenhouse Gas (GHS) Emissions from Electricity Consumption

Based on total electricity consumption and national emission factors, annual greenhouse gas (GHG) emissions were estimated at 285,108.85 $kgCO_2eq$/year. As shown in Table 2, emissions were dominated by carbon dioxide (CO_2), which accounted for 99.86% of total emissions, while methane (CH_4) and nitrous oxide (N_2O) together accounted for less than 0.2%.

Table 2. Greenhouse gas emissions by gas type

Gas	Emission Factor (kg/kWh)	GWP	Emission ($kgCO_2eq$)	Contribution
CO_2 (Carbon dioxide)	0.7744	1	284,713.90	99.86%
CH_4 (Methane)	0.000016	28	164.5	0.06%
N_2O (Nitrous oxide)	0.000009	256	230.5	0.08%
Total			285,108.85	100%

Table 3. Annual energy use intensity and efficiency classification

Indicator	Value	Reference Threshold	Classification
Energy Use Intensity (EUI)	17.34 kWh/m²/month	<18.5 kWh/m²/month	Moderately Efficient
Total Annual Energy (kWh)	366,897.70	–	–
Total Area (m²)	3,024	–	–

Table 4. Demographic Profile of Building Occupants

Category	Group	Number of Respondents (n)	Average Age (years)	Average Duration of Stay (hours/day)
Gender	Male	134	–	–
	Female	58	–	–
Position	Lecturers	13	47.54	4–6
	Adm. Staff	17	41.35	6–8
	Students	161	18.35	4–6

The high emission intensity reflects the carbon-intensive electricity generation mix, as indicated by the applied emission factor of 0.774 $kgCO_2$/kWh, which is considerably higher than that of many developed regions. This result implies that electricity savings achieved at the building level translate directly into substantial carbon mitigation benefits.

4.3. Energy Use Intensity and Efficiency Classification

At the building scale, the calculated Energy Use Intensity (EUI) was 17.34 kWh/m²/month, corresponding to 208.1 kWh/m²/year (Table 3). According to the Regulation of the Minister of Energy and Mineral Resources No. 13 of 2012, this value classifies the building as “Moderately Efficient”.

Although the building complies with national efficiency benchmarks, floor-level consumption patterns suggest uneven efficiency performance, indicating that further improvement potential exists through operational and system-level optimization rather than solely through area-based metrics.

4.4. Occupant Perceptions, Attitudes, Behaviors, and Expectations

Survey responses were obtained from 192 building occupants, including students, lecturers, and administrative staff. Table 4 summarizes the demographic characteristics of the respondents, including gender, institutional role, age, and average daily occupancy duration. As shown, the sample is dominated by students (n = 161), reflecting the building's primary academic function.

Respondents reported high levels of environmental awareness and pro-environmental orientation. As presented in Figure 3, mean scores for perception of green energy implementation, environmental attitude, energy-use behavior, and expectation toward future green practices ranged from 74.04% to 79.28%

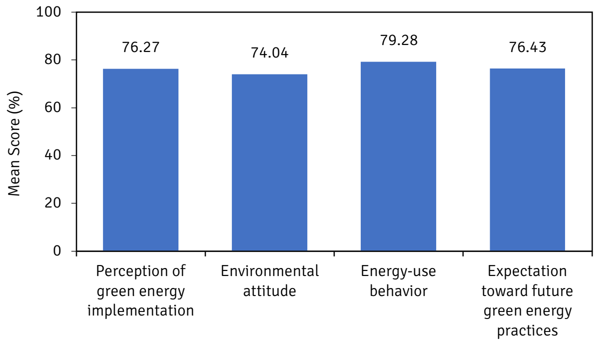

Figure 3. Mean scores of user-related variables (scale 0–100): 0–20 Very Low; 21–40 Low; 41–60 Moderate; 61–80 High; 81–100 Very High.

These findings indicate that occupants exhibit a strong awareness of sustainable energy practices, reflecting the institution's growing culture of environmental responsibility. Among the four constructs, energy-use behavior recorded the highest mean score (79.28%), indicating that occupants perceive themselves as actively engaging in energy-saving practices, such as switching off unused lights and electrical equipment. Expectation toward future green energy practices also showed a relatively high score (76.43%), suggesting a forward-looking orientation that later emerges as a key variable in the correlation analysis. However, despite these positive self-reported scores, subsequent analyses reveal that high awareness and behavior do not always translate into proportionally lower energy consumption, indicating an intention–behavior gap, which is further explored through correlations and qualitative findings.

4.5. Exploratory Correlation Analysis at Floor Level

An exploratory Pearson correlation analysis was conducted to examine associations between aggregated user-related variables and floor-level annual energy consumption (n = 4). As presented in Table 5, all behavioral variables exhibit negative correlations with energy consumption, suggesting that higher levels of environmental perception, attitude, behavior, and future expectations are generally associated with lower electricity use at the floor level.

Among the examined variables, expectations regarding future green energy practices show a very strong inverse correlation with energy consumption ($r = -0.968$, $p = 0.032$), indicating a statistically significant association despite the limited number of analytical units. In contrast, perception of green energy implementation ($r = -0.472$, $p = 0.528$), environmental attitude ($r = -0.589$, $p = 0.411$), and energy-use behavior ($r = -0.641$, $p = 0.359$) show moderate negative correlations that are not statistically significant ($p > 0.05$).

Table 5. Correlation between user variables and energy consumption

Variable	Pearson r	p-value	Direction	Interpretation
Perception of green energy implementation	−0.472	0.528	Negative	Moderate
Environmental attitude	−0.589	0.411	Negative	Moderate
Energy-use behavior	−0.641	0.359	Negative	Moderate
Expectation toward green energy practices	−0.968	0.032	Negative	Very strong

Table 6. Summary of qualitative findings from semi-structured interviews (R1–R10)

Theme	Description	Example Quotes	Analytical Interpretation
Awareness	Most respondents recognized the importance of saving energy, primarily through simple and visible actions such as switching off lights or unplugging devices. This reflects general awareness and positive intention toward green energy practices.	"We just switch off the lights when not needed." (R3)	Indicates high pro-environmental intention and baseline awareness, consistent with survey results showing high environmental attitude scores.
Routine	Some respondents reported consistent energy-saving habits, while others admitted irregular routines influenced by convenience, forgetfulness, or competing priorities.	"Sometimes I unplug the charger, sometimes I forget." (R7)	Reveals an intention–action gap, where positive attitudes do not consistently translate into sustained daily practices.
Barriers	Respondents identified motivational and practical constraints, including comfort preferences, limited user control, and lack of feedback on actual energy impacts.	"We do not really know how much we actually save." (R2)	Demonstrates energy invisibility and absence of feedback, explaining why high awareness does not necessarily lead to measurable reductions in energy consumption.

Given the small sample size, these results are interpreted as exploratory rather than confirmatory. The limited number of analytical units reflects the building-scale nature of the case study, in which each floor constitutes an aggregated unit of analysis. Nevertheless, reporting both effect sizes (r) and p-values provides transparency and allows the observed correlation patterns to be meaningfully contextualized. Similar exploratory approaches have been adopted in building energy studies where access to granular, unit-level energy data is inherently constrained. Accordingly, the findings are presented as indicative trends that support subsequent qualitative interpretations and discussion, rather than as evidence of causal relationships.

4.6. Qualitative Interview Results

Ten respondents (R1–R10) were selected using purposive sampling to represent variation in institutional roles (students, lecturers, and administrative staff) and daily occupancy duration. Semi-structured interviews lasted approximately 20–30 minutes, were audio-recorded, transcribed verbatim, and thematically analyzed.

As summarized in Table 6, three dominant themes emerged: awareness, routine, and barriers. Most respondents demonstrated general awareness of energy-saving practices, particularly simple actions such as switching off lights. However, daily routines were often inconsistent, influenced by forgetfulness, comfort preferences, and lack of feedback regarding actual energy impacts.

4.7. Summary of Findings

The case study building exhibits moderate energy efficiency, with an annual electricity consumption of 366,897.7 kWh and associated emissions of 285,108.85 kgCO$_2$eq. HVAC systems were identified as the dominant energy consumers, emphasizing the importance of cooling optimization strategies in tropical academic buildings.

Analysis of user-related factors indicates that occupants generally report high levels of environmental awareness, positive attitudes, and pro-environmental behaviors. Exploratory correlation results suggest inverse associations between aggregated behavioral variables and floor-level energy consumption, highlighting potential links between user engagement and building energy performance, while acknowledging the limited number of analytical units.

Complementing the quantitative analysis, qualitative insights from semi-structured interviews revealed three recurring themes—awareness, routine, and barriers—that help contextualize observed behavioral patterns. Although respondents expressed support for green energy initiatives, daily practices were sometimes constrained by convenience, forgetfulness, and the absence of real-time feedback. These findings underline the importance of integrating technological measures with behavioral reinforcement and awareness programs to support comprehensive energy management strategies in higher education buildings.

Table 7. Integrated joint display of energy audit results

Audit findings	Survey findings	Interview quote(s)	Implications
The building's annual electricity use is 366,898.19 kWh/year, with HVAC as the largest load (55.40%), followed by plug/equipment loads (37.70%) and lighting (6.90%).	Respondents (n=192) reported high scores across behavior/attitude measures (74.04%–79.28%); reported energy-saving behavior was the highest (79.28%).	Most energy-saving actions mentioned by respondents were "visible" and simple (e.g., turning off lights).	Because HVAC is the largest load, the most impactful savings should focus on cooling optimization (operations, setpoints, scheduling), not just "turn off the lights" campaigns.
There is clear variation by floor: Floor 4 is the highest (143,305.76 kWh/year), while Floor 1 is the lowest (33,481.56 kWh/year), suggesting operational differences, especially in large shared spaces.	The behavior–consumption relationship was analyzed at the floor level (n=4 zones) to align behavioral data with zonal sub-metering.	Barriers often relate to limited user control in shared spaces/building operations.	Prioritize interventions in high-use zones (e.g., Floor 4) via HVAC zoning and demand-based scheduling for shared spaces (e.g., library/auditorium), so systems do not follow rigid schedules during low occupancy.
The building's EUI is 17.34 kWh/m²/month ("moderately efficient" under the national threshold <18.5), but floor-level patterns indicate further potential via operational optimization.	Despite high behavior/attitude scores, findings suggest an intention–behavior gap: high awareness does not always translate into lower energy use.	"Sometimes I unplug the charger, sometimes I forget." (R7)	Complement education with habit reinforcement (prompts/reminders, room shutdown SOPs, area champions) to make behaviors consistent rather than sporadic.
Annual emissions are estimated at 285,108.85 kgCO$_2$eq/year; the high emissions intensity is driven by the electricity emission factor	Behavioral variables show negative correlations with consumption, but	"We do not really know how much we actually save." (R2)	Implement eco-feedback (real-time energy dashboards/feedback) to make savings visible, improve accountability

Audit findings	Survey findings	Interview quote(s)	Implications
(0.774 $kgCO_2/kWh$), so saving electricity directly supports carbon mitigation.	interpretations are exploratory (small n).		and motivation, and communicate the carbon benefit per kWh saved.
The audit confirms HVAC dominance, limiting the impact of individual actions if system design/operations are not adaptive.	Expectations for future green practices show a very strong, significant negative correlation with consumption ($r = -0.968$; $p = 0.032$), stronger than that of other variables (moderate, non-significant).	"We just switch off the lights when not needed." (R3)	Use "future expectations" as a program lever (goal-oriented campaigns, student/staff participation) and integrate energy literacy into curricula/campus activities—paired with technical HVAC optimization so intentions can translate into measurable impact.

The joint display shows a mismatch between occupants' common energy-saving actions (e.g., turning off lights) and the building's main energy driver (HVAC), implying that meaningful reductions require optimizing cooling operations (setpoints, scheduling, zoning), especially in high-use floors and shared spaces. Although survey scores suggest strong pro-saving attitudes and behaviors, interviews reveal an intention–behavior gap due to inconsistent implementation and limited control, so habit-supporting measures (prompts, shutdown SOPs, area champions) and eco-feedback (dashboards) are needed to make savings visible and sustain change.

5. DISCUSSION

5.1. Energy Performance and Benchmarking in a Tropical Campus Context

The building examined in this study registered an Energy Use Intensity (EUI) of 17.34 kWh/m²/month, placing it within the "moderately efficient" category under the Regulation of the Minister of Energy and Mineral Resources of Indonesia No. 13 of 2012 (<18.5 kWh/m²/month). While this result indicates compliance with national efficiency standards, it requires critical contextualization when compared with international benchmarks. Previous studies on university buildings in hot–humid climates report a wide range of EUI values, from approximately 47 to 628 kWh/m²/year (≈3.9–52.3 kWh/m²/month) [41]. Accordingly, although the case-study building satisfies domestic regulations, its performance appears to fall within the mid-range of global benchmarks, suggesting that regulatory compliance does not necessarily equate to optimal energy performance. This finding highlights the importance of moving beyond minimum standards toward more integrated operational and behavioral strategies to achieve higher efficiency in tropical campus buildings.

5.2. Dominance of HVAC Systems and Structural Constraints

HVAC systems accounted for approximately 55% of total electricity consumption, confirming the dominant role of cooling loads in tropical academic buildings. This finding is consistent with previous research in tropical and subtropical educational environments [42], [43]. However, the magnitude of HVAC demand also reveals structural and operational constraints that limit the effectiveness of individual energy-saving actions. Centralized cooling systems, limited zoning flexibility, fixed schedules, and aging equipment reduce occupants' ability to influence actual energy outcomes, even when pro-environmental attitudes are present.

The substantial difference in annual energy consumption between the fourth floor (143,305.76 kWh/year) and the first floor (33,481.56 kWh/year) cannot be explained solely by occupant numbers. This suggests that large-volume spaces—such as multi-purpose halls and libraries—are often cooled according to rigid schedules rather than real-time occupancy levels, resulting in inefficient operation during low-use periods.

5.3. Occupant Behavior, Awareness, and the Intention–Behavior Gap

Survey results indicated high levels of environmental awareness, positive attitudes, and self-reported energy-saving behavior among building occupants. Nevertheless, qualitative findings from semi-structured interviews (R1–R10) reveal a persistent gap between intention and behavior. While respondents expressed willingness to conserve energy and described routine actions such as switching off lights or computers, they rarely adjusted thermostats or questioned HVAC operating schedules. Commonly cited barriers included convenience, forgetfulness, lack of authority, and limited control over shared spaces.

This discrepancy between awareness and consistent practice aligns with well-established findings in sustainability research, which show that pro-environmental intentions do not automatically translate into sustained behavioral change [36], [37], [44]. The present findings underscore that occupant awareness alone is insufficient to deliver significant energy savings unless supported by enabling system design and operational policies.

This behavioral paradox is largely driven by energy invisibility, whereby electricity consumption remains abstract and imperceptible to occupants. Interview participants repeatedly indicated uncertainty regarding the actual impact of their actions, suggesting that the absence of feedback weakens behavioral reinforcement. Without visible or real-time information, energy use is easily deprioritized in daily routines, even among environmentally aware users.

To address this limitation, technology-based eco-feedback interventions are essential. The installation of real-time energy dashboards at the building or floor level—displaying electricity consumption by zone—can translate invisible energy use into tangible information. Previous studies have shown that visual eco-feedback systems can reduce electricity consumption by approximately 5–15% in institutional and educational buildings, making them a practical complement to HVAC optimization and operational control strategies.

5.4. Interpreting the Role of “Expectation toward Green Energy”

Among the behavioral variables examined, expectations regarding green energy implementation showed a very strong negative correlation with energy consumption ($r = -0.968$). This relationship warrants careful interpretation, particularly given the exploratory nature of the floor-level analysis. Rather than reflecting comfort-driven demand, this pattern likely captures normative and future-oriented motivations that influence behavioral intention and operational discipline. From the perspective of the Theory of Planned Behavior (TPB) and the Value–Belief–Norm (VBN) framework, expectations can serve as antecedents that activate norms and reinforce intentions to engage in pro-environmental action.

Interview responses further suggest that occupants with higher expectations for green energy were more likely to support institutional initiatives to improve efficiency and to question wasteful practices. These findings indicate that expectation toward green energy may represent a distinct and influential construct that complements traditional TPB and VBN variables [45]–[47].

5.5. Carbon Intensity and the Indonesian Energy Context

From a greenhouse-gas (GHG) perspective, the results emphasize the critical role of Indonesia’s fossil-fuel-dominated electricity mix in amplifying the environmental impact of building energy use. The applied emission factor (0.774 $kgCO_2/kWh$) indicates that each unit of electricity consumed carries a relatively high carbon burden. Consequently, energy efficiency measures in Indonesian campus buildings deliver disproportionately large climate benefits compared to regions with cleaner grids. In this context, energy efficiency is not merely an economic issue but a critical climate mitigation strategy [48]–[50].

6. IMPLICATIONS AND LIMITATIONS

Theoretically, this study contributes original empirical evidence by integrating measured building energy performance with detailed survey and interview data on occupant behavior in a tropical developing-country campus context. This area remains underrepresented in the literature. Bibliometric evidence suggests that fewer than 20% of campus energy studies explicitly link occupant behavior with real performance data [51]. The strong role of expectations toward green energy suggests that future TPB- and VBN-based models should treat expectations as a distinct construct that influences norm activation and behavioral intention.

Practically, the findings support the implementation of integrated energy-management strategies that combine technical optimization with occupant-centered interventions, including: (1) HVAC zoning and demand-based scheduling in large shared spaces; (2) installation of real-time energy dashboards or eco-feedback systems; (3) integration of energy literacy and feedback-based learning into engineering and environmental curricula [46], [52], [53]. By positioning students and staff as active participants in energy governance, higher-education institutions in tropical regions can foster a durable culture of energy responsibility and advance sustainable campus transitions aligned with global low-carbon development goals [27], [54]–[57].

The study acknowledges several limitations, including the small number of analytical units for correlation analysis and the dominance of student respondents. However, these limitations are partially mitigated through mixed-methods triangulation, combining measured energy data with qualitative behavioral insights to enhance interpretive robustness.

7. CONCLUSION

This study provides empirical evidence from a tropical, developing-country context that integrating measured building energy performance with detailed behavioral and qualitative data yields a more nuanced understanding of energy efficiency in university buildings. The assessed faculty building operates within a moderately efficient range (17.34 $kWh/m^2/month$); however, overall performance is strongly constrained by HVAC systems, which account for more than half of total electricity consumption. This confirms that in hot-humid academic environments, structural and operational factors can be more decisive than individual behavioral efforts.

Although occupants reported high environmental awareness, positive attitudes, and conservation-oriented behaviors, energy use remained substantial, indicating an intention–behavior gap in which pro-environmental intentions do not reliably translate into measurable savings. The strong negative association between expectations regarding green energy and energy consumption suggests that normative and future-oriented motivations—rather than attitudes or habits alone—may be key behavioral levers. Qualitative interviews further explain this pattern by highlighting energy invisibility, limited user control, and rigid operational routines as persistent barriers to effective action, underscoring that behavioral effectiveness is contingent on system design, feedback mechanisms, and institutional context—particularly in carbon-intensive electricity systems such as Indonesia's, where each kilowatt-hour saved can yield disproportionately large climate benefits.

From educational and managerial perspectives, universities can serve as living laboratories for sustainability learning by combining HVAC optimization and zoning with occupant-centered interventions, such as real-time eco-feedback, curriculum-integrated energy literacy, and participatory sustainability initiatives, to cultivate a durable culture of energy responsibility. Future research should expand this integrative framework across multiple buildings and institutions, use longitudinal designs to track behavioral dynamics, and experimentally evaluate targeted interventions (e.g., real-time dashboards, incentive-based feedback, and adaptive control systems) to strengthen causal inference and generate actionable evidence on synergizing behavioral and technological strategies for sustained reductions in campus energy consumption in developing-country contexts.

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CONFLICTS OF INTEREST

The authors declare that no conflicts of interest are associated with this study. All aspects of the research were conducted with the utmost integrity and transparency.

DATA AVAILABILITY

The datasets utilized and analyzed during this research are available from the corresponding author upon reasonable request.

ETHICAL STATEMENTS

The authors confirm that the study complied with all applicable local laws, ethical standards, and institutional guidelines, including obtaining approval from relevant ethics committees.

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