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Assessment of Electricity Consumption of Middle-income Households in Tanzania

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ABSTRACT

Electricity is the foundation of modern society, powering a vast array of daily activities and technological advancements. Despite increased electricity access, the majority of Sub-Saharan African countries face the dilemma of energy consumption outpacing generation. Gaining a good grasp of behavioral drivers of energy use, especially among middle-income households (MIHs), is necessary to reduce energy consumption. This study assesses the electricity consumption from MIHs in a targeted area of Masaki, Dar es Salaam region, Tanzania. The study integrated the household characteristics and electrical load consumption patterns in the electricity consumption of MIHs. The 1-month data, between May 2024 and June 2024, were gathered from 99 respondents using an e-questionnaire. The household characteristics included the number of occupants per household, awareness of energy management programs, adoption rate, and interested features and expectations in energy management programs. The electrical load consumption patterns include types of electrical loads, hourly usage, average monthly bills, and fluctuations in monthly energy bills. Findings revealed that the average number of occupants per household was 6, but only two out of 6 occupants per household were aware of energy management programs. Appliance control was the most adopted energy management program (44.12%) followed by real-time energy monitoring (11.76%) and integration with renewable energy sources (8.82%). Contrary, about 96% of respondents were interested in engaging in energy management initiatives aiming at cost-saving (62%) and convenience (20.7%). Evening hours reported to use the most energy (68.7%), followed by night hours (50.5%). The average monthly energy bills were found to range between TZS 70,000 and TZS 300,000 with 48.5% of respondents reporting large swings in their electricity expenses. The findings of this study provide policymakers with evidence that awareness initiatives should be included when formulating energy consumption and efficiency strategies.

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1. Introduction

As the global population continues to grow and economic development progresses [1-5] the electricity demand has been steadily increasing [6-8]. According to Statista (Statista, 2024), electricity consumption has more than quadrupled, while the global population has grown to about eight billion people [9] due to increased industrialization and the availability of electricity worldwide. As of 2022, global electricity consumption has steadily increased and reached around 25,500 terawatt-hours [10].

The building sector consumes a significant amount of energy [11-16] in developed and developing countries. Data from multiple [17-19] countries show that residential accounted for about one-fifth to one-third of the total electricity consumed at the end-use level. In America, the residential sector contributed about 21% of the electricity used, resulting in an average of 1945 US$/year per capita in annual bills [20]. Similarly, more than 30% of electricity was utilized in Ireland [21], Belgium, and Denmark while about 20% in Japan [22], and Germany [22, 23]. In Australia, the Department of Industry and Science (2015) reported that the building sector consumed around 11% of total final energy consumption in 2013-2014 [24]. Observations are not much different in developing countries; the average household in Peru and cities in Mexico - Guadalajara, Mexico City, and Monterrey - spent approximately 20% of gross monthly income on energy-related expenses; in Ecuador, Colombia, and India, this was around 10%. In Jordan, the building sector consumes more than 60% of the total electricity produced with 20% of the country's GDP coming from energy bills [25]. Between 2009 and 2011, the construction and buildings sector in Palestine consumed around 57% of the total energy [26]. Ghana's residential sector accounts for over 40% of total energy usage [27].

Governments primarily use an economic barometer to define and monitor the state and overall health of the middle class. Researchers, policy economists, and policymakers have used statistics about mean and median income and a variety of cutoff points (often expressed in terms of earnings deciles, or quintiles) to categorize who is in the middle class. The concept of a "middle-income household" is often discussed in the context of economic and social policies, but it can be challenging to define this group based on traditional income-based metrics alone. One alternative approach is to examine household electricity consumption patterns, which can provide insights into the energy usage behaviors and requirements of different income groups. Several recent studies [28-33] have explored the relationship between household income and electricity consumption. These studies have found that higher-income households tend to consume more electricity overall, likely due to factors such as larger home sizes, more energy-intensive appliances, and greater willingness to pay for electricity. However, the relationship between income and electricity usage is not always linear [6, 33-39], as lower-income households may also have high consumption levels due to inefficient housing, reliance on electric heating/cooling, or other factors. Several recent studies have explored the relationship between household income and electricity consumption [40-46]. These studies have found that higher-income households tend to consume more electricity overall, likely due to factors such as larger home sizes, more energy-intensive appliances [34, 35], and greater willingness to pay for electricity [38, 39]. However, the relationship between income and electricity usage is not always linear [44-46], as lower-income households may also have high consumption levels due to inefficient housing, reliance on electric heating/cooling, or other factors.

To better define a "middle-income household" from an electricity consumption perspective, researchers have started to utilize clustering techniques to identify distinct consumption patterns [47]. By analyzing smart meter data alongside socioeconomic survey information, these studies have been able to categorize households into high, medium, and low electricity consumption groups, which may provide a more nuanced understanding of energy usage behaviors across the income spectrum. Rokonuzzaman, Jahan, and Haque [48] used a time series monthly electricity data of a middle-class family in Chittagong, Bangladesh from January 2001 to November 2015 to find out the monthly average household electricity consumption and fit a suitable time series model to predict the electricity use. Masebinu & Kambule [49] captured the real-time hourly electricity consumption data of a middle-income household in Gauteng, South Africa for 30 months (2019 to 2021) over three different residential properties. The data were logged from single-phase electricity distribution sub-panels for 20,852 hours. Liu et al. [50] developed a reduced piecewise linear model from panel data of 540 observations in 30 Chinese provinces over the 1995–2012 period to investigate the relationship between residential electricity consumption and income in China. In the study of Never et al. [51] where electricity consumption was measured in middle-class households in Ghana, Peru, and the Philippines, many households were unwilling to share their last electricity bill. Overall, behavioral interventions are viewed as an important step in achieving the substantial energy management and efficiency targets [52] required for the clean energy transition and promotion of energy conservation [53] in buildings. Despite the necessity to manage home power use, past research has disregarded household variables. Furthermore, many studies do not consider electrical load utilization, which is critical for understanding the effective deployment of energy management systems [24, 27, 54-57].

This study aims to offer a nuanced exploration of the household characteristics and energy consumption patterns observed among middle-income households across the Dar es Salaam region, Tanzania, delving into the intricate household characteristics that shape their energy usage habits. The contributions of this study are as follows:

- The middle-income household characteristics including number of occupants and their awareness on the energy management systems.
- The energy consumption patterns including types of electrical equipment, hourly usage, average energy bills, and fluctuations in monthly energy bills.
- The relationship between household characteristics and energy consumption patterns.

2. Materials and Methods

2.1. Study Area

In this study, the targeted area is Masaki area located in Kinondoni District, Dar es Salaam, Tanzania. The selection of this region is based on several factors such as the rapid increase in urbanization (8.7% growth rate and 5,383,728 population as of 2022 census [58] and 4.9% growth rate and 7,161,000 population in 2023), high average income per capita [59], and high electricity demand (total of about 5 TWh in the region and 1135.1 kWh per capita) [60], the fact that more than 80% of its residents are connected have access to electricity [61], and the presence of natural gas pipeline routes within the city as well as natural gas power plants and grid substation. The region is an important economic center, populous, and one of the fastest-growing cities in the globe. As of 2022, the vast majority of the electricity is produced comes from eight natural gas power plants, seven hydropower plants, two heavy fuel oil plants, and seven small gas oil power plants [62]. To date, natural gas is considered as the main source of power generation, contributing to about 48% of the energy mix in the national grid. Moreover, the region is the Tanzania's commercial hub

This study targets the Masaki area (see the rightest photo in Fig. (**1**)). It's roughly 10 kilometers north of the Dar es Salaam central business region. This focal area in the North and East is bordered by the Indian Ocean; in the South by the Kinondoni (Hananasif ward) and Ilala Municipal Council (Kivukoni ward); and in the west is bordered by Mikocheni and Kawe. Masaki is a vibrant and upscale area within the Kinondoni District. Masaki is situated along the coastline of the Indian Ocean, making it a prime spot for both residential and commercial activities. The area is known for its affluent residents, and features a mix of high-end apartments, luxurious villas, and modern housing. It is a popular choice for expatriates and professionals working in Dar es Salaam due to its high standard of living and proximity to the ocean. Its proximity to the ocean provides beautiful seaside views and recreational activities like beach outings. The area is home to various international businesses, banks, and upscale restaurants. It's also known for its vibrant social scene, with numerous cafes, bars, and entertainment venues that cater to both locals and foreigners. The community in Masaki is diverse and includes a mix of Tanzanians and expatriates from various countries. This multicultural environment contributes to the area's dynamic atmosphere. Moreover, the area boasts several amenities such as shopping centers, schools, and medical facilities. The area is well-connected to other parts of Dar es Salaam via major roads. Public transportation options, such as buses and taxis, are readily available, though many residents also use private vehicles. Overall, Masaki stands out as one of Dar es Salaam's most desirable neighborhoods, known for its blend of modernity, luxury, and coastal charm. Masaki's mix of housing options, economic opportunities, and evolving urban dynamics contribute to the presence of middle-income households alongside its more affluent residents.

This area is the best representative of Tanzania's middle-income households (MIHs), which are notable for their high energy consumption and associated costs. As of 2023, Masaki had an approximate population of 48,9201. The selection of this area is crucial for understanding the MIHs' characteristics and their associated energy usage patterns. Furthermore, Masaki, a vibrant neighborhood in Dar Es Salaam, Tanzania, offers a variety of features, including a coral beach and village museum, making it the most attractive area, with high-class hotels, apartments, world-top organization offices, and top leaders' residents.

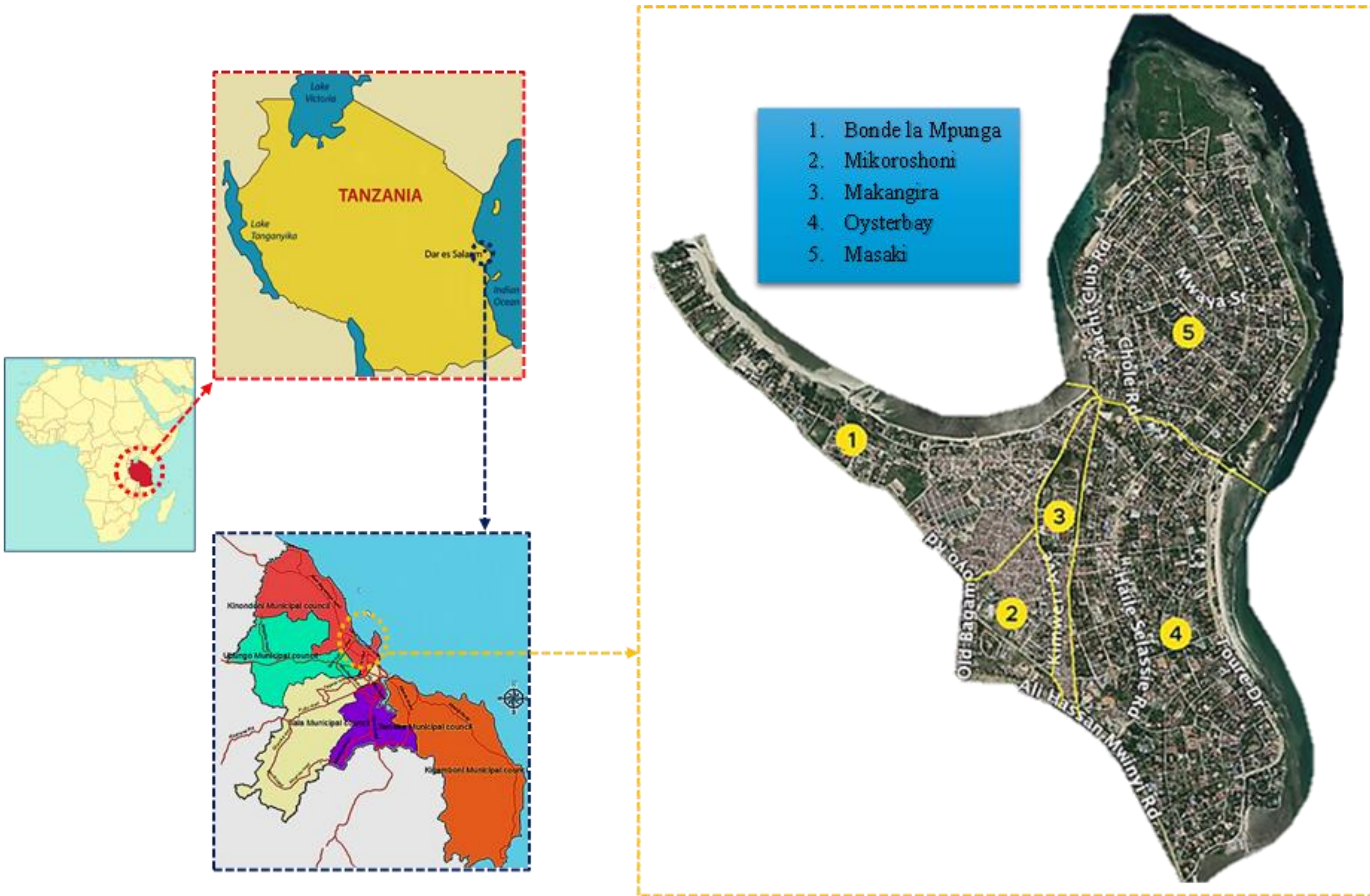


Figure 1: The target area of Masaki.

3. Methodology

3.1. Sample Data

The data sampled in this study were focused into two categories: household characteristics and energy consumption patterns (Table **1**). In household characteristics, the research design was that of an inductive exploratory study, allowing the researcher to seek new insights from multiple in-depth semi-structured questions. As portrayed in previous studies, psychological motivation is quantified at an individual level. In this sense, it is considered that acquiring data from a representative member of a household is adequate to characterize the distribution of traits in the household. Thus, a subjective framework was adopted to include the motivation, feelings, and contexts for each participant. This category intended to gain understanding on the average number of occupants in a household, as this number has influence on energy consumption. Moreover, the category intends to understand their levels of awareness on computerized systems for managing household appliances, as well as their adoption rate and expected features. In energy consumption patterns, the research was designed to understand the major electrical loads used in MHIs, their hourly energy consumption pattern, daily energy distribution, average monthly energy bills, and fluctuation in monthly energy bills.

Table 1: Categories and questions of sampled data.

Category	Questions
Household characteristics	Number of occupants in a household
	Awareness of computerized system technologies used for managing household appliances
	Adoption rate of computerized system features for managing household appliances
	Type of computerized systems implemented for managing household appliances
	Households who are interested to participate in a computerized system for managing household appliances
	Households' expectation on computerized system for managing household appliances
Energy consumption pattern	Major electrical loads in a household
	Hourly energy consumption pattern
	Daily energy distribution
	Average monthly energy bills
	Fluctuations in monthly energy bills

3.2. Data Collection Method

To conduct this research, the e-questionnaire survey was used to collect primary and secondary data from MHIs in the targeted area. The e-questionnaire was developed through an online form using Google software. The Google form is an open access and had needed no credentials for respondents to access. The e-questionnaire was distributed to respondents as a link for respondents to access. Because the respondents were either household leaders or purchasing decision-makers, we hypothesized the respondent had a significant impact on the behaviors of others in the family, particularly children.

3.3. Data Gathering

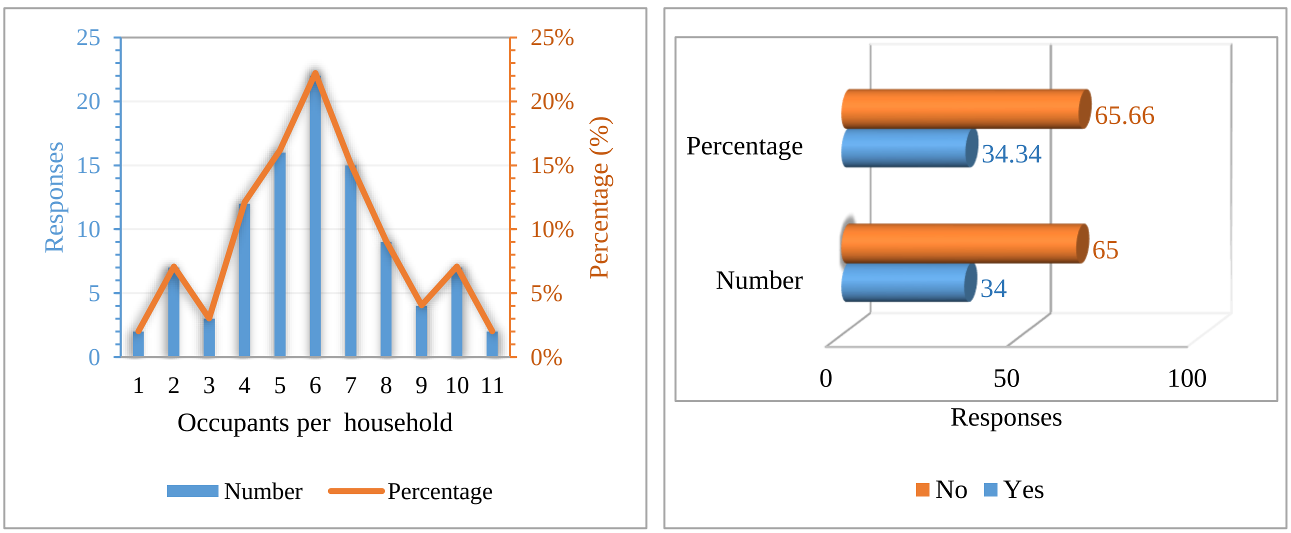
Prior the inception of this study, the questions were first piloted with academic staff in the Section of Energy, Department of Electrical Engineering at the Dar es Salaam Institute of Technology. The questionnaires were drawn up from the literature reviewed and validated using three experts from the Section of Energy and two statisticians from the Dar es Salaam Institute of Technology. Experts were involved in checking the relevancy, language, length, and if the questions addressed the notion of interest. The questionnaire was created using Google Forms and disseminated online to residents in the target area. Residents were assumed to have access to the internet. Part I of the questionnaire requested the participants to provide information regarding their psychological behavior on energy management. In part 2, participants were asked to respond on their electrical equipment ratings, most hourly use, and their expectations when engaging in energy management program. The data were collected over one month from 30 May 2024 to 30 June 2024. The majority of questions were accurately responded and were all received via online platform, indicating that they were decision-makers in the respective households with internet access. Results revealed that the majority of the participants were either practicing or interested in engaging themselves in energy management initiatives. This demonstrates that participants were sufficiently knowledgeable to participate in this investigation.

4. Results and Discussions

4.1. Occupants Per Household and Awareness of Energy Management Programs

Fig. (**2a**) shows the number of occupants reported in households. In Fig. (**2a**), the *x*-axis indicates the number of occupants per household while left and right *y*-axis represent the number of responses and their respective percentages. In this sub-category, a total of 99 responses were received. As indicated in Fig. (**2a**), the highest number of occupants per household reached eleven but was only reported by 2%. On the other side, responses with the highest percentage were found to have six occupants, followed by five, seven, and four occupants. Households with one, two and three occupants are less common, having less than 8% or less than ten responses. This data highlights the prevalence of larger households in the surveyed area, indicating a trend towards more occupants per household. Based on the responses shown in Fig. (**2a**), the average number of occupants per household can be stated to be 6.

Fig. (**2b**) shows the proportion of occupants per household who are aware of energy management programs used for managing household appliances. In this sub-category, 99 responses were received. It can be seen that 65 occupants were not aware of these programs, while 34 occupants were aware. In percentage wise, 65.66% of the occupants were not aware of these programs while 34.34% were aware. It can be seen that there is a significant proportion of occupants lack who awareness, indicating gaps in information dissemination or accessibility issues. When relating the average number of occupants per household and the level of awareness, it is clear that only two out of six occupants per household are aware of energy management programs. This can be a barrier to adoption since people may not comprehend the benefits or how to apply these solutions. Addressing the knowledge gap via focused education and outreach can lead to increased adoption and improved home energy efficiency.

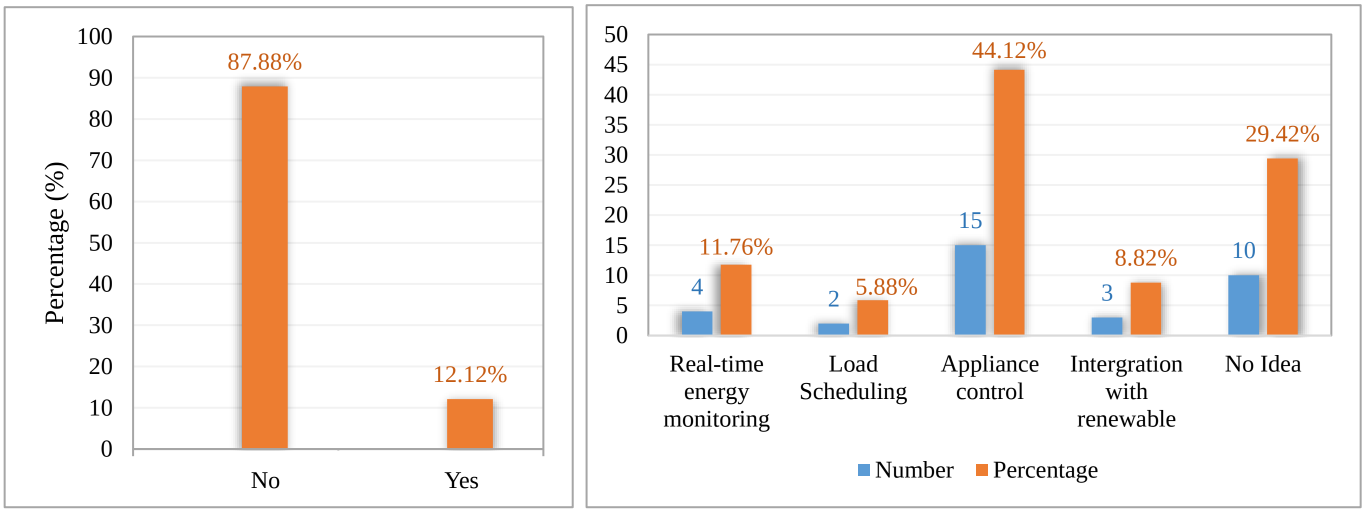


(**a**) (**b**)

Figure 2: The number of occupants per household and awareness of energy management programs.

4.2. Adoption Rate and Types of Energy Management Programs Adopted

Fig. (**3a**) shows the adoption rate of energy management programs. As shown in Fig. (**3a**), 87.88% of participants who were aware of the energy management programs were not implemented in their households. In contrast, only 12.12% indicated that they have adopted such programs. This data reveals that energy management programs are not widely adopted among the assessed population. This knowledge is critical for identifying the challenges to the adoption of sophisticated energy management technologies, as well as developing methods to raise awareness and utilization of these programs. Fig. (**3b**) shows the types of energy management programs implemented by occupants. These programs were classified into four groups namely real-time energy monitoring, load scheduling, appliance control and integration with renewable. It was found that the most commonly used program is appliance control (smart plugs/switches), which was adopted by 44.12%. This was followed by the real-time energy monitoring program, which was adopted by 11.76%, and integration with renewable energy sources, which was adopted by 8.82%. The remained program of load scheduling was seen to be adopted by 5.88%. According to the findings, occupants preferred appliance control systems over other sophisticated programs. This insight is useful for analyzing existing trends and potential areas for boosting the adoption of computerized energy management programs in households.



(**a**) (**b**)

Figure 3: The responses in (**a**) adoption rate and (**b**) types of energy management programs adopted.

4.3. Occupants' Interests, Preference, and Expectations on Energy Management Programs

Fig. (**4**) depicts the proportion of respondents who expressed an interest in participating in energy management programs for household appliances. This sub-category received 99 responses. As illustrated in Fig. (**4a**), 95 responders, equivalent to 96% showed an interest in participating in energy management programs. An overwhelming interest came after quick motivations provided through the Google form. For an average of 6 occupants per household, it is clear that 5 out of 6 occupants became interested with the programs. This outcome indicates a high degree of curiosity and readiness to deploy energy management programs. This information is useful for planning and promoting future projects employing computerized programs.

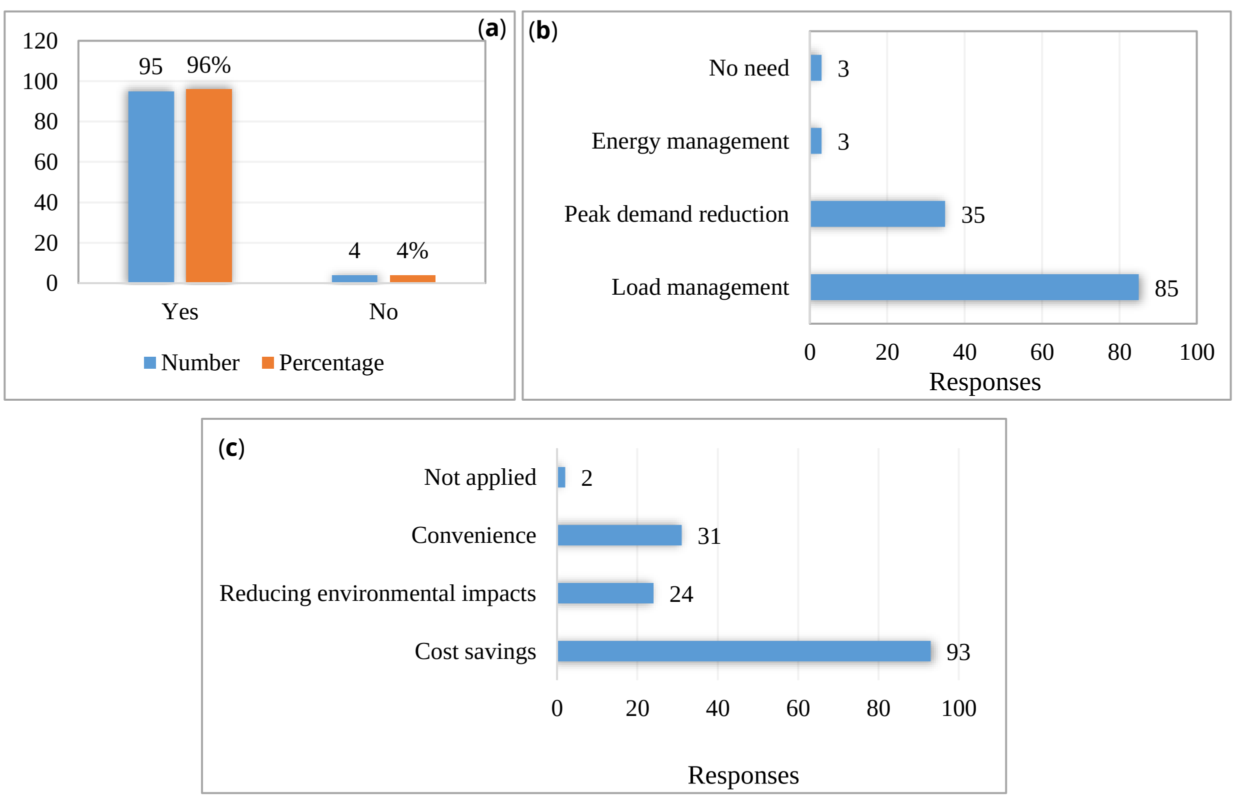


Figure 4: The responses in (**a**) occupants' interests, (**b**) preference and (**c**) expectations on energy management programs.

Regarding the preferences on the energy management programs, three features such as energy management, peak load reduction, and load management were set for respondents to choose. In this sub-category, respondents were able to choose more than one feature. Consequently, more than 99 responses were gathered. Fig. (**4b**) depicts the findings on preferences for several features of the energy management program. As can be observed, 85 responses (87.6%) chose load management, whereas 35 responses (36.1%) preferred peak demand reduction. In contrast, just 1% expressed interest in an energy management system, with the remaining 1% indicating no need for any feature. These results highlight a substantial interest in load management and peak demand reduction, reflecting the goals of the studied population to manage their energy usage more effectively.

Responders were given three options for expected benefits from energy management initiatives, including financial savings, reduced environmental consequences, and convenience. This sub-category also allowed the respondents to choose more than one option. As indicated in Fig. (**4c**), the majority of respondents (93 responses or 62%) preferred cost-saving outcomes, whereas 31 respondents or 20.7% preferred convenience. These findings highlight a substantial interest in cost reductions, reflecting the studied population's aspirations for better controlling their energy use.

4.4. Electrical Loads and Hourly Energy Consumption Patterns

Fig. (**5**) shows the major electrical loads used by the respondents. The *x*-axis of Fig. (**5**) indicates hourly usage whereas the *y*-axis shows the number of responses. As seen in Fig. (**5a-g**), the major electrical loads observed include air conditioner, electric cooker, refrigerator, light, washing machine, water heater, and water pump. The power rating of each electrical load is indicated underneath. For the case of air conditioner, the ratings in British thermal units (BTU) were 7000, 12,000, 24,000, and 36,000 BTU. The most popular sizes of air conditioners were discovered to be 7000, 12,000, and 24,000 BTU, and they were generally utilized between 20:00 pm and 06:00 am. The most typical sizes for electric cookers were 1500 to 5000 W, and they were utilized from 6:00 to 08:00; 12:00 to 14:00; and 17:00 to 20:00. The refrigerator sizes ranged from 150 W to 250 W and were discovered to work throughout the day. The sizes of the lights ranged from 15W to 50W and were operational throughout the night. Washing machines with power ratings ranging from 1000 W to 1400 W garnered a lot of attention, and they were exclusively used during the day. Common water heater ratings ranged from 2500 to 3000 W, whereas water pumps ranged from 500 to 1500 W.

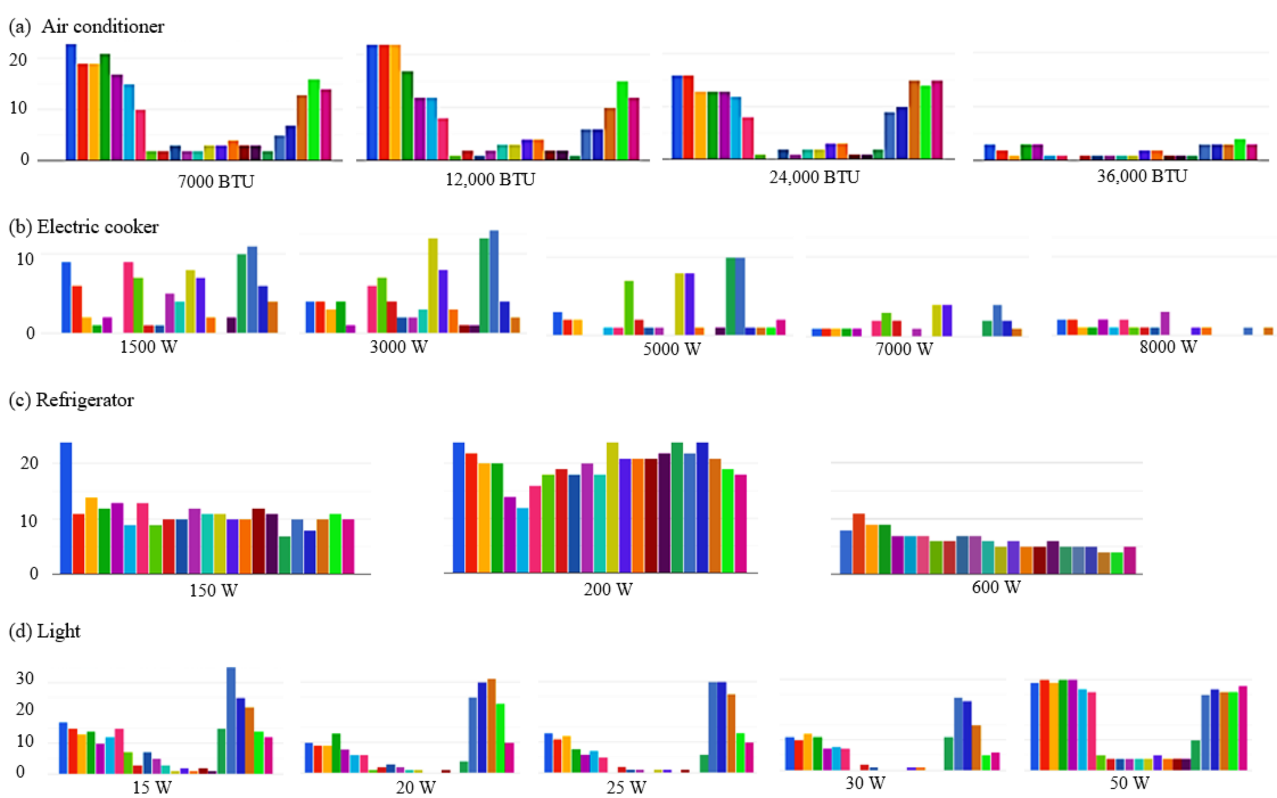


Fig. 5 (Contd……)

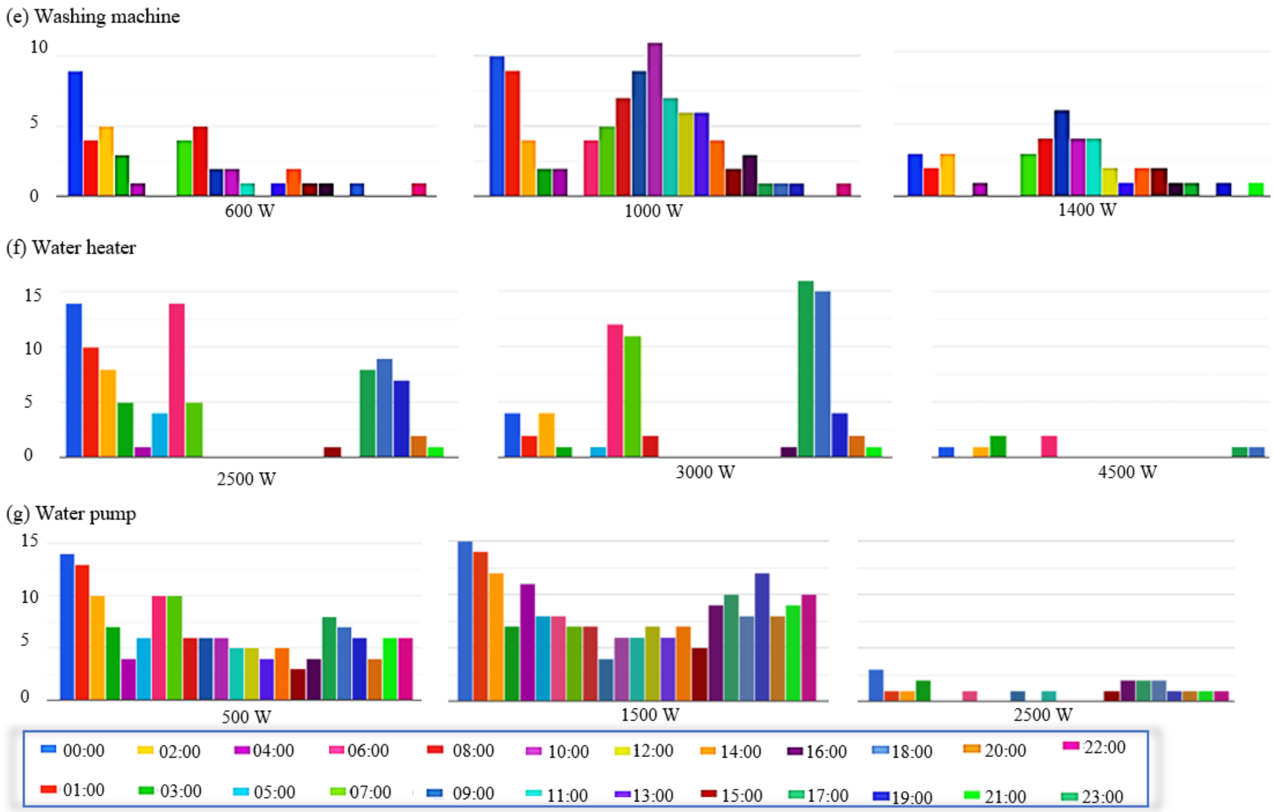


Figure 5: Electrical loads (**a**) air conditioner (**b**) electric cooker (**c**) refrigerator (**d**) light (**e**) washing machine (**f**) water heater (**g**) water pump.

Overall, space and food cooling were noted to require a lengthy time to operate each day. For example, air conditioners were found to function throughout the night, whereas refrigerators worked during the day. In the case of heating, for example, a water heater and an electric cooker function sporadically throughout the day, consuming less energy. Lights and washing machines have modest power ratings and short operation times, resulting in lower energy use per day.

4.5. Energy Usage Distribution, Average Monthly Energy Bills, and Bill Fluctuations

Fig. (**6a**) shows the daily energy usage distribution. This category assessed the peak energy usage in the following patterns; morning, afternoon, evening, and night. In this category, responders were asked to allocate their peak times in energy usage. As depicted in Fig. (**6a**), majority of respondents (68.7%) reported using the most energy in the evening, followed by 50.5% who indicated that their highest energy usage occurs at night. Morning hours also depicted significant energy usage, with 44.4% of respondents indicating this period. The afternoon sees lower energy usage, with only 20.2% reporting it as their peak time.

In terms of monthly energy bills, Fig. (**6b**) illustrates the distribution of responses regarding monthly energy bills in Tanzanian Shillings (TZS). As observed in other studies, there were some difficulties on acquiring the monthly energy bills. In this sub-category, the responses were somewhat less than in the other sub-categories. From Fig. (**6b**), the monthly energy bills were found to range between 70,000 to 300,000 TZS. This distribution suggests that most respondents had greater monthly energy expenses. More initiatives might help to lower total energy expenditures and increase residential energy efficiency. On the other hand, the majority of respondents (48.5%) reported large swings in their energy expenses, whilst 29.3% observed no significant changes. This data reveals that over half of those polled have seen notable variations in their energy bills, which might be due to changing energy usage patterns or external factors influencing energy pricing.

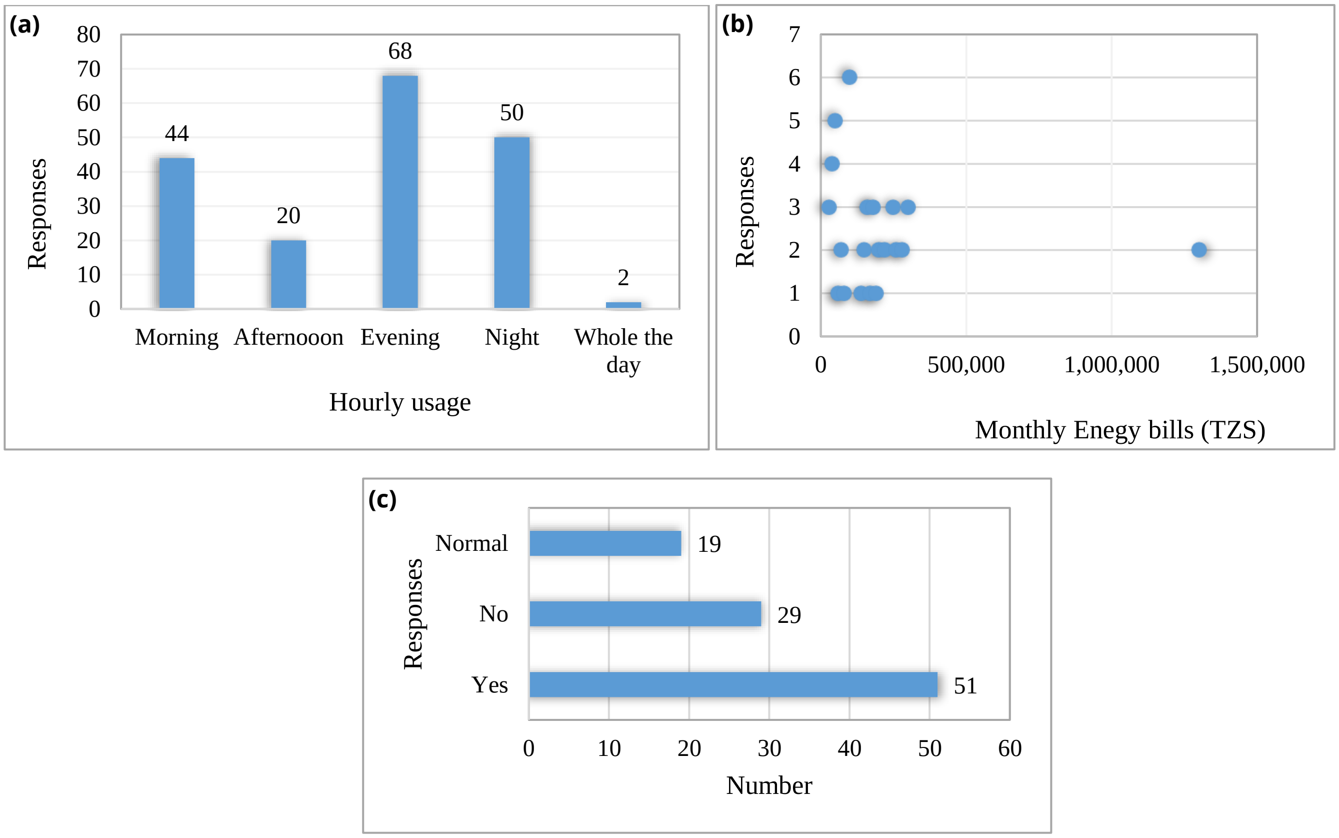


Figure 6: Electrical energy usage (**a**) energy hourly usage (**b**) average monthly energy bills and (**c**) fluctuation in energy bills.

5. Conclusion and Policy Implication

In this study, the electricity consumption of the middle-income households (MIHs) in the targeted area of Masaki, Dar es Salaam region, Tanzania is assessed. The study was designed to incorporate the household characteristics and implications of electrical loads in the electrical consumption of MIHs. The following conclusion can be drawn from this study:

- The electricity consumption of MIHs was successfully conducted.
- The average number of occupants per household was found to be 6, but 65.65% of the occupants were found to be unaware of the energy management programs. This indicates that only two out of six occupants per household are aware of energy management programs.
- For those who were aware of the energy management programs, 87.88% did not implement them in their households. Contrary, 12.12% of the respondents indicated adopting such programs including appliance control (44.12%) followed by real-time energy monitoring (11.76%) and integration with renewable energy sources (8.82%).
- 96% of respondents showed an interest in participating in energy management programs, particularly in load management (87.6%) and peak demand reduction (36.1%) aiming at cost-saving (62%) and convenience (20.7%).
- The major electrical loads observed include an air conditioner, electric cooker, refrigerator, light, washing machine, water heater, and water pump. Evening hours were reported to use the most energy (68.7%), followed by night hours (50.5%).
- For majority of respondents, the average monthly energy bills ranged between TZS 70,000 and TZS 300,000 with 48.5% of respondents reported large swings in their energy expenses.

Future studies are recommended to integrate data from apartments, hotels, restaurants, supermarkets, shopping malls, world-based organizational offices, and top leader residents. Furthermore, studies are recommended to widen the scope to cover all energy consumers.

As a policy implication, given the low percentage of respondents who are aware of energy management programs, it is apparent that policymakers should include awareness programs when developing energy consumption and energy efficiency policies. Because monthly expenses fluctuate significantly, regulators should deploy energy-saving techniques such as smart devices and smart applications for monitoring and controlling them. However, due to the lack of energy efficiency standards, it is important to highlight the substantial opportunity for energy savings in the residential sector. The Tanzanian government must enact several policies to encourage residential energy efficiency in addition to working with academics to carry out in-depth research in the areas of precise building energy consumption prediction and knowledge of residential characteristics impacting energy use for efficient energy management, conservation, and policy development. To accelerate the shift to energy-efficient buildings, energy consumption might be simply assessed using simulation models. On the other hand, public interest groups, utilities, and state officials might conduct market surveys in the building sector to get an understanding of their respective energy performance and agree on efficiency criteria.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' Contribution

Regina Mvungi and Pius Victor: Conceptualization, methodology, data collection, data curation, investigation, writing –original draft.

Pius Victor and Respicius Kiiza: Writing –review.

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