

Elevator Energy Consumption and Upward Travel Load Patterns in A University Lecture Building

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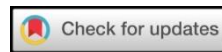
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ABSTRACT

This study analyzes passenger elevator operation patterns and their contribution to building electricity consumption in a university lecture building. Previous research has mainly focused on system simulations or control optimization, resulting in limited empirical studies that integrate large-scale directional passenger movement data with aggregated building-level electricity consumption, especially in academic settings. To address this gap, the study examines elevator usage patterns based on 31,265 observed trips and links directional travel with building-level electricity consumption. Data were collected over a two-week period (13–24 October 2025) through direct observation and MDP-based energy measurements, then analyzed using Pearson correlation and linear regression. Results show that 44.6% of total traffic occurred in the morning, with 83.0% concentrated during peak periods. Upward trips accounted for 52.7% of movements, indicating directional asymmetry associated with increased traction motor load during peak hours. Pearson correlation analysis revealed a significant positive relationship between elevator usage intensity and daily electricity consumption ($r = 0.813$, $p = 0.004$, 95% CI [0.35–0.96]). Linear regression showed that 66.1% of variation in daily energy consumption could be explained by elevator usage intensity. This study provides a context-specific empirical analysis by integrating directional elevator travel data with aggregated building-level electricity consumption in a university lecture building, based on real-world observations. These findings demonstrate that dominant upward travel during academic transition periods is measurably associated with overall building energy consumption dynamics.



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1. INTRODUCTION

The use of passenger elevators in high-rise buildings in Indonesia has become increasingly widespread in line with the rapid development of office properties, vertical residential buildings, shopping centers, and educational institutions [1]. The building and construction sector which includes office buildings, commercial facilities, residential buildings, and institutions such as university campuses has been reported to contribute the largest share of national final energy consumption [2]. This indicates that building operations significantly contribute to national electricity demand, making facilities such as elevators an integral part of overall energy consumption [3]. In high-rise buildings with high mobility levels, electricity consumption can increase substantially, particularly when elevators are used intensively on a daily basis. In the campus context, the high frequency of elevator use driven by student, faculty, and staff mobility has the potential to increase the proportion of electricity consumption in campus buildings.

At the campus where this study was conducted, three buildings are equipped with elevator systems as vertical transportation facilities [4]. However, this research focuses on one main lecture building, as it has the highest elevator usage intensity and serves as the central hub of daily academic activities for students and faculty members. The high density of academic activities, structured class schedule transitions, and concentration of classrooms make this building representative for empirically analyzing vertical mobility patterns and elevator operational loads.

The lecture building under study is equipped with ten elevator units arranged symmetrically, consisting of five units on the right side and five units on the left side of the building. Of these, eight are passenger elevators and two are designated as freight elevators. The passenger elevators are strategically located near the main entrance, classroom corridors, and other vertical circulation areas, making them the primary mode of vertical transportation for the academic community. In addition to elevators, the building is equipped with two general staircases (not emergency stairs) located relatively close to the elevator areas, as well as two escalators operating up to the third floor to support mobility on the lower levels. Although these facilities provide alternative options for users, passenger elevators remain the dominant choice, particularly during peak hours.

The high frequency of elevator usage is associated with significant electricity consumption and higher campus operational costs [5]. Therefore, elevator usage functions not only as a mobility facility but also as an important contributor to the operational load of campus buildings. Previous studies on elevator energy consumption have been conducted by various institutions; however, most of these studies focus on overall building system optimization or the development of elevator control technologies rather than on empirical analyses of actual usage patterns based on academic activities.

Differences in location context, building characteristics, and mobility intensity make this study particularly relevant, as it specifically evaluates elevator operational dynamics in a high activity lecture building. Elevator operational analysis requires a quantitative approach based on actual data through direct monitoring and usage recording [6]. This method enables a more objective evaluation of vertical mobility patterns, usage intensity per time interval, and their relationship with building operational loads [7]. Preliminary observations indicate that elevator usage in the lecture building is significantly associated with the daily electrical load dynamics of the campus, especially during class schedule transitions.

These findings are consistent with internal reports indicating that a substantial portion of operational expenditures is allocated to electricity needs, particularly for operating mechanical and electrical facilities such as elevators [8]. The urgency of this research becomes even more pronounced when considered within the national energy context. The majority of Indonesia's electricity generation still relies on fossil fuel based power plants, such as coal and natural gas [9]. According to 2022 data from the International Energy Agency (IEA), the electricity sector accounts for approximately 40% of total national carbon emissions. This highlights that improving efficiency and operational management of building facilities, including vertical transportation systems, carries significant environmental implications [10].

Data from the Ministry of Energy and Mineral Resources (ESDM) indicate that Indonesia's electricity consumption reached 273.8 TWh in 2022 and continues to increase annually. This condition reinforces the urgency of implementing more efficient operational management strategies within campus environments. Several empirical studies demonstrate that proper energy management and data-driven operational strategies can generate significant savings and support the achievement of the Sustainable Development Goals (SDGs), particularly Goal 7 and Goal 13 [11]. Although several studies have examined elevator energy consumption and energy-saving strategies in high-rise buildings, most focus on model simulations, control algorithm optimization, or system design-based approaches.

Previous studies have examined elevator energy consumption primarily from system optimization, control algorithm development, or simulation-based modeling perspectives [12]. While these studies provide valuable insights into technological improvements, they rarely integrate empirical passenger movement data with actual aggregated building-level electricity consumption [13]. In particular, limited attention has been given to the directional imbalance between upward and downward travel and its measurable contribution to daily building energy dynamics in academic environments.

Moreover, campus buildings present distinctive mobility characteristics due to structured class schedules and synchronized transition periods, which differ from commercial office or residential contexts [14]. However, empirical studies linking directional travel dominance, peak hour clustering, and building-wide electricity consumption in university lecture buildings remain scarce [15]. Despite the growing body of literature on elevator energy efficiency, a clear research gap persists in empirically quantifying how large-scale directional passenger movement patterns influence aggregated building-level electricity consumption in academic environments. Existing studies predominantly emphasize technological enhancements, simulation modeling, or control algorithm optimization, with limited integration of real-world operational data capturing movement intensity, directional imbalance, and total building kilowatt hour (kWh) consumption. This lack of integrated empirical analysis constrains the development of evidence based operational strategies specifically tailored to university lecture buildings.

Although sub-metering for elevator systems is not available in many existing buildings, including the present case, analyzing aggregated MDP data remains valuable. This approach reflects real operational conditions and enables evaluation of how vertical mobility interacts with total building energy demand. Directional travel patterns are particularly important, as upward movement requires higher motor torque due to gravitational load and passenger mass distribution, while also potentially coinciding with peak HVAC demand

during high occupancy periods. Therefore, analyzing directional asymmetry provides meaningful insight into building-wide energy dynamics despite the absence of dedicated elevator energy measurements.

Therefore, this study is associated with the existing literature by providing a quantitative and data-driven evaluation of elevator operational dynamics in a high-activity university lecture building. By integrating directional passenger usage data, user behavioral analysis, and aggregated building-level electricity consumption records within a unified empirical framework [16], this research offers measurable evidence of how mobility patterns influence overall building energy performance. The findings establish an empirical foundation for operational and load management strategies aimed at improving energy efficiency in campus vertical transportation systems.

This study aims to: (1) quantify directional elevator travel patterns, (2) examine their relationship with daily building electricity consumption, (3) estimate the proportion of variance explained, and (4) discuss operational implications for building energy management. The primary contributions of this research are: (A) the development of an empirical dataset consisting of 31,265 directly observed elevator users, (B) the quantification of upward travel dominance and its statistically significant correlation with daily building energy consumption, and (C) the formulation of data-driven operational recommendations to support peak load management in campus vertical transportation systems.

2. RESEARCH METHODS

2.1 Research Design and Study Object

This study employs a quantitative approach to analyze the relationship between elevator usage intensity and the dynamics of electrical energy consumption in an academic building. The research does not focus on developing new devices or systems, but rather on conducting an operational evaluation based on actual data. The object of the study consists of four passenger elevator units operating in the Main Campus Building, which serves as the center of academic activities with high vertical mobility intensity. The building is equipped with ten KONE MonoSpace Machine Room-Less (MRL) elevators, each with a maximum capacity of 24 persons or 1800 kg per unit, utilizing an electric motor traction system with a counterweight. Of the ten units, eight are passenger elevators and two function as freight elevators.

In addition to the elevator system, the building is also equipped with two public staircases and two escalators as alternative modes of vertical transportation. Four passenger elevators were selected as the primary research objects because they demonstrated the highest operational intensity during academic hours. The four selected passenger elevators are located in two symmetrical banks positioned near the main entrance lobby and central classroom corridors, serving floors 1–10 of the lecture building. The selection criteria included: first, proximity to the main entrance and classroom corridors second, the highest usage frequency based on preliminary observations and third, their status as primary passenger elevators rather than freight elevators. Potential sampling bias includes location bias and operational time bias, as observations were conducted during active academic hours 08:00 a.m. – 04:00 p.m. Western Indonesian Time (WIT). To minimize recording bias, a manual tally counter method was used, with simultaneous verification during peak hours to improve the accuracy of user counts.

2.2 Energy and Elevator Usage Data Collection

Energy consumption measurements were conducted using the main digital kWh meter installed on the building's Main Distribution Panel (MDP). Data were recorded on working days over two consecutive weeks (13–24 October 2025). The meter is classified as IEC Class 1 accuracy, meeting energy measurement standards for commercial building applications. Calibration and accuracy verification of the meter are performed periodically by the building facility management in accordance with the campus's internal operational procedures. Since the meter is installed on the building's main supply side, the data obtained represent aggregate energy consumption, including elevators, lighting, air conditioning, and other electrical loads. The instruments and measurement configurations used in this study are summarized in Table 1.

Table 1. Instruments and measurement settings

INSTRUMENT	SPECIFICATION	SETTING
Digital kWh Meter	IEC Class 1	Daily cumulative reading
Manual Tally Counter	Handheld mechanical counter	Hourly recording
Observation Log Sheet	Structured format	Upward & downward separation
Statistical Software	Documented computational software	Pearson & linear regression

Elevator usage observations were conducted directly by the researchers using a structured log sheet to record the number of users based on travel direction upward and downward at one-hour intervals. Observations were conducted directly by trained observers using structured log sheets. Elevator observations were conducted by two observers during peak hours, and inter-rater reliability was assessed using percentage agreement, which

indicated high consistency in manual counting. During peak hours, parallel verification was performed to minimize recording bias. To minimize double counting, a manual tally counter method was employed, with simultaneous monitoring at elevator entrance areas and cross-verification during peak hours. The observation data were then accumulated to generate hourly user profiles for each direction of movement.

Prior to the main data collection, the observation instruments and questionnaire were pilot-tested to ensure clarity of the recording format and consistency in respondents' understanding of the questions. During the observation period, elevator operations were confirmed to be in normal condition without technical disruptions or scheduled maintenance, if operational anomalies occurred, the data for those intervals were excluded from the analysis. Observations were conducted simultaneously across the selected elevator units to maintain consistency and avoid time-related bias [17]. Time synchronization between elevator observations and energy measurements was ensured by aligning all records to the building's standard operational clock, with hourly intervals used as the common temporal reference. All data collection and processing procedures were systematically documented to enable replication in other buildings with similar vertical transportation systems. Because the energy data are aggregate in nature, the analysis of the relationship between vertical mobility intensity and energy consumption is interpreted as correlational rather than causal, and does not represent the energy consumption of elevator motors separately.

2.3 User Behavior Preference Survey and Data Analysis

As a complement to the observational data, an online survey was conducted using a questionnaire developed through Google Forms. The questionnaire consisted of closed-ended questions, using either multiple-choice options or Likert scale items as appropriate for each question. It covered aspects such as the frequency of elevator use, preferred usage times (morning, afternoon, evening), reasons for choosing a particular mode of vertical transportation, and perceptions of waiting time. A total of 100 respondents participated using a convenience sampling technique, with the majority being active students who regularly use the building. Potential biases include representativeness bias due to the non-random sampling method and subjective perception bias regarding waiting time. These limitations were considered in the interpretation of the results and were not used as a basis for broad population generalization.

The survey results were used to complement the observational and energy consumption data in order to provide a more comprehensive interpretation of vertical mobility patterns. Data analysis employed a quantitative time-series approach with one-hour intervals to align elevator usage intensity with aggregated building electricity consumption. The relationship between hourly elevator usage and building energy consumption was examined using Pearson correlation and simple linear regression to evaluate the strength of linear association between variables. To enhance data stability, a moving average technique was applied to reduce short-term fluctuations, and outliers were identified using the Z-score method ($|z| > 3$), with no observations exceeding this threshold. Data intervals indicating operational anomalies were excluded from the analysis to maintain result validity. All numerical processing was conducted using documented analytical software, and the complete analysis script can be provided as Supplementary Material to support research transparency and reproducibility.

To further enhance replicability, the dataset structure and analytical procedures were standardized prior to statistical processing. Elevator usage data were organized in hourly intervals with separate columns for upward and downward passenger counts, while building electricity consumption data were recorded as total daily kWh values obtained from the MDP. Data preprocessing included validation of time synchronization between mobility records and energy measurements, exclusion of intervals affected by operational anomalies, and aggregation of hourly mobility intensity into daily totals for correlation analysis. Daily aggregation was used to ensure consistency between elevator usage data and MDP energy measurements, which are recorded cumulatively. Hourly modeling was not applied due to limitations in disaggregating load components at finer temporal resolution.

Statistical analysis was performed using documented computational software, including normality testing, Pearson correlation, and simple linear regression modeling with elevator usage intensity as the independent variable and total daily energy consumption as the dependent variable. The moving average window was applied consistently across hourly datasets to smooth short-term fluctuations before aggregation. All parameter settings, calculation formulas, and exclusion criteria were explicitly defined to ensure analytical transparency. The statistical workflow consisted of (1) normality testing using Shapiro–Wilk, (2) Pearson correlation analysis, (3) simple linear regression modeling, (4) Z-score outlier detection ($|z| > 3$), and (5) moving average smoothing prior to daily aggregation. The complete analysis script is archived and available as Supplementary Material to ensure reproducibility. The structured dataset template and step-by-step analysis workflow can be made available as supplementary material to enable independent replication in buildings with comparable elevator traction systems and centralized energy metering configurations.

3. RESULTS AND DISCUSSION

Based on the accumulated data on elevator users over the two week observation period during operational hours from 08:00 a.m. to 04:00 p.m. WIT, Table 2 shows differences in elevator usage distribution

by travel direction and time period: Morning (08:00–10:59 a.m.), Afternoon (11:00 a.m.–2:29 p.m.), and Evening (2:30–4:00 p.m.). The data are divided into two movement categories: from the 1st floor to the upper floors and from the upper floors to the 1st floor. In the first week, elevator usage from the 1st floor to the upper floors was recorded at 3,703 users in the morning, decreased to 2,800 users in the afternoon, and declined significantly to 1,059 users in the evening. Meanwhile, movement from the upper floors to the 1st floor during the first week showed 2,131 users in the morning, increasing to 2,599 users in the afternoon, and reaching 1,315 users in the evening.

In the second week, a similar pattern was observed, with generally higher numbers. Elevator usage from the 1st floor to the upper floors reached 4,478 users in the morning, 3,231 users in the afternoon, and 1,197 users in the evening. For the opposite direction, 3,625 users were recorded in the morning, increasing to 3,367 users in the afternoon, and 1,760 users in the evening. Overall, during the two-week observation period, the highest total number of elevator users occurred in the morning period with 13,937 users, followed by the afternoon period with 11,997 users, and the lowest in the evening period with 5,331 users. These results indicate that elevator usage intensity is strongly influenced by academic activity schedules, particularly at the beginning of morning classes and during transition periods before or after break times [18]. The significant decline in the evening suggests reduced vertical mobility as academic activities come to an end.

Table 2. Data Collection Results

Data Collection	Elevator Condition Used	Number of Elevator Passengers per Data Collection Preference		
		Morning (08:00–10:59 a.m.)	Afternoon (11:00 a.m– 2:29 p.m)	Evening (2:30–4:00 p.m.)
Total Passenger Accumulation for the First Week of Data Collection	From the 1st floor and above	3,703	2,800	1,059
	From the upper floor to the first floor	2,131	2,599	1,315
Total Passenger Accumulation for the Second Week of Data Collection	From the 1st floor and above	4,478	3,231	1,197
	From the upper floor to the first floor	3,625	3,367	1,760
Total		13,937	11,997	5,331

In contrast, elevator usage from the upper floors to the 1st floor exhibits a different distribution pattern. Based on the two-week cumulative observation data, downward movement was relatively high during both the morning and afternoon periods, reaching a total of 5,756 users in the morning (2131 in the first week and 3,625 in the second week) and 5,966 users in the afternoon (2,599 in the first week and 3,367 in the second week). In the evening period, however, the number declined to 3,075 users (1,315 in the first week and 1,760 in the second week). This pattern indicates that vertical mobility does not occur in a balanced manner throughout the day [19]. In the morning, upward movement is more dominant as most members of the academic community head to classrooms.

During the afternoon period, downward traffic increases in association with break times or class schedule transitions. In the evening, both upward and downward movements decline as academic activities come to an end. Overall, the data demonstrate that elevator usage follows a dynamic pattern aligned with the daily cycle of academic activities. The difference in intensity between upward and downward directions indicates an imbalance in operational load during certain time intervals. This condition implies increased elevator motor workload during periods of high mobility, which operationally may affect instantaneous power consumption and contribute to potential long-term mechanical component wear. The figure illustrating these results is presented below.

Figure 1 shows that elevator usage during operational hours follows a consistent pattern in both the first and second weeks, with the highest intensity occurring in the morning period. This is particularly evident in upward movement from the 1st floor to the upper floors, which reached 3703 users in the first week and increased to 4478 users in the second week. Entering the afternoon period, upward movement tends to decline, while downward traffic relatively increases in line with break times and class schedule transitions. During the evening period, both upward and downward movements decrease significantly, reflecting the reduction in academic activities. Overall, this pattern confirms that vertical mobility in the lecture building is strongly influenced by academic schedules and demonstrates dynamic variations in elevator operational load throughout the day.

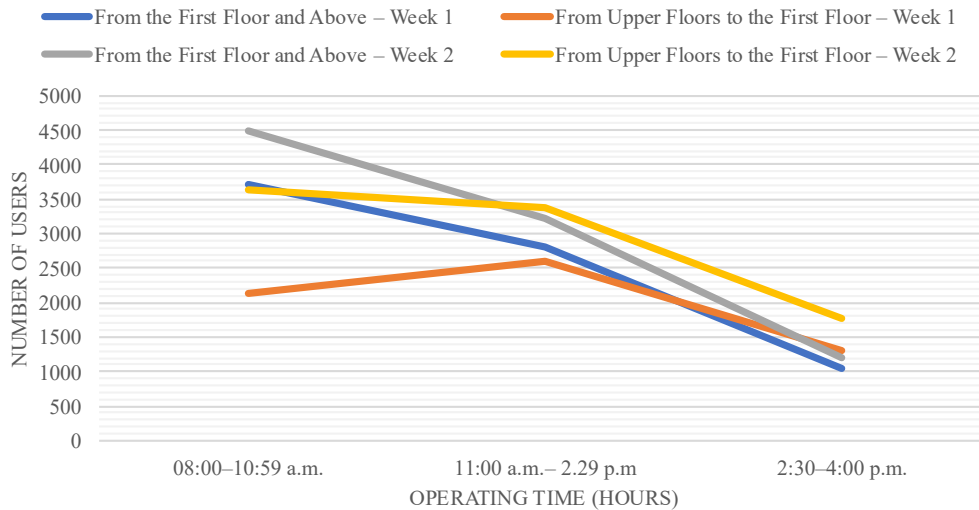


Figure 1. Data collection results

This operational pattern is further supported by the daily electrical energy data presented in Table 3 daily electrical energy consumption and efficiency, which indicates fluctuations in total daily energy consumption corresponding to variations in elevator usage intensity. Days with higher accumulated passenger traffic tend to exhibit relatively higher total energy consumption values, suggesting a measurable association between vertical mobility demand and overall building energy performance.

Table 3. Daily electrical energy consumption and efficiency

Day	Total Daily Energy (kWh)	Upward Trips (1st Floor → Above)	Downward Trips (Above → 1st Floor)
1	5,980	1,536	1,236
2	5,780	1,508	1,026
3	5,780	1,593	1,063
4	5,310	1,642	1,453
5	5,560	1,283	1,267
6	6,630	1,778	1,801
7	6,950	2,200	2,099
8	6,230	1,652	1,826
9	7,370	2,020	1,767
10	5,860	1,256	1,259

Note: Energy values are expressed in kWh; trip counts represent total daily passenger movements. Table 3 presents the relationship between daily elevator usage and total building electricity consumption. The results show that elevator usage ranged from 2,515 to 4,299 trips per day, while daily energy consumption varied between 5,310 kWh and 7,370 kWh. Higher elevator usage generally corresponds to increased building energy consumption, supporting the observed positive correlation between vertical mobility intensity and electricity demand. However, it is important to note that the energy data used in this study are aggregated at the building-level. Therefore, other factors such as air conditioning systems, lighting, and additional electrical loads may also contribute to variations in total energy consumption. The questionnaire was distributed to 100 respondents, targeting students as the main users of elevators during campus operating hours. The use of this questionnaire aimed to obtain an overview of perceptions, elevator usage habits, and elevator usage trends among students. The questionnaire data was used as supporting data to validate the field observation results, so that the analysis of elevator usage patterns was more comprehensive and reflected the actual mobility conditions of users on campus. The figure showing the distribution of daily elevator usage can be seen below.

Figure 2 the pie chart shows that 38.1% of people use the elevator 1–2 times a day, 34.3% use it more than 4 times a day, 23.8% use it 3–4 times a day, and only 3.8% never use the elevator. This data shows that most people on campus still rely on elevators as their main means of vertical transportation. This high frequency of elevator use has the potential to increase electricity waste and cause queues during peak hours. The figure showing the distribution of elevator usage time each day can be seen below.

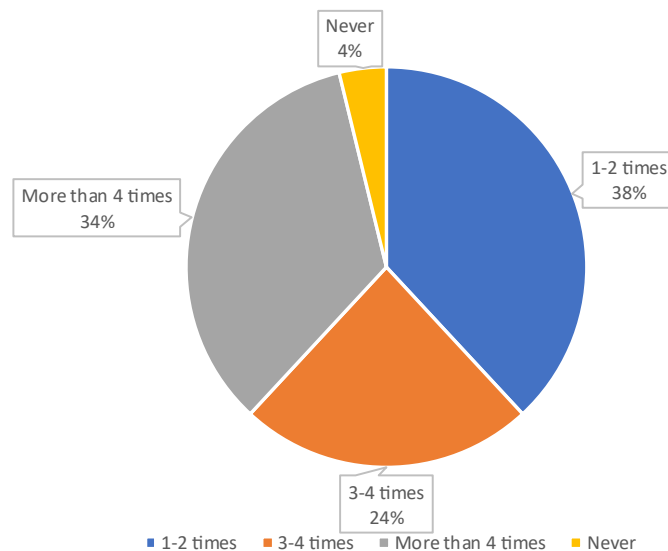


Figure 2. Elevator usage

Figure 3 indicates that elevator usage peaks during the daytime at 53.3%, followed by the morning at 40%, and drops to only 6.7% in the afternoon. This pattern aligns with the previous figure, showing the highest demand during the morning class period 08:00–10:59 a.m. and the class transition period 11:00 a.m.–1:30 p.m.. For categorization, usage between 08:00–10:59 a.m. is considered morning, 11:00 a.m.–2:29 p.m. as daytime, and 2:30–4:00 p.m. as afternoon. These findings suggest that both the morning and daytime periods represent peak elevator operation times due to high user density [20].

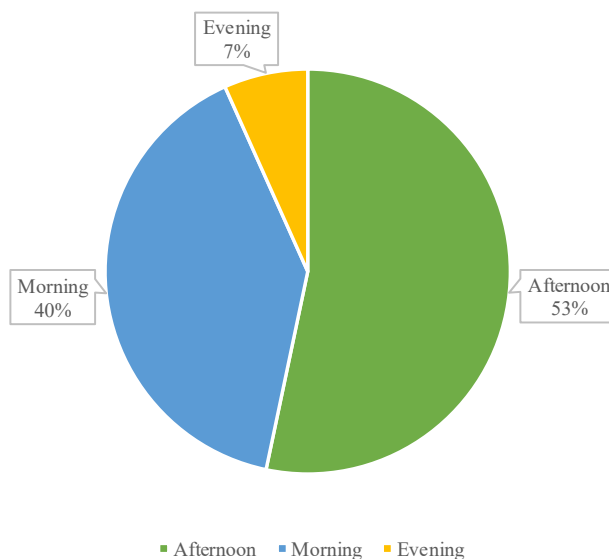


Figure 3. Elevator Operational Preferences

To strengthen the quantitative analysis, a Pearson correlation test was conducted between the total daily elevator usage and the total daily electricity consumption over a ten-day observation period ($n = 10$). The Shapiro–Wilk normality test indicated that both elevator usage ($p = 0.312$) and energy consumption ($p = 0.418$) were normally distributed ($p > 0.05$), making parametric analysis appropriate. The correlation results showed a significant positive relationship between elevator usage intensity and daily electricity consumption ($r = 0.813$, $p = 0.004$, 95% CI [0.35–0.96]). Linear regression analysis yielded an R^2 value of 0.661, meaning that 66.1% of the variation in daily energy consumption could be explained by variations in elevator usage, while the remaining variation was influenced by other building systems such as air conditioning, lighting, and other electrical operational loads.

It is important to note that these findings indicate a correlational relationship rather than causation, as the analysis is based on aggregated building-level energy data. Given the relatively small sample size ($n = 10$ days), the findings should be interpreted as preliminary and context-specific rather than broadly generalizable. Nevertheless, the observed relationship remains technically plausible and consistent with established principles

of elevator system operation. The main statistical outputs of the correlation and regression analyses are summarized in table 4 for clarity.

Table 4. Summary of correlation and regression results

Parameter	Value	Description
n	10 days	Observation period
Pearson r	0.813	Strong positive correlation
p-value	0.004	Statistically significant ($p < 0.01$)
95% CI (r)	[0.35–0.96]	Confidence interval
R ²	0.661	66.1% of variance explained
Adjusted R ²	0.619	Adjusted for sample size

Regression diagnostics were conducted to validate model assumptions. The Shapiro–Wilk test confirmed normality, while residual analysis indicated no significant heteroskedasticity (Breusch–Pagan test) and no autocorrelation (Durbin–Watson statistic ≈ 2). These results support the validity of the regression model. From a technical perspective, this relationship can be explained by the principles of traction system operation [21]. During upward movement, the elevator motor must lift the cabin and passengers against gravity, requiring higher torque and power. This finding is consistent with [12] and [21], which report that motor load increases significantly during upward travel due to gravitational resistance. Additional factors such as counterweight imbalance, mechanical friction, and system losses also increase energy consumption. In addition, frequent start–stop cycles during peak periods may contribute to transient power spikes, further increasing total energy demand. Conversely, during downward movement, gravity assists the cabin’s motion, and modern systems allow regenerative braking, resulting in lower power requirements. Therefore, the dominance of upward trips during peak hours is associated with increased motor load and overall electricity consumption.

These findings are consistent with Thebuwena et al. (2024) in “Optimization of energy consumption in vertical mobility systems of high-rise office buildings: A case study from a developing economy” and Wardani et al. (2023) in “Konsumsi Energi Listrik pada Penggunaan Lift Penumpang di Rumah Sakit Adam Malik Medan” (Electricity Consumption of Passenger Elevators at Adam Malik Hospital, Medan), which report that usage frequency and travel direction significantly affect elevator energy consumption. Thebuwena et al. Also indicated that elevators can account for 5–15% of total energy consumption in high-rise buildings. Gölitzer et al. (2023), in “Saving energy at university campuses via interventions to reduce elevator usage—a case study from Germany”, noted that high usage concentrations still occur due to structured academic schedules. The statistical results of the correlation and regression analysis, together with inter-rater reliability, regression diagnostics, and robustness evaluation, are summarized in table 5. These results provide a comprehensive assessment of data quality, model validity, and the stability of the observed relationship between elevator usage and building energy consumption.

Table 5. Reliability, regression diagnostics, and robustness analysis

Category	Parameter	Value	Interpretation
Inter-Rater Reliability	Percentage Agreement	95.8%	High consistency between observers
	Cohen’s Kappa (κ)	0.89	Strong agreement (almost perfect)
Regression Diagnostics	Shapiro–Wilk (p-value)	> 0.05	Data normally distributed
	Breusch–Pagan (BP)	1.64 ($p = 0.20$)	No heteroskedasticity
	Durbin–Watson	2.11	No autocorrelation
Main Model	Pearson Correlation (r)	0.813	Strong positive relationship
	p-value	0.004	Statistically significant ($p < 0.01$)
	R ²	0.661	66.1% variance explained
	Adjusted R ²	0.619	Adjusted for sample size
Robustness Check	Pearson (after exclusion)	0.782	Relationship remains strong
	R ² (after exclusion)	0.611	Slight decrease, still stable
	Outlier Detection (Z-score)	0	None

Z-score screening did not identify extreme values. Therefore, a separate comparison without exclusion was not required. These technical characteristics imply that improving elevator energy efficiency can be achieved not only through hardware upgrades but also through managing usage patterns and operational strategies [22]. Compared with Thebuwena et al. (2024), who reported that elevators contribute between 5–15% of total building energy consumption in high-rise office buildings, the R² value observed in this study (0.661) indicates a moderately strong explanatory power within an academic lecture building context. The difference may be attributed to building typology and data granularity, as this study integrates directional passenger counts with aggregated daily kWh measurements rather than system-level sub-metering. In contrast to Zubair and Zhang

(2020), who developed a predictive data-driven model using annual consumption data, the present study employs short-term high-resolution empirical observation ($n = 10$ days), which may explain the wider confidence interval observed.

Furthermore, consistent with Gölitzer et al. (2023), the dominance of structured academic schedules is linked to peak clustering effects, however, unlike their intervention-based study, this research quantifies directional asymmetry (52.7% upward trips) and directly links it to building-level electricity consumption. These methodological differences likely explain variations in explanatory strength across studies. The dominance of directional upward travel during certain periods creates opportunities for implementing time and load based control strategies, such as elevator operation scheduling, load distribution among elevator units, and adaptive control systems during off-peak periods. Thus, elevator energy efficiency emerges from the interaction between the technical characteristics of the drive system and user behavior patterns. The data-driven approach applied in this study provides a strong technical foundation for developing more effective and sustainable elevator energy management strategies in campus environments. Optimizing elevator performance not only enhances user comfort but also is associated with long-term reductions in campus operational costs.

4. CONCLUSION

This study confirms that elevator usage intensity is significantly associated with building-level electricity consumption, with a positive relationship explaining 66.1% of the variation in daily energy demand. The dominance of upward travel during peak academic periods increases traction motor load and is associated with overall consumption. By combining directional passenger data with aggregated kwh measurements, this research provides real-world validation beyond simulation-based studies and supports the development of energy efficiency strategies in campus vertical transportation systems. However, the findings are limited by the use of a single building, a short observation period ($n = 10$ days), and the absence of sub-metering, suggesting that future studies should include longer durations, multiple buildings, and direct elevator energy measurements for improved accuracy and generalizability.

Author Contributions: E.W. conceptualized the study, developed the research methodology, conducted data collection and analysis, and drafted the initial manuscript. P.A.R. contributed to methodological validation, supervised the overall research process, and provided critical review and refinement of the manuscript. All authors have read and approved the final version of the manuscript.

Data and Supplementary Materials: The data supporting the findings of this study were obtained from direct observations of elevator usage and aggregated building-level electricity measurements. The processed datasets, including elevator usage records, statistical analysis results, and other supplementary materials, are available from the corresponding author upon reasonable request for academic purposes and research replication.

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Conflicts of Interest: The authors declare no conflict of interest regarding the publication of this paper.

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