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Energy Use Vs Staff Performance at Soekarno Hatta: Partial Least Squares Structural Equation Modeling and Importance Performance Map Analysis Approach

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Abstract
This study investigates the operational impact of four key infrastructure systems (HVAC, lighting, electrical equipment, and internal transport) on staff performance at Terminal 3 of Soekarno-Hatta International Airport. Despite consuming 86.59% of the terminal's energy, HVAC systems show no statistically significant contribution to staff performance. In contrast, lighting, electrical equipment, and internal transport significantly improve staff productivity, with internal transport having the highest influence. A structural equation modeling approach using PLS-SEM and Importance-Performance Map Analysis (IPMA) was employed to analyze data from 400 respondents. The model yielded strong explanatory (R^2 = 0.613) and predictive relevance (Q^2 = 0.505), validating its robustness. Findings show that although HVAC systems consume the most energy, this does not correlate with their impact on staff performance. Instead, internal transport, electrical equipment, and lighting are considered important factors influencing staff performance.

Keywords: *Airport terminals, HVAC systems, IPMA, PLS-SEM, Staff performance.*

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1. INTRODUCTION

Airports are among the most complex public infrastructures in terms of both spatial design and energy consumption. As global air traffic intensifies, airport terminals—especially those handling international passengers—are under increasing pressure to deliver high-quality services while managing their operational efficiency. One major operational cost component in airport terminals is energy, with HVAC (Heating, Ventilation, and Air Conditioning) systems typically being the largest energy consumers. Studies such as [1], [2] reported that HVAC systems in airport terminals contribute to more than 70% of total annual energy use. In Terminal 3 of Soekarno-Hatta International Airport, HVAC accounts for 86.59% of energy consumption, far exceeding that of lighting (9.33%), electrical equipment (2.41%), and internal transport (1.76%).

Despite the sheer magnitude of HVAC-related energy usage, whether this consumption translates into operational effectiveness remains unclear. The effectiveness of such energy expenditure should ideally be reflected in improved staff performance, user satisfaction, or reduced service disruptions. However, preliminary observations and complaint reports suggest a misalignment: high HVAC energy use does not always coincide with enhanced human productivity or positive user experience. [3] notes consistent user dissatisfaction regarding thermal conditions in Terminal 3, raising doubts about the efficiency-performance correlation.

The traditional approach to facility planning in airports has heavily emphasized energy-intensive solutions under the assumption that physical comfort leads directly to operational effectiveness. Yet, recent literature suggests this relationship may be more nuanced. [4], [5] show that air quality and thermal comfort do affect staff behavior, but only under specific operational contexts. Similarly, [6], [7] emphasize lighting and ergonomic design as more proximate influences of both staff and passenger experience.

This raises a critical management question: are resources (especially energy) being allocated optimally in terminals? If HVAC systems consume the largest share of energy but do not significantly influence key performance outcomes such as staff efficiency or passenger satisfaction, then facility managers need to rethink infrastructure prioritization. Transport systems like escalators and elevators, or digital tools such as check-in kiosks and electronic signage, may deliver more value per unit of energy consumed. A comprehensive study comparing the impact of all key operational systems on staff performance is therefore essential to refine future infrastructure strategies.

HVAC systems are critical infrastructure elements in airport terminals, designed to maintain thermal comfort, regulate humidity, and ensure acceptable indoor air quality across vast interior spaces. Given the scale and continuous operation of international airport terminals, these systems must cater to thousands of passengers and staff across waiting areas, boarding gates, retail zones, and administrative offices. HVAC configurations in airports typically consist of large chillers, air handling units, duct systems, and energy management controls, often operating 24/7. Due to the volume of conditioned air required and the complexity of zoning, HVAC systems are among the highest contributors to both energy consumption and carbon footprint. Despite their operational prominence, the actual impact of HVAC on user satisfaction and staff performance is highly context-dependent, as factors like uneven temperature distribution, overcooling, or air stagnation may counteract the intended benefits.

Lighting plays a fundamental role in airport terminal operations, extending beyond mere visibility to influence safety, aesthetics, energy efficiency, and user well-being. Modern airport terminals are designed with a combination of natural daylighting and artificial illumination, using technologies such as LED lighting systems, motion-sensor controls, and zoned lighting schemes. Properly designed lighting enhances navigational clarity for passengers, reduces errors among operational staff, and supports circadian alignment, particularly in facilities that operate round the clock. Studies have shown that poor lighting design can lead to increased fatigue, eye strain, and reduced alertness among workers, especially those stationed in check-in counters, security checkpoints, or baggage handling zones. Therefore, lighting is not only a utility feature but also a determinant of occupational health and productivity.

Electrical equipment encompasses a broad array of devices that support administrative, operational, and passenger service functions within an airport terminal. This includes computers, monitors, scanning devices, power outlets, communication equipment, HVAC controllers, and public announcement systems. Many of these devices are mission-critical and must operate with high reliability and minimal downtime. Although individually these systems may not consume as much energy as HVAC, their cumulative use contributes significantly to the terminal's operational efficiency. Moreover, electrical infrastructure must support uninterrupted power supply systems (UPS), fire alarms, and emergency lighting, which are essential for safety and regulatory compliance. The smooth operation of these components indirectly enhances staff performance by reducing disruptions and enabling a seamless working environment.

Internal transportation within airport terminals refers to the mechanisms that facilitate the movement of passengers and staff across large terminal spaces. This includes escalators, elevators, walkalators (moving walkways), shuttle vehicles, and baggage handling systems. Efficient internal transport is crucial in reducing physical strain on both travelers and personnel, minimizing delays, and improving crowd flow during peak hours. For staff, particularly those involved in security, maintenance, or boarding operations, quick and reliable mobility translates to faster task execution and reduced fatigue. In some modern terminals, automation and real-time monitoring are integrated into transport systems to further optimize energy use and operational responsiveness. The performance of these systems, though relatively modest in energy consumption, may have an outsized impact on operational efficiency and user satisfaction.

Staff performance within an airport terminal reflects the efficiency, accuracy, and responsiveness of employees engaged in various operational roles, such as security screening, customer service, facility maintenance, and baggage handling. Performance is influenced by both individual competencies and environmental factors, including thermal comfort, lighting, noise levels, accessibility, and the functionality of supporting systems. High-performing staff contribute to reduced passenger wait times, improved compliance with safety protocols, and enhanced overall service quality. In contrast, environmental stressors (such as poor air circulation, inconsistent lighting, or inefficient mobility infrastructure) an lead to fatigue, cognitive overload, and increased error rates. Understanding the environmental determinants of staff performance is therefore essential for designing terminal systems that support both productivity and well-being.

Furthermore, few studies have employed a robust quantitative modeling approach to assess this relationship. Structural Equation Modeling using Partial Least Squares allows for the simultaneous analysis of multiple latent constructs and their interactions. This technique is particularly suitable for analyzing complex environments like airport terminals, where multiple systems operate concurrently and influence human behavior in interconnected ways. The inclusion of Importance Performance Map Analysis (IPMA) further enriches the evaluation by highlighting which system components, despite being important, underperform in practice.

In response to these gaps, this study investigates the relative influence of HVAC, lighting, electrical equipment, and internal transportation systems on staff performance in Terminal 3 of Soekarno-Hatta Airport. Specifically, it aims to test whether HVAC, despite its massive energy footprint, plays a significant role in improving staff productivity compared to other less energy-intensive systems. The findings contribute to both academic knowledge on infrastructure-performance alignment and provide practical insights for airport facility management in optimizing energy use and resource allocation.

2. METHOD

The study employed quantitative design [8], [9], [10], [11], [12], [13], [14], [15] with a causal-explanatory approach using Partial Least Squares Structural Equation Modeling (PLS-SEM) [16], [17], [18], [19], [20], [21], [22], [23], [24]. Data was collected through a structured questionnaire distributed to 400 respondents who were users and staff of Terminal 3, Soekarno-Hatta International Airport.

$$n = \frac{N}{1 + N(e)^2} = \frac{147000}{1 + 147000(0.05)^2} \approx 400 \quad (1)$$

The survey instrument included reflective indicators for four independent constructs: HVAC (X1), Lighting (X2), Electrical Equipment (X3), and Internal Transport (X4); and one dependent construct: Staff Performance (Y1). Structural Equation Modeling using Partial Least Squares (SEM-PLS) is a multivariate statistical technique designed to examine complex causal relationships between latent variables (unobservable constructs) and their corresponding indicators (observable variables). Unlike covariance-based SEM, PLS-SEM is prediction-oriented and works well with small sample sizes or non-normally distributed data. The primary goal of PLS-SEM is to maximize the explained variance in the endogenous (dependent) constructs. The approach is structured around two interconnected models: the measurement model (outer model), which relates indicators to their latent variables, and the structural model (inner model), which describes relationships between the latent constructs[25].

The measurement model defines how observed indicators reflect their corresponding latent constructs. In the case of reflective constructs, the model can be expressed as [26]:

$$x_{ij} = \lambda_j \xi_j + \varepsilon_{ij} \quad (2)$$

Where x_{ij} is the observed score of the ii-th indicator for latent variable ξ_j, λ_j is the outer loading, and ε_{ij} is the measurement error. Indicators are considered reliable if their loadings exceed 0.70. To further assess reliability and internal consistency, researchers calculate Composite Reliability (CR) and Average Variance Extracted (AVE). AVE must be ≥ 0.50, indicating that the construct explains at least half of the variance of its indicators.

The structural model explains the relationships among latent constructs. It is often written as:

$$\eta = B\eta + \Gamma\xi + \zeta \quad (3)$$

where η is a vector of endogenous latent variables, ξ represents exogenous latent variables, B is a matrix of relationships among endogenous variables, Γ is a matrix of effects from exogenous to endogenous constructs, and ζ denotes structural error. Path coefficients in the structural model are estimated iteratively through PLS algorithms until convergence. These coefficients are tested for significance using bootstrapping, which provides standard errors, t-statistics, and p-values for hypothesis testing.

After estimating the model, its explanatory and predictive capabilities are evaluated. The R-squared (R^2) value measures how much variance in the endogenous construct is explained by the model:

$$R^2 = 1 - \frac{\sum\left(Y_i - \widehat{Y}_i\right)^2}{\sum(Y_i - \bar{Y})^2} \tag{4}$$

To assess predictive relevance, Q-squared (Q^2) values are derived using blindfolding procedures. Values above zero indicate acceptable predictive power. In addition, direct, indirect (mediation), and total effects are analyzed. For example, a mediation effect is computed as:

$$\text{Indirect Effect} = \beta_{X \to M} \times \beta_{M \to Y} \tag{5}$$

where X is the predictor, M the mediator, and Y the outcome variable. A significant indirect effect implies that M mediates the relationship between X and Y.

Importance-Performance Map Analysis (IPMA) is an advanced extension of PLS-SEM that enhances interpretability by combining importance (total effect size) with performance (mean scores) for each construct. IPMA is useful for identifying improvement priorities. For example, a construct that has high importance but low performance becomes a strategic focus for managerial intervention. The results are usually visualized in a two-dimensional map, dividing constructs into quadrants (high/low importance vs. high/low performance). In applied settings, IPMA bridges statistical results with actionable insights, helping practitioners target areas with the greatest impact potential. This makes SEM-PLS not only a powerful analytical tool but also a practical decision-making framework [27].

All items were measured using a 5-point Likert scale. Based on [27], Likert scales can be treated as interval-level data under certain conditions, particularly in the context of multivariate analysis such as PLS-SEM. Technically, Likert scales are ordinal because they represent ranked categories without assuming equal distances between each level. However, Hair emphasizes that when the scale is symmetric and contains a sufficient number of response categories (typically 5 or 7), it can approximate interval properties, making it appropriate for use in parametric statistical analyses. For instance, in a 7-point Likert scale ranging from (1) “strongly disagree” to (7) “strongly agree,” it is commonly assumed that the perceived distance between adjacent categories is equal. Still, researchers must pay attention to the clarity and linguistic structure of the scale points. If the midpoint, such as “neither agree nor disagree,” is vague or not conceptually equidistant, it can compromise the interval assumption. Hair suggests using Likert scales with clearly defined, symmetric, and linguistically distinct categories, as this enhances interpretability and measurement precision. When these conditions are met, the scale becomes a reasonable approximation of an interval scale, especially in PLS-SEM, which is robust against violations of distributional assumptions. In practice, this means that well-designed Likert scales can be coded numerically and analyzed as if the underlying variables are continuous, allowing researchers to apply sophisticated modeling techniques like SEM-PLS with greater confidence in the validity of their inferences.

The SEM-PLS analysis for reflective measurement model followed the guidelines of [27], including reliability checks via outer loadings (> 0.70), internal consistency through Composite Reliability (CR > 0.70), and convergent validity via AVE (> 0.50). Discriminant validity was assessed using HTMT (< 0.90). Bootstrapping with 5000 resamples was conducted to test the significance of path coefficients. Importance-Performance Map

Analysis (IPMA) was then used to evaluate each construct's relative importance and actual performance in affecting staff performance.

3. RESULTS AND DISCUSSION

Prior to analyzing the structural model, it is essential to confirm the reliability and validity of the measurement model. Given that the constructs in this study are reflective in nature, the evaluation includes checking outer loadings, composite reliability (CR), average variance extracted (AVE), and discriminant validity using HTMT. Ensuring the validity and reliability of the constructs strengthens the credibility of the structural relationships tested in the next stage.

Table 1. AVE, CR and Outer Loadings

Construct	AVE	CR	Indicator Codes	Outer Loadings
HVAC	0.872	0.953	X1.1, X1.2, X1.3	0.939, 0.940, 0.923
Lighting	0.828	0.935	X2.1, X2.2, X2.3	0.902, 0.922, 0.905
Electrical Equipment	0.787	0.917	X3.1, X3.2, X3.3	0.858, 0.898, 0.905
Internal Transport	0.840	0.940	X4.1, X4.2, X4.3	0.923, 0.914, 0.912
Staff Performance	0.848	0.944	Y1.1, Y1.2, Y1.3	0.914, 0.920, 0.928

All the outer loadings on **Table 1** exceeded 0.85, which indicates excellent reliability of the indicators. Meanwhile, the AVE value is above 0.5 for all. Also, CR has a value above 0.7 for all constructs.

Table 2. Heterotrait-Monotrait Ratio

Construct ←→ Contruct	Heterotrait-monotrait ratio (HTMT)
Lighting ←→ HVAC	0.830
Electrical Equaipment ←→ HVAC	0.817
Electrical Equaipment ←→ Lighting	0.831
Internal Transport ←→ HVAC	0.851
Internal Transport ←→ Lighting	0.839
Internal Transport ←→ Electrical Equaipment	0.836
Staff Performance ←→ HVAC	0.738
Staff Performance ←→ Lighting	0.767
Staff Performance ←→ Electrical Equaipment	0.795
Staff Performance ←→ Internal Transport	0.803

Meanwhile, the total HTMT value in **Table 2** is below the threshold (0.9), so it can be said that validity and reliability have been met. The Variance Inflation Factor (VIF) test is used to detect the presence of multicollinearity between constructs in structural models. High multicollinearity can lead to parameter estimation instability and weaken the interpretation of model results. In general, a VIF value below 5 is considered to indicate that there is no serious multicollinearity problem. Table 3 presents the VIF values of the relationships between constructs in this model.

Table 3. Inner Model Multicollinearity Test Results

Laten Variable → Laten Variable	VIF
X1 → Y1	3.253
X1 → Y2	3.277
X2 → Y1	3.043
X2 → Y2	3.136
X3 → Y1	2.787
X3 → Y2	2.963
X4 → Y1	3.315
X4 → Y2	3.573
Y1 → Y2	2.581

The test results showed that all VIF values in this model were below the 5 threshold, with the highest value of 3.573 in the relationship of the Internal Transport (X4) variable to User Satisfaction (Y2), which is still acceptable in the context of social and behavioral research. This shows that there are no serious multicollinearity problems that can interfere with the interpretation of the relationship between latent variables. Thus, the contribution of each construct to the dependent variable remains statistically and theoretically accountable in the constructed model.

To evaluate the structural relationships between latent variables, the structural model (inner model) was analyzed following the confirmation of measurement reliability and validity. This phase involved assessing the magnitude and significance of the path coefficients, as well as the model's predictive accuracy. Additionally, the Importance-Performance Map Analysis (IPMA) was applied to visualize which constructs have the greatest influence on staff performance while identifying areas where performance may still be improved.

Table 3. Path Coefficients & P-Values

Dirrect Effect	Path Coefficients	P values
HVAC → Staff Performance	0.098	0.184
Lighting → Staff Performance	0.189	0.023
Electrical Equipment → Staff Performance	0.261	0.000
Internal Transport → Staff Performance	0.316	0.000

The results of the path coefficient and p-value analysis provide further insight into the strength and statistical significance of the relationships between each facility component and staff performance. The path from HVAC to staff performance yielded a coefficient of 0.098 with a p-value of 0.184, indicating a weak and statistically insignificant relationship. This suggests that, despite the large energy investment in HVAC systems, there is no compelling evidence that they enhance the productivity of terminal staff. In contrast, lighting was found to have a path coefficient of 0.189 with a p-value of 0.023, showing a moderate but significant effect on staff performance. This implies that visual comfort and appropriate lighting levels play an important role in facilitating effective work environments. Electrical equipment demonstrated a stronger effect, with a coefficient of 0.261 and a highly significant p-value of 0.000. This highlights the importance of reliable and functional operational tools such as computers, check-in machines, and security scanners in improving staff efficiency. The most substantial impact was observed in the internal transport variable, which had a coefficient of 0.316 and a p-value of 0.000. This emphasizes the critical role of vertical and horizontal mobility aids (e.g., elevators, escalators, and walkalators) in supporting the physical performance of personnel in expansive terminal areas.

The R-square (R^2) and Q-square (Q^2) statistics are essential to evaluate the explanatory and predictive capability of the structural model. R^2 reflects the proportion of variance in the dependent variable (staff performance) that is explained by the independent variables (HVAC, lighting, electrical equipment, and internal transport). A higher R^2 value suggests a better model fit. Meanwhile, Q^2 measures the model's predictive relevance, with values above zero indicating that the model has predictive power.

Table 4. R^2 & Q^2

R-square	0.613
Q-square	0.505

The R^2 value for staff performance is 0.613, which indicates that approximately 61.3% of the variance in staff performance can be explained by the four independent constructs: HVAC, lighting, electrical equipment, and internal transport. This suggests a strong explanatory capability of the model, affirming that the chosen variables are effective predictors of the outcome. In terms of predictive relevance, the Q^2 value for staff performance is 0.505. Since this value is substantially above zero, it confirms that the model possesses strong predictive power, indicating that the constructs not only explain past observations but are also useful for forecasting future outcomes. These results validate the robustness of the model and its relevance for both theoretical exploration and practical application in the context of airport infrastructure performance evaluation.

The Importance-Performance Map Analysis (IPMA) provides valuable insights into which constructs not only have strong effects on staff performance but also how well each construct is currently performing. While path coefficients indicate the relative importance of each factor, performance scores reflect how respondents perceive the current quality or adequacy of those factors within the airport terminal context. This dual perspective is critical for guiding managerial decisions that aim to maximize operational impact by focusing on high-importance but low-performance areas.

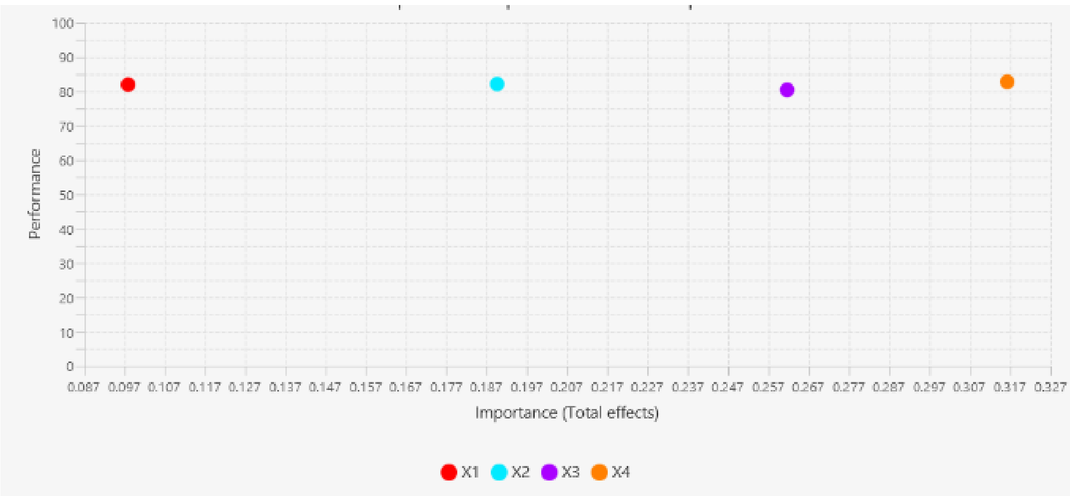

Figure 5. **Importance Performance Map Analysis**

Electrical Equipment showed a high importance score (0.261) but moderate performance (80.453), indicating a leverage point for improvement. HVAC had the highest performance score but the lowest effect, suggesting over investment relative to impact. This study confirms that HVAC, despite its overwhelming energy consumption, has no statistically significant influence on staff performance in the airport terminal context. These findings align with observations by [3] and support earlier claims by [28] and [6] that thermal comfort is important but not always a strong predictor of productivity.

Conversely, internal transport and electrical systems, despite consuming only 1.76% and 2.41% of energy respectively, exhibited higher influence on staff performance. These systems directly affect staff mobility, response time, and task efficiency, particularly in spatially large facilities like airport terminals. Similar findings were observed by [29], [30], who stressed the importance of system responsiveness and accessibility for operational performance. The lighting system, with its significant contribution to performance (β = 0.189), corroborates studies by [7], [31], showing that visual comfort and clarity of visibility significantly affect employee concentration and accuracy. These findings suggest that energy allocation strategies in airport terminals need to shift from consumption-based budgeting toward performance-based prioritization. Investing in systems that directly enhance operational effectiveness may yield greater returns than reinforcing ambient comfort systems like HVAC, which are already performing adequately but offer limited marginal benefits.

4. CONCLUSION

Although HVAC systems dominate energy consumption in Terminal 3 of Soekarno-Hatta International Airport, they do not significantly influence staff performance. Greater operational impact was observed from transport and electrical systems that consume much less energy. These findings underscore the need for a strategic realignment in facility management, favouring performance (driven infrastructure investment over traditional energy) centric approaches.

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Author Contributions Statement

Table 5. Author Contributions

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mc Ali Muchtar	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Erry Rimawan	✓			✓								✓		
Mawardi Amin				✓								✓		

Conflict Of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data Availability

The data that support the findings of this study are available from the first author, **[MAM]**, upon reasonable request.

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