Identification of factors influencing indoor electricity Consumption in Surabaya and energy saving strategies in tropical climate

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Abstract
Growing urban centers and rising living standards in tropical regions like Surabaya are driving significant increases in building energy consumption. This trend poses considerable challenges to energy infrastructure sustainability and contributes to environmental concerns, particularly given the inherent climatic demands for cooling and dehumidification. Addressing this effectively necessitates a clear understanding of the primary drivers influencing energy use patterns. Therefore, this study comprehensively identifies the diverse factors impacting indoor electrical energy consumption within this context. Furthermore, it aims to formulate practical and effective energy conservation strategies specifically tailored to mitigate consumption while leveraging the unique characteristics and constraints presented by the tropical climate. Employing a mixed-methods approach, the research integrated foundational knowledge from a thorough literature review with primary data collected via questionnaires distributed to 70 residents in Surabaya, capturing specific local conditions, behaviors, and perceptions related to energy use. The findings reveal that electricity consumption is shaped by a complex interplay across six main categories: occupant characteristics and behaviors, prevailing socioeconomic conditions, inherent building design and material features, the effectiveness of natural ventilation and lighting systems, the types and efficiency of electronic devices used, and the reliance on active air conditioning systems. Based on these insights, relevant and context-specific energy conservation strategies were identified. Key approaches include optimizing building design for effective cross-ventilation, maximizing the utilization of abundant natural daylight, systematically implementing passive tropical architectural design principles, and encouraging the adoption of certified energy-efficient appliances. Ultimately, this study strongly recommends a holistic approach, integrating both technical solutions and non-technical measures like promoting behavioral changes, to achieve meaningful and sustainable energy efficiency improvements in buildings within tropical regions.

Keywords: electrical energy consumption, energy conservation strategies, tropical ventilation, user behavior, energy efficiency.

1. Introduction

Energy is a fundamental requirement for economic development and human well-being. Over the past few decades, global energy consumption has significantly increased, driven by population growth, urbanization, and industrialization [1]. This rising energy demand, particularly prominent in developing nations including Indonesia, presents substantial challenges concerning energy supply security and environmental impacts.

In this context, the building sector, encompassing residential and commercial structures, plays a crucial role. This sector accounts for a significant portion of total global final energy use, estimated at around 31% to 40%, and is responsible for approximately 54% of the world's total electricity demand [2]. Consequently, buildings are among the largest consumers of natural resources, following the industrial and agricultural sectors. Furthermore, building operations (heating, cooling, lighting, appliances) and their life cycle (construction, materials) account for a substantial share of global greenhouse gas (GHG) emissions, estimated between 27% and 37% from operational energy-related emissions, plus embodied carbon emissions in materials and construction processes [3]. Building energy consumption, particularly for heating and cooling, is directly linked to climate change issues, driving an urgent need to enhance energy efficiency and decarbonize this sector [4]. Reducing energy use in buildings not only contributes to climate change mitigation but can also improve indoor environmental quality and occupant health.

Data indicates that building energy consumption is not merely a technical issue, but a complex phenomenon intertwined with broader global trends. Global population growth drives increased urbanization, which in turn spurs economic activity [2]. Both require more buildings and infrastructure. These buildings consume vast amounts of energy, much of which still comes from fossil fuels, thereby causing increased GHG emissions and contributing to climate change [5]. This creates a feedback loop, where climate change itself, such as rising temperatures, can further increase energy demand for cooling. Therefore, addressing building energy consumption is crucial to tackle these interconnected global challenges [5].

The residential sector plays a significant role in Indonesia's total national building energy consumption, estimated to account for 14% to 29% of the national final energy consumption [3]. Energy consumption in this sector is projected to increase sharply in the future, primarily driven by the growth of the urban middle class. The building envelope – comprising walls, roofs, floors, windows, and doors – acts as a mediator between indoor and outdoor environments, and its performance is crucial in controlling heat transfer. Key characteristics of the building envelope significantly influence energy consumption in tropical climates. Household appliances contributing significantly to electricity consumption include lighting (lamps), refrigerators, water heaters, cooking appliances (rice cookers, electric stoves), and electronic devices (televisions, computers, fans). The use of LED lamps is far more efficient than incandescent or CFL technology [6]. Appliance ownership rates (saturation), especially for air conditioning (AC), vary significantly depending on household income levels. Studies in Indonesia show AC ownership increases sharply with rising house categories (based on income). Standby power consumption from electronic devices not fully switched off can also account for 5-10% of household annual electricity consumption [7].

Several pillars within the Smart City concept are closely related to building energy management:

- **Smart Environment**: This pillar directly targets sustainable resource management, energy efficiency, pollution control, and climate action [8]. Smart technologies are used to monitor environmental conditions (e.g., air quality, pollution levels) and optimize resource use. Examples include smart waste management systems that can reduce transport routes and related emissions, as well as smart urban planning that integrates energy-efficient buildings [9].
- **Smart Living**: This pillar focuses on enhancing citizens' quality of life, health, safety, and comfort. This often involves implementing smart home technologies such as smart thermostats, smart lighting, and home automation systems that can enhance comfort while optimizing energy use [10].

Electrical energy consumption in tropical regions, such as Surabaya, tends to be high, particularly for air conditioning and lighting needs. The hot and humid climate throughout the year increases the use of cooling devices and artificial lighting, which impacts high electricity consumption. This condition adds to household economic burdens and accelerates the depletion of energy resources. Therefore, electricity saving becomes important to support environmental and economic sustainability [11]. Electricity saving efforts often face challenges in maintaining occupant comfort. Most energy efficiency strategies focus on technology or building designs requiring significant investment. However, in tropical regions, simple approaches like using appropriate building materials, managing ventilation, and optimizing natural lighting can contribute significantly. However, comprehensive understanding of the factors influencing indoor electrical energy consumption is still limited, especially in tropical regions like Surabaya [12]. Estimated electricity demand for Surabaya City from 2018-2023 continuously increased, with an average increase up to 1,038,237 MWh or 9.11% [12].

This research focuses on reducing indoor electrical energy consumption without sacrificing occupant comfort. An in-depth understanding of electricity usage patterns and the factors influencing them is necessary to formulate relevant and applicable strategies. This is important for developing countries with limited financial and technological resources [13], [14]. The main objectives of this research are to identify the factors influencing indoor electrical energy consumption in Surabaya and to formulate saving strategies suitable for tropical conditions. By integrating approaches related to technology, user behavior, and building design, this research is expected to provide holistic and implementable recommendations. This study can also serve as a reference for government policies and practitioners in designing more energy-efficient and environmentally friendly built environments [15].

2. Literature review

Electrical energy saving in buildings involves efforts to reduce energy consumption without sacrificing function and comfort. This approach involves efficient architectural design, the use of energy-saving technology, and energy-conscious user behavior. According to previous research, certain design strategies can modify an uncomfortable outdoor climate into a comfortable indoor environment with minimal electrical energy consumption [11]. Tropical regions are characterized by high temperatures, high humidity, and intense solar radiation throughout the year. These conditions increase the need for indoor cooling and artificial lighting, resulting in high electrical energy consumption. Research indicates that thermal comfort and energy savings can be achieved through architectural design that considers the characteristics of the tropical climate [15].

Energy-saving technologies, such as LED lighting, inverter air conditioners (AC), and smart home automation systems, have proven effective in reducing energy consumption. The implementation of these technologies, combined with efficient building design, can yield significant energy savings. Energy savings achieved through building design lead to reduced electricity consumption for air conditioning, artificial lighting, and other electrical appliances [16]. Case studies in tropical regions show that natural ventilation and the use of reflective materials on roofs can reduce the need for air conditioning. Research indicates that appropriate roof design and material selection can lower indoor temperatures, thereby reducing the load on air conditioning systems [14].

Furthermore, the green building concept, which integrates passive and active design strategies, can achieve energy savings of up to 50%. The application of appropriate design and technology in green buildings can significantly reduce electrical energy use without substantial additional investment during construction [17].

3. Methodology

This study employs a mixed-methods approach, comprising qualitative analysis of literature and scientific journals, as well as quantitative analysis based on questionnaire data. The literature review focused on relevant scientific publications concerning energy consumption in buildings within tropical regions, specifically Surabaya. Additionally, a questionnaire survey was distributed to 70 Surabaya residents who are household electricity users. The questionnaire data included aspects of electricity usage habits, building characteristics, types of devices used, as well as perceptions and behaviors regarding energy conservation. The questionnaire results were then analyzed to identify patterns and correlations between these factors and the level of electrical energy consumption.

4. Discussion

Electrical energy consumption in buildings in tropical climate regions, including Surabaya City, is the result of a complex interaction of various influencing factors. These factors cannot be separated from each other as they form a multidimensional and interconnected system. In the context of tropical urban areas, the contributing factors can be categorized into six main groups: occupant characteristics, socioeconomic conditions, physical building characteristics, natural ventilation and lighting systems, types and usage patterns of electronic devices, and Heating, Ventilation, and Air Conditioning (HVAC) system planning. Each category contributes, either directly or indirectly, to the patterns of electrical energy consumption in buildings.

Occupant characteristics are the initial aspect requiring in-depth analysis. The number of occupants in a household, the intensity of space utilization, and the types of activities conducted indoors influence the magnitude of energy needs. For instance, households with more members tend to use electrical appliances simultaneously, ultimately leading to increased consumption load during specific hours. Furthermore, occupant behavior regarding energy efficiency, such as the habit of turning off lights when not in use or choosing energy-efficient household appliances, also plays a crucial role in controlling electricity consumption. A study by Christofer et al. (2024) indicates that improving energy literacy through community education can significantly reduce household electricity consumption by more than 15% [18].

Additionally, the socioeconomic dimension exerts considerable influence. The level of education and household income determine the extent to which society can access energy-efficient technology. Households with better economic capacity generally have greater purchasing power for high-tech, energy-efficient electronic appliances. However, this group also tends to use more devices, necessitating wise management in their usage. In this regard, providing incentives and subsidy programs to encourage the use of energy-saving devices among middle-to-low-income communities is a strategy that needs prioritization so that energy efficiency can be applied evenly. Regarding building characteristics, aspects like construction materials, orientation towards the sun, and the configuration of ventilation openings and natural lighting determine thermal comfort and the magnitude of the cooling load. Buildings designed without considering local climate conditions potentially have higher energy consumption levels to maintain comfortable indoor temperatures. The implementation of passive architectural principles, such as the use of double-skin façades, roofs with reflective colors, and thermal insulation on walls, has been empirically proven to reduce cooling energy needs [19].

Cross-ventilation and natural lighting are two potential sources of energy efficiency that can be maximized in tropical buildings. However, in practice, many residences still do not optimally utilize this potential. Lack of adequate ventilation causes indoor air to become stagnant and temperatures to rise, making the use of cooling devices like AC highly dominant, even during the day. Applying building designs with strategic cross-openings, as well as utilizing diffuse transparent materials for natural lighting, has been proven to significantly reduce dependence on electrical energy. This aligns with the findings of Karyono's study (1998) which emphasized the urgency of applying tropical architectural principles to support energy efficiency without sacrificing occupant comfort [15].

Next, the number and types of electronic devices owned, along with their usage patterns, are determining factors for the magnitude of electricity consumption. Household appliances with high heat loads such as ACs, water heaters, and electric ovens contribute significantly to energy consumption spikes. However, the effectiveness of use is just as important as quantity. Using energy-labeled appliances, setting air conditioner temperatures at optimal ranges (24–26°C), and implementing automatic timer systems or smart power strips are interventions that can be done at the household level. Nasrullah et al. (2023) noted that behavioral approaches in using household appliances can reduce energy consumption by up to 20% [20].The final, equally significant factor is the HVAC system, especially in the context of buildings located in regions with high temperatures and humidity like Surabaya. Many air conditioning systems are used continuously without considering the surrounding environmental conditions, leading to energy waste. Integrating vegetation as shading elements, proper ventilation settings, and using hybrid ventilation systems responsive to environmental temperature and humidity are more efficient alternative strategies. Furthermore, conducting periodic energy audits is important to ensure that the HVAC system operates optimally and does not suffer from undetected energy losses.

Considering all the factors presented from Table 1, it can be concluded that efforts to reduce electrical energy consumption in tropical buildings cannot be done partially. An integrated approach is needed, encompassing technical planning based on tropical architectural principles, fostering energy-saving behavior among building users, and public policy support that encourages the development of environmentally sound buildings. Achieving a comprehensive understanding of the intricate interplay between key factors—such as building design, material choices, occupant behavior patterns, technology integration, and prevailing climatic conditions—is crucial. This deeper insight is expected to empower Surabaya City to develop and implement truly adaptive energy management strategies, enabling buildings to respond efficiently to fluctuating demands and environmental shifts. Simultaneously, it will foster sustainable practices that significantly reduce the city's overall carbon footprint, lower operational costs, and enhance resource efficiency. By successfully navigating these complexities, Surabaya is poised not merely to be encouraged, but to establish itself as a pioneering and replicable model for adaptive and sustainable building energy management, offering valuable lessons for other urban centers facing similar challenges in tropical regions..

Table 1. Factors of Electrical Energy Consumption

Category	**Factors Influencing Electrical Energy Consumption**	**Energy Saving Strategy (Tropical Climate)**	**Scientific Journal Reference**
Occupant Characteristics	- Number of occupants - Daily activity patterns - Electronic device usage behavior	- Energy saving education - Change in appliance usage habits	[21]
Socioeconomic	- Education level - Income - Access to energy-efficient technology	- Subsidies or incentives for energy-saving appliances - Energy conservation socialization	[21]
Building Characteristics	- Building materials - Window and opening area - Building orientation - Wall/roof color	- Double skin façade - Reflective or green roof - Insulated walls - Optimal window placement	[19]
Natural Ventilation and Lighting	- Lack of natural ventilation - Use of lights during the day	- Optimization of cross-ventilation - Open design for circulation - Natural lighting	[15]
Electronic Devices	- Number and type of electrical appliances - Appliance efficiency - Use of AC and heaters	- Use energy-labeled appliances - Set optimal AC temp (24–26°C) - Use timers and power strips	[20]
HVAC Planning	- Use of AC system without considering microclimate - Inefficient HVAC system	- HVAC energy audit - Passive cooling (cross-ventilation, vegetation)	[20]

Building User Status, the following table shows the type of building inhabited by respondents, Table 2.

Table 2. Type of building inhabited by respondents

What category does your building type fall into?	Quantity (People)
a. House	68
b. Apartment	2

Analysis using the Chi-square test shows a highly significant relationship between the number of family members and the behavior of leaving appliances in standby mode. The obtained Chi-square value is 72.55 with a p-value of 1.22×10^{-13}. The p-value, much smaller than the significance level of 0.05, confirms that this relationship is not coincidental but indicates a strong statistical association. Conceptually, leaving appliances in standby mode is a form of less efficient energy consumption habit. Standby mode, although appearing inactive, continuously draws a certain amount of energy. Therefore, this behavior can be considered an indicator of energy efficiency awareness within the household.

This finding suggests that households with more members tend to have lower compliance rates with energy-saving behaviors, particularly regarding fully switching off electronic devices. This might be due to the high intensity of appliance use, the complexity of coordination among family members, or a lack of central control over energy use. The more people in a household, the greater the likelihood that one or more members do not turn off appliances after use. From an energy policy perspective, this finding provides an important basis for designing family-based behavioral education and intervention strategies. Energy efficiency socialization programs need to consider household demographic composition, especially in larger families prone to wasteful energy practices like standby power. Moreover, energy-saving campaigns could be more effective if packaged with approaches based on the roles and responsibilities of each family member, including educating children from an early age. Consequently, the significant correlation established between household size and standby energy behavior for electronic devices provides compelling evidence for the importance of social context in energy use. This relationship acts as a valuable initial indicator, highlighting the potential to move beyond purely technical or appliance-based predictions. It underscores the need to develop new household energy consumption models that are inherently more adaptive by explicitly integrating key socio-demographic factors, with family size being a demonstrated starting point for capturing the human element in energy demand..

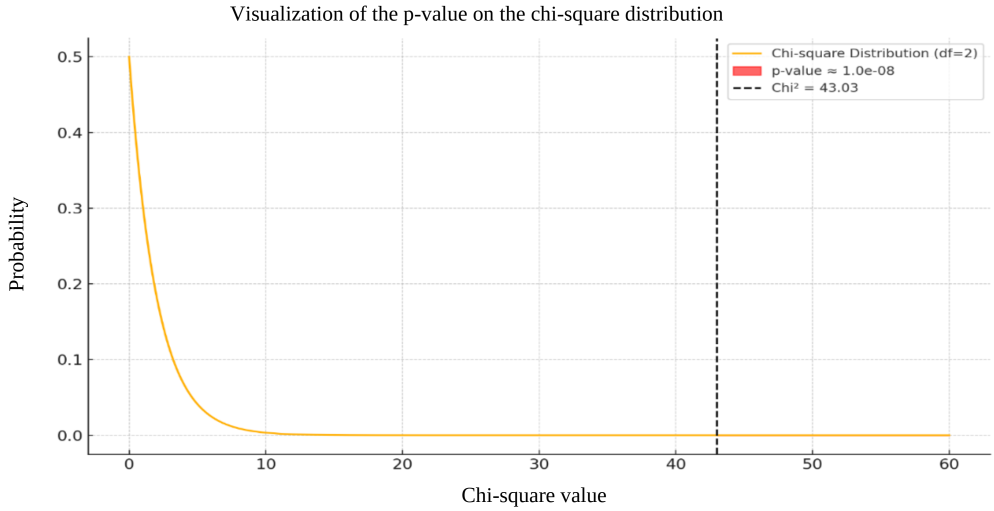

Fig. 1. Visualization of the p-value on the chi-square distribution

Data analysis from Fig. 1 using the Chi-square test yielded a value of 43.03 with a p-value of 1.02×10^{-8}. The p-value, much smaller than the 0.05 significance level, indicates a highly significant statistical relationship between the frequency of AC use and the intensity of lamp use during the day. Thus, it can be concluded that the usage patterns of these two types of electrical appliances are not random but behaviorally interconnected. This finding suggests that households using AC more frequently also tend to turn on lights more often during the day. This correlation indicates potential issues with the quality of natural lighting inside the home, even if ventilation might be available. Ventilation that only regulates air circulation does not necessarily guarantee optimization of natural light entering the room. Conversely, lack of natural lighting encourages occupants to turn on lights even during daytime. This phenomenon carries important implications for energy efficiency in the household sector. The combined use of AC and lights during the day signifies relatively high and not entirely efficient energy consumption. From an architectural and building design perspective, this result reinforces the importance of implementing home designs adaptive to tropical climates—including window placement, building orientation, and light openings—to maximize natural lighting and minimize dependence on artificial energy sources.

Furthermore, from a behavioral education standpoint, efforts are needed to increase public awareness about the cumulative impact of appliance usage habits on energy consumption. Behavior-based education emphasizing the importance of utilizing natural light and efficiently using AC can be an effective intervention in reducing overall household electricity consumption. Therefore, the highly significant statistical relationship discovered between the operation of air conditioning (AC) systems and the concurrent use of artificial lamps during daylight hours serves as a critical key indicator for energy management in Surabaya. This strong correlation suggests that energy use patterns are interconnected and cannot be tackled effectively with isolated measures. It highlights the urgent need to formulate comprehensive energy efficiency strategies that move beyond merely promoting efficient technologies. These strategies must adopt an integrated approach, explicitly considering how spatial design—optimizing natural light ingress through better architecture and interior layouts—and habitual user behaviors—such as the tendency to switch on lights regardless of daylight when the AC is running—collectively influence consumption. Addressing this AC-lighting nexus is fundamental to creating truly effective and sustainable energy reduction plans in tropical urban households.

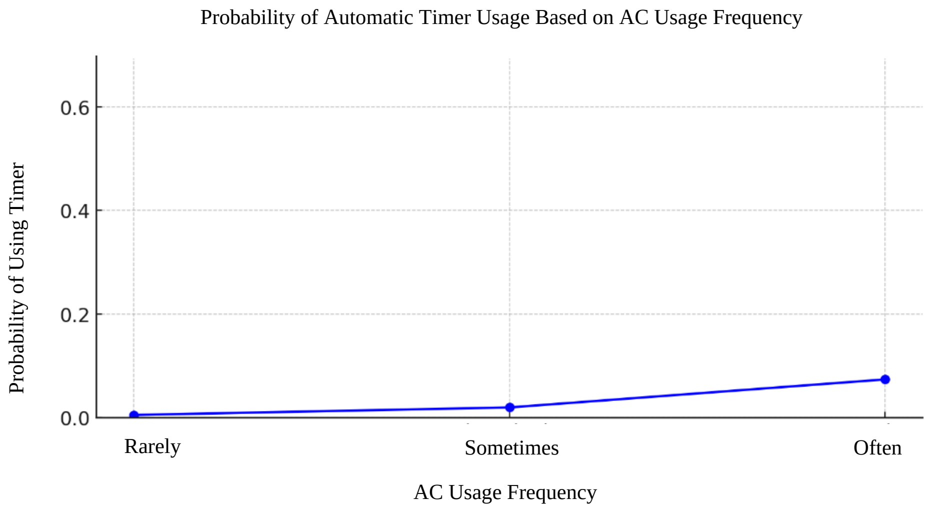

Fig. 2. Probability of Automatic Timer Usage Based on AC Usage Frequency

From Fig. 2 Chi-square test analysis shows a significant relationship between the frequency of AC use and the habit of using an automatic timer ($\chi^2 = 11.20$; $p = 0.0037$). This finding is supported by logistic regression results, indicating that each one-level increase in AC usage frequency significantly increases the log-odds of timer usage ($\beta = +1.3851$; $p = 0.021$). A pseudo R^2 value of 0.1797 and a log-likelihood ratio (LLR) test with a p-value of 0.0042 indicate that the model has a reasonably good fit. Practically, this result suggests that users who operate their AC more frequently tend to be more conscious of energy efficiency, exemplified by the use of automatic controls like timers. This could also reflect an adaptive user response to high power consumption, where automation devices are employed as a strategy for wiser electricity use control.

5. Conclusions

Indoor electrical energy consumption in tropical cities like Surabaya is influenced by a combination of internal factors (including occupants, socioeconomic status, and devices/appliances) and external factors (such as building characteristics and climatic conditions). Effective energy saving strategies must combine technical approaches (like passive architecture and appliance efficiency) with non-technical ones (such as education and socioeconomic incentives). These efforts are crucial for creating sustainable buildings that are energy-efficient and adaptive to future tropical climate challenges.

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