SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Assessing Public Awareness of Smart Home Technologies for Enhancing Energy Efficiency in Sustainable Urban Development

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ABSTRACT

The escalating environmental issues, particularly climate change, have driven global governments to set guidelines for sustainable development. Urbanization, a significant factor in increasing greenhouse gas emissions, underscores the need for sustainable practices. The United Nations' Sustainable Development Goals (SDGs), adopted by 193 Member States including Malaysia, provide a framework for achieving the Malaysia Vision 2030 sustainability agenda. To realize these goals, balancing economic, social and environmental aspects is essential for developing new cities. At the residential level, addressing environmental challenges is critical. Smart Home Technologies (SHTs) have emerged as a strategic approach to reducing energy consumption, a key factor in mitigating greenhouse gas emissions. SHTs involve intelligent devices that automate and control household functions such as lighting, temperature and security, offering substantial potential for energy optimization in new urban developments. This study evaluates the potential of SHTs for energy optimization in Iskandar Puteri, Johor, Malaysia, from the perspectives of end-users and construction stakeholders. It aims to assess awareness of SHTs, explore their energy-saving potential and identify adoption challenges. Data was collected through a questionnaire distributed to 214 respondents, with subsequent statistical analysis, including reliability, normality tests and the Relative Importance Index (RII). Findings indicate high sustainability awareness regarding SHTs among both end-users and construction stakeholders. Smart lighting control emerged as the top energy-saving feature for end-users, while smart air-conditioners were prioritized by construction stakeholders. Privacy and security concerns were identified as major challenges for end-users, whereas high costs were the primary barrier for construction stakeholders. These insights provide valuable guidance for policy and decision-making aimed at promoting sustainable development.

Keywords:

Smart technologies; energy savings; smart home; IOT

1. Introduction

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https://doi.org/10.37934/araset.XX.X.182198

The greenhouse effect, driven by greenhouse gases (GHGs), is a primary factor behind global warming and climate change, with urbanization significantly contributing to GHG emissions. Cities account for over 70% of global GHG emissions, which are major drivers of anthropogenic global warming and climate change. Extensive research has explored the link between energy demand and urbanization, with studies such as those by Wang *et al.,* [1] elucidating the impact of urbanization on carbon emissions and energy consumption. Additionally, research has assessed the effects of population growth in urban areas on carbon emissions in BRICS and ASEAN countries, including Malaysia.

The development of smart home technologies (SHTs), including various appliances, devices and sensors, aims to reduce energy consumption and support sustainability goals [2]. However, effective adoption of SHTs requires end-users and construction stakeholders in new Malaysian cities to understand their functionalities and applications. Evidence indicates that implementation rates for SHTs among individual users in developing Asian countries, including Malaysia, remain low [3,4]. According to the Department of Statistics Malaysia [5], only 5.1% of Malaysian homes are equipped with smart home technology, compared to 32.2% in the US.

Further research is needed to explore the potential of SHTs in reducing energy consumption and to identify the barriers and challenges to their adoption. Understanding these factors is essential for the practical application of SHTs and achieving significant reductions in energy use. This research focuses on the significance of adopting sustainable heating technologies (SHTs) in new city development, specifically in Iskandar Puteri, Johor. The study aims to evaluate the potential of SHTs for energy optimization from the perspectives of both end-users and construction stakeholders. Key objectives include investigating the potential for SHTs to reduce energy consumption and exploring the challenges and barriers to their adoption.

1.1 Internet of Things (IoT)

The concept of Internet of Things (IoT) is crucial to understanding smart city, smart home and SHTs. IoT is defined as *"objects that consist of virtual identification and personalities in smart spaces or areas by implementing intelligent interfaces to communicate, connect and exchange data within environmental, social, medical and user's context"* [6]. In IoT concept, computing devices are typically embedded systems equipped with sensors and actuators, interconnected via the internet to perform specialized functions according to their programmed tasks. IoT is an essential technology to address future challenges, working in conjunction with disruptive technologies, big data, agile processing, hybrid servers, pervasive computing and seamless access and transactions [7]. This technology enables internetworking of devices such as buildings, vehicles and home appliances to connect to the internet and form a dynamic environment for data transfer. The development of various communication technologies such as 4G-LTE and 5G network, Bluetooth, ZigBee and Wi-Fi has facilitated the connection of different devices to networks, thus transforming them into smart devices [8]. These networks have the capability to fetch online services and applications and provide network playback to control electronic appliances and devices, enabling them to function efficiently [9]. In this context, IoT has the potential to connect devices and people in the same building, home or local area network. For the purpose of this paper, the focus is on smart home design and SHTs within the broad spectrum of IoT.

1.2 Smart Home Technologies (SHTs)

The smart city concept has become a 21st-century utopia that many cities are striving towards, with significant investments and partnerships with companies such as Siemens orange, Cisco and IBM to improve energy management, safety, security, environment, health, transportation and education [10,12]. The smart city vision relies on billions of IoT devices operating within a common space to enhance living standards. Khatoun *et al.,* [12] identified six components of smart cities, including living, governance, environment, mobility, economy and people, with the smart home concept falling under the smart living dimension. A smart home is a conceptual application that utilizes new information technologies to automate domestic activities and enhance home management, thereby enhancing living quality and space in future homes [13]. Smart homes include apartments, standalone houses or units within social housing developments, with five fundamental characteristics such as automation, multifunctionality, adaptability, interactivity and efficiency [14].

Smart Home Technologies (SHTs) are aimed at enhancing human well-being and have become the basis for the innovative concept of the "smart home" [15,16]. SHTs are the technological space within a smart home that collect and retrieve information from the environment and react accordingly, providing a range of services such as energy management, comfort, security, access control and entertainment [17]. The design for a smart home typically includes a central communication device that connects the IoT gateways and smart devices to enable end-to-end data communication and remote monitoring [18]. SHTs, equipped with sensors, controls and microprocessors, communicate with the network to exchange data and enable remote monitoring [19].

1.3 Sustainability Awareness towards SHTs in Malaysia

There is a lack of research on the adoption of SHTs in Malaysia, indicating a lack of awareness and efforts toward their adoption [20]. A study conducted in Hulu Langat, Malaysia found that limited knowledge about SHTs led to a lack of awareness of their existence and function [21]. Similarly, Goh *et al.,* [22] noted low awareness among Malaysian residents regarding sustainability and the benefits of SHTs, likely due to the country's abundance of natural resources such as oil and water, as well as limited knowledge about their implementation in the housing industry in the southern region. However, research on the adoption of SHTs in Malaysia is limited, with several studies indicating a lack of awareness and knowledge of these technologies [20]. In contrast, recent studies have shown a growing interest and awareness of SHTs among Malaysian residents. For instance, Ahmed *et al.,* [23] found that over 89% of respondents in Kajang and Putrajaya were aware of residential energy consumption and willing to adopt SHTs to reduce energy consumption and electricity costs. Suratman *et al.,* [24] also reported that respondents in Setia Alam had good knowledge about energy saving and had implemented sustainable technology. Similarly, Yeon *et al.,* [25] found that most respondents believed SHTs such as alarm systems, sensors and closed-circuit televisions were essential in smart homes. About 61% of young people in Johor had knowledge and awareness of smart home design and technologies and believed that SHTs could bring benefits such as energy, time and cost savings and improve quality of life [26]. However, as previous research and surveys indicate, the region or state of the research conducted may affect the results, therefore it is important to investigate the sustainability awareness of end-users in Iskandar Puteri and construction stakeholders in Malaysia towards smart home design and technologies.

1.4 Potential of SHTs in Reducing Energy Consumption

Due to the global environmental issues, the adoption of the SHTs to achieve energy saving is a global trend. Accordingly, smart homes and smart technologies have acted as the priority area in many of the strategic energy planning and national policy in each of the countries to have sustainable development. This research focuses on each smart appliances (SHTs) which make up the smart home. There are few studies about the SHTs and the energy efficiency. In the study by Marszal *et al.,* [27], it was concluded that the significance of the SHTs in achieving “zero energy building” and “net energy building”. Another study by Koomey *et al.,* [28] highlighted the importance of adopting “intelligent systems” and “home automation” to reduce energy consumption. In the same year, Hu *et al.,* [29] concluded that the Smart Home Energy Management (SHEMS) can reduce electricity bills and its demand. The policy and industry agree that the SHTs include the explicit and assumption that SHTs can increase environmental sustainability by domestic energy efficiency [30].

A study conducted by the Housing and Development Board (HDB) and Energy Market Authority (EMA) in Singapore [31], showed that the implementation of SHTs resulted in a reduction of energy consumption by 20%. This system allows homeowners to track their energy consumption and control their appliances through a management system. The New York State Energy Research and Development Authority (NYSERDA) completed a survey in 2017 on 50 homes in New York and found that SHTs have the potential to save 5-22% of energy costs and 10-13% of electricity [32]. However, a study by IEA (2017) notes that SHTs could result in energy rebound effects and increase average energy consumption [33]. Short-term trials of SHTs in 10 households in the UK by Hargreaves *et al.,* [34] found little evidence to prove that SHTs increase energy efficiency and may actually intensify energy use by pre-warming spaces before occupancy. The Internet of Things (IoT) is likely to increase energy consumption to provide a certain level of service for devices [35].

1.5 Challenges and Barriers in the Adoption of SHTs

Smart Home Technologies (SHTs) have the potential to reduce energy consumption and promote sustainable living. However, several issues related to the concept, management and technical aspects of SHTs could act as barriers to their successful adoption. SHTs face various conceptual, management and technical issues that may hinder their integration into smart homes [36]. The authors argue that the transformation and implementation of smart homes and technologies is a complex process and the adoption of SHTs faces several challenges. Edwards *et al.,* [37] research highlights the barriers to adopting SHTs and smart concepts in homes, including interoperability, administration, reliability, security and system intelligence and behaviour inference. These barriers include issues such as the ability of devices from different manufacturers to operate together, the availability of expertise to maintain and operate the system, the possibility of malfunction or failure, the risk of exposure of personal data and the system not fitting the occupants' current requirements. Balta-Ozkan *et al.,* [38] categorized the challenges of adopting SHTs into five groups: fitting with user lifestyle, administration, interoperability, privacy and security and reliability. Greenough [39] identified additional barriers such as high cost, limited demand, long replacement cycles and device fragmentation within the smart home ecosystem, which can lead to interoperability issues and consumer confusion.

Various researchers have identified various barriers and challenges to the adoption of SHTs [36,40-42]. These include technical challenges such as interoperability, complexity, security and privacy; economic challenges such as high cost, long replacement cycles and limited customer demand; policy challenges such as lack of government support and tax incentives; and social challenges such as not fitting with users’ current lifestyles. The study by Sovacool *et al.,* [36] also highlighted the energy rebound effect as a rarely mentioned barrier. Overall, these studies emphasize the importance of addressing these challenges in promoting the widespread adoption of SHTs in smart homes.

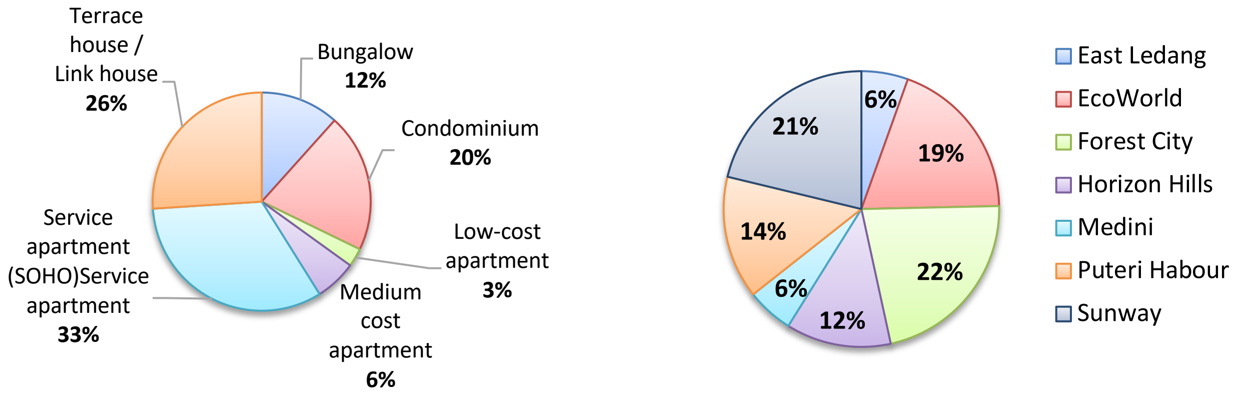
2. Methodology

This research employs a quantitative research method to investigate the research aims and objectives. The study relies on primary data to achieve the research objectives and address research questions. To gather primary data, questionnaires were distributed using Microsoft Forms. End-users received the Microsoft Forms through QR code scanning and link sharing between communities, while construction stakeholders received them via company email. The study is geographically focused on Iskandar Puteri, Johor Bahru, Malaysia, which is the second-largest state in Peninsular Malaysia with a land area of 19,166 km^2 [5]. Iskandar Puteri, formerly known as Nusajaya, is one of the five flagship zones in Iskandar Malaysia, launched in 2007 as a rapidly emerging economic zone. Currently, Iskandar Puteri is the third largest urban development in Malaysia and is aligned with the 10th Malaysia Plan for continued growth and development. Iskandar Puteri has been designated as a smart city in Malaysia and numerous projects such as Forest City, Ecoworld and Medini are underway to achieve this goal. The research team aimed to collect responses from 400 end-users and 325 construction stakeholders in Iskandar Puteri. The sample size for the construction stakeholders was determined based on previous studies that focused on similar perspectives in Malaysia, which suggested a range of 250-480 participants. The Relative Importance Index (RII) was used in this study to rank variables related to the respondents' perceptions of significance, agreement and other key factors. The RII method is useful when the normal distribution of results cannot be confirmed [43]. A higher RII value indicates a greater level of significance for a given variable.

3. Results

3.1 Demographic Information of End Users

According to the results of the survey, 57% of the end-users' respondents were owners, while 43% were tenants. Among the respondents who were end-users (as in Figure 1), the majority lived in "Service Apartment (SOHO) Service Apartment," comprising 33% of the sample. "Terrace House/Link House" was the second most popular dwelling type, with 26% of the respondents living in such housing, followed by "Condominium" at 20%, "Bungalow" at 12%, "Medium Cost Apartment" at 6% and "Low-Cost Apartment" at 3%. Moreover, most of the respondents had "more than three bedrooms" in their residences, constituting 36% of the sample. The percentages of respondents who lived in residences with "three bedrooms," "two bedrooms," and "single room" were 27%, 26% and 11%, respectively. The distribution of respondents is as follows: 6% of respondents are from the "East Ledang" area, 21% are from "Sunway Iskandar", 12% are from "Horizon Hill", 6% are from "Medini", 22% are from "Forest City" and 14% are from "Puteri Harbour".

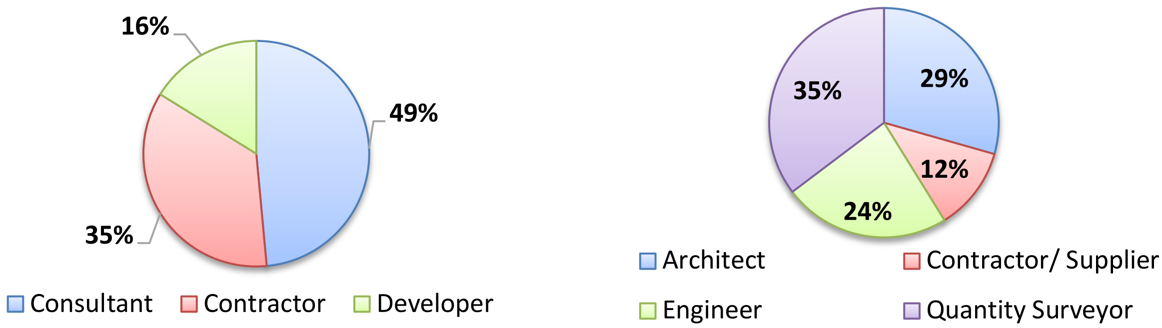


(a) (b)

Fig. 1. (a) Types of accommodation (b) The location of residents

3.2 Demographic Information of Construction Stakeholders

The construction stakeholders in this research were surveyed regarding their professional roles in the construction industry. Most respondents identified themselves as “Quantity Surveyors”, constituting 35% of the sample. Following closely behind were “Architects”, representing 29% and “Engineers”, comprising 24% of the sample. The role of “Contractor/ Supplier” was the least represented, accounting for only 12% of the sample. In terms of the type of company they work for, nearly half of the respondents work for “Consultant Companies” (49%), while 35% work for “Contractor Companies” and only 16% work for “Developer Companies”.



(a) (b)

Fig. 2. (a) Type of company (b) Professional roles

3.3 The Level of Sustainability Awareness to SHTs

To assess the level of sustainability awareness among end-users regarding sustainable housing technologies (SHTs), respondents were asked to rate the significance level of each sustainability aspect, their level of awareness towards the function of SHTs and the level of agreement towards the sustainability benefit of SHTs. According to the survey results in Figure 3, over 70% of end-users consider various sustainability aspects as “significant” or "most significant.

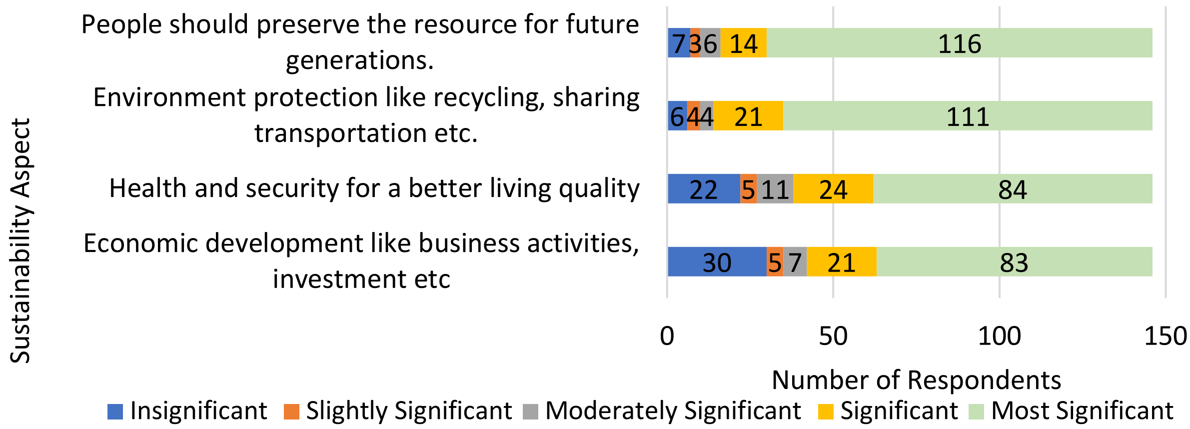


Fig. 3. The level of significance towards each sustainability aspects

Additionally in Figure 4, only 9% of respondents are "not aware at all" or "slightly aware" of the characteristics of Smart Home Technologies (SHTs). Most respondents recognize the sustainability benefits of SHTs, with energy saving and convenience ranking as the top two benefits from the end-users' perspective. Among the sustainability benefits, 87% of the respondents strongly agreed that energy saving is a significant sustainability benefit of SHTs, followed by convenience at 79%.

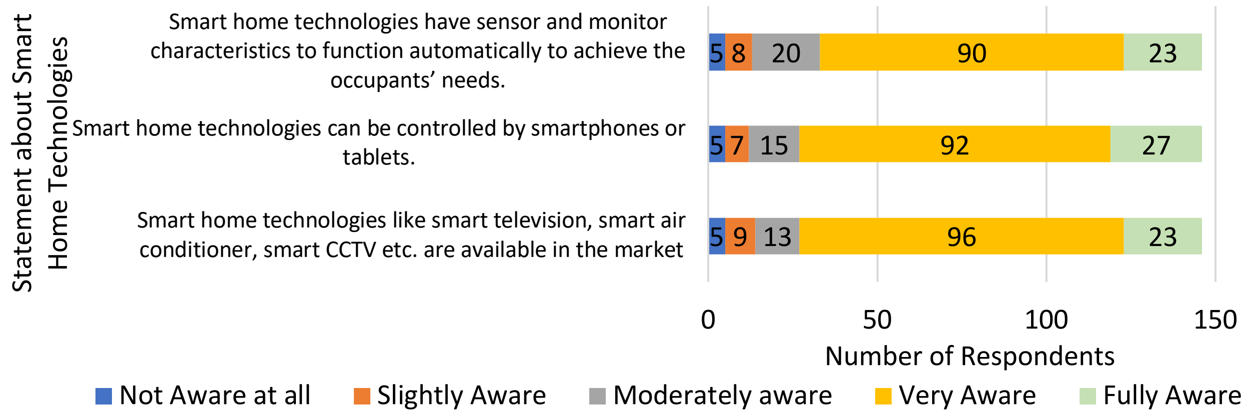


Fig. 4. The level of awareness of the end-user to SHTs

The survey results differ from the study conducted by Goh *et al.,* [22], which found that the level of sustainability concept and knowledge towards SHTs among societies in the southern region of Malaysia was low. However, the survey results are consistent with the findings of Rasyidah *et al.,* [26], who conducted their research in Johor, Malaysia and found that most respondents were aware of SHTs and believed that they could bring benefits such as energy saving. The survey results are also consistent with the studies conducted by Ahmed *et al.,* [23] and Suratman *et al.,* [24] in Putrajaya, one of the smart city developments in Malaysia and Setia Alam, which found that end-users were aware of SHTs and their energy saving benefits. Furthermore, the high ranking of energy saving and convenience among the sustainability benefits of SHTs from end-users' perspectives is also supported by the surveys conducted by Hargreaves *et al.,* [44] and Wilson *et al.,* [45].

The survey also included a question regarding the preferences of construction stakeholders and end-users when planning to build a smart home. The results show that, according to construction stakeholders' experiences, customers prioritize money saving (84%), followed by convenience (62%), energy saving (35%), comfort (32%) and entertainment (19%). On the other hand, construction stakeholders stated that they would first recommend convenience (72%), followed by energy saving (63%), money saving (49%), comfort (44%) and entertainment (28%). Notably, one of the respondents answered "Never" to both questions. These findings are presented in Figure 5.

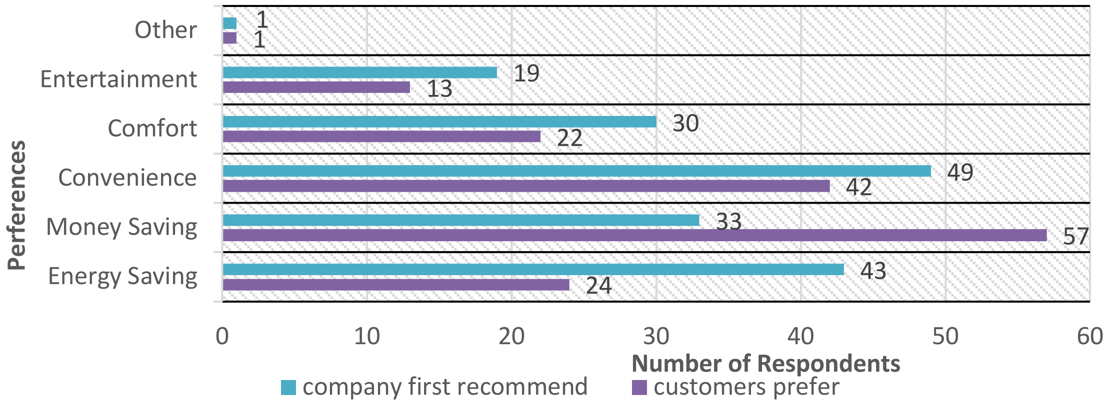


Fig. 5. The comparison preference between end-users and construction stakeholders from perspective of construction stakeholders

The adoption of SHTs as a means of reducing energy consumption is influenced not only by end-users but also by construction stakeholders. Figure 6 reveals that more than 55% of construction stakeholders perceive the level of SHT adoption to be "relatively high" or "high" in Iskandar Puteri. Among the construction stakeholders surveyed, only 27% are "rarely" or "never" involved in smart home projects and only 37% report that their companies "rarely" or "never" provide training on smart home design. From their experiences, most end-users prioritize cost savings and convenience, with energy saving as their third priority. In contrast, construction stakeholders primarily emphasize convenience and energy saving when recommending smart home technologies (SHTs) to clients.

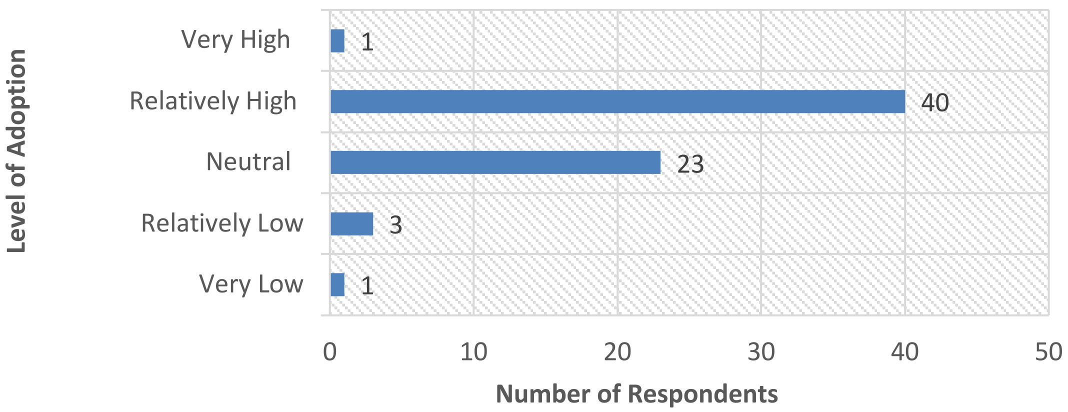


Fig. 6. The level of adoption of SHTs in Iskandar Puteri from construction stakeholders' perspectives

There is a lack of research on the adoption of Smart Home Technologies (SHTs) in Malaysia, indicating a lack of awareness and efforts towards their adoption, as noted by Salimon *et al.,* [20]. However, the current study's findings reveal that most construction stakeholders in Iskandar Puteri perceive the adoption level of Smart Home Technologies (SHTs) as relatively high. Additionally, a majority of respondents have participated in smart home projects and received training in smart home design, reflecting a substantial awareness of SHTs among construction professionals in the area. Nevertheless, the construction stakeholders rated money saving as the top priority for end-users when building a smart home, followed by convenience and then energy saving. This finding differs from the end-users' responses, which identified energy saving and convenience as the top sustainability benefits of SHTs.

The prioritization of economic benefits for end-users by construction stakeholders aligns with the findings of Balta-Ozkan *et al.,* [46], which indicate that economic considerations tend to exert a stronger influence than environmental concerns among urban end-users. Nonetheless, construction stakeholders' prioritization of convenience, followed by energy savings, aligns with the end-users' top sustainability benefits, though the order differs. Based on Figure 7 and Figure 8, out of the 68 construction stakeholders who participated in the study, it was found that 40% rated their involvement in smart home projects as "often", followed by 31% who rated it as "sometimes", 15% as "rarely", 12% as "never" and only 3% rated it as "always". Similarly, with regards to the training provided by their respective companies on smart home design, 35% of the construction stakeholders rated it as "often", 25% rated it as "sometimes", 21% rated it as "rarely" and 16% rated it as "never".

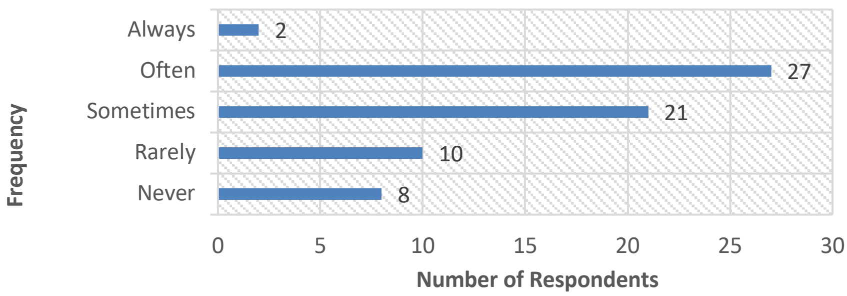


Fig. 7. The involvement frequency of the construction stakeholders in smart home projects

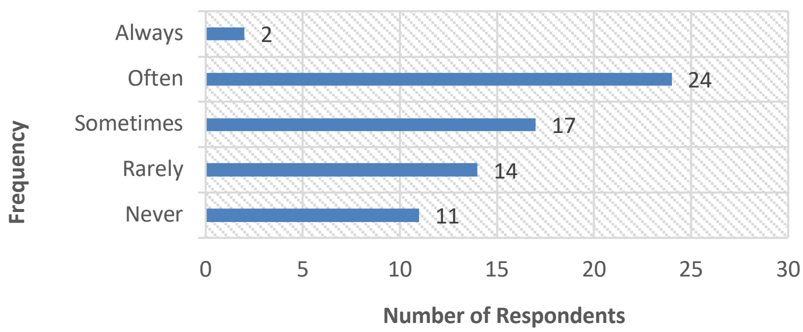


Fig. 8. The frequency of training among construction stakeholders in smart home design

3.4 Potential of the SHTs in Reducing Energy

The research findings indicate that most end-users are cognizant of the severe and major impact of commercial and residential electricity and heat production on the environment. In addition, the study shows that the majority of construction stakeholders concur that SHTs have the potential to reduce energy consumption, which is in line with findings of the literatures [27,28,31,32,47]. The study further assessed the perceived potential of 10 smart appliances (Figure 9) in reducing energy consumption among both end-users and construction stakeholders. The results indicate differences in the rankings of the smart appliances.

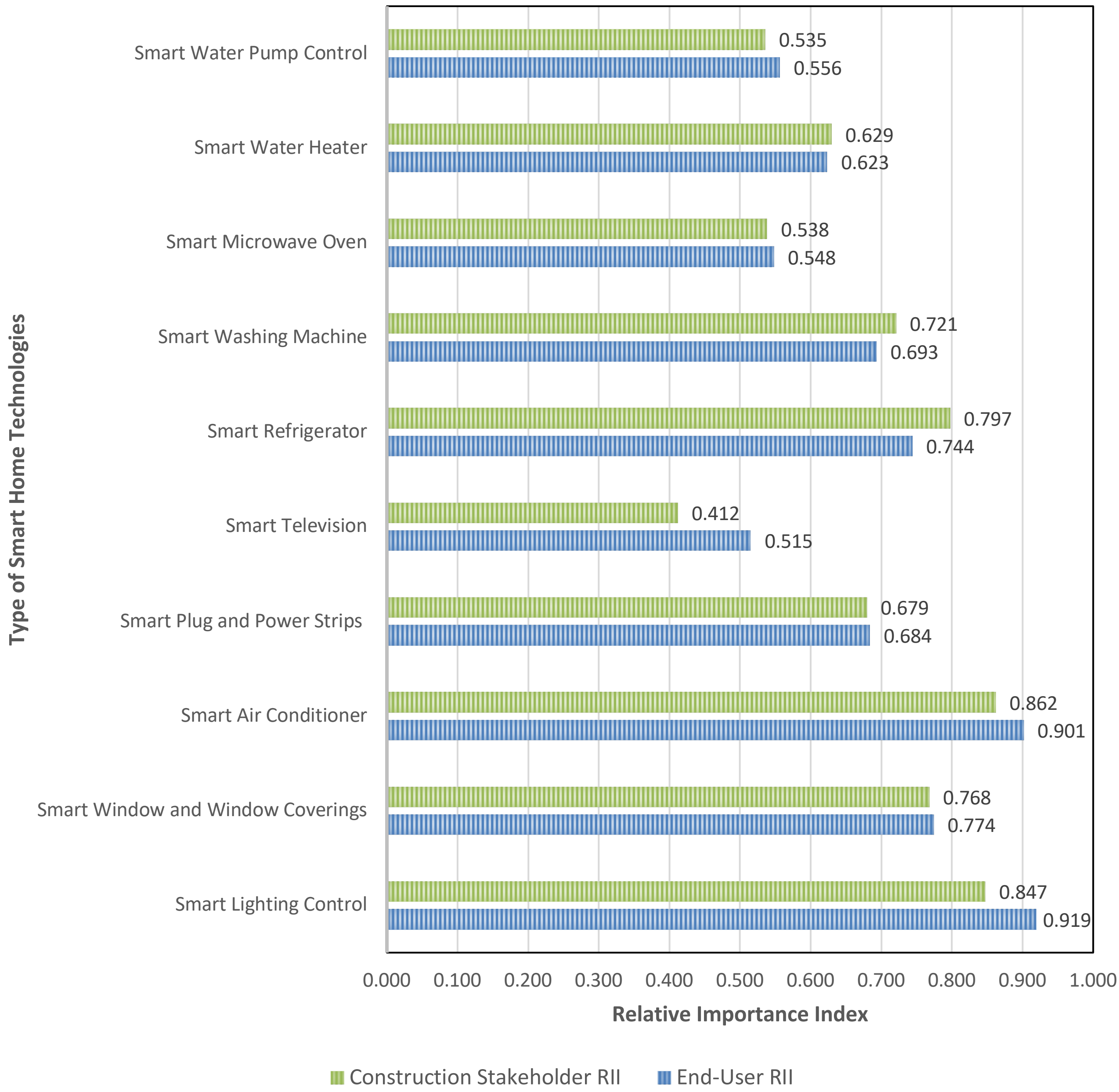


Fig. 9. Comparison of RII value for the potential of SHTs in reducing energy between end-users' and construction stakeholders' perspectives

According to Figure 10, the smart air conditioner is ranked highest by construction stakeholders and second by end-users due to its potential to reduce energy consumption. With multiple sensors, smart air conditioners offer substantial energy-saving benefits through autonomous management that adapts to changing weather and environmental conditions. Both end-users and construction stakeholders also rank smart windows and smart window coverings highly for their energy-saving potential. These technologies help reduce energy consumption by automatically adjusting lighting, cooling and heating through sensor-based functions. This finding is supported by existing literature, which has shown that smart windows and window coverings are effective in reducing energy consumption by adjusting the thermal comfort of spaces, particularly in hot climate regions. Research has indicated that smart windows can lead to savings of up to 60% for lighting, 20% for cooling and 26% for peak power [48-50].

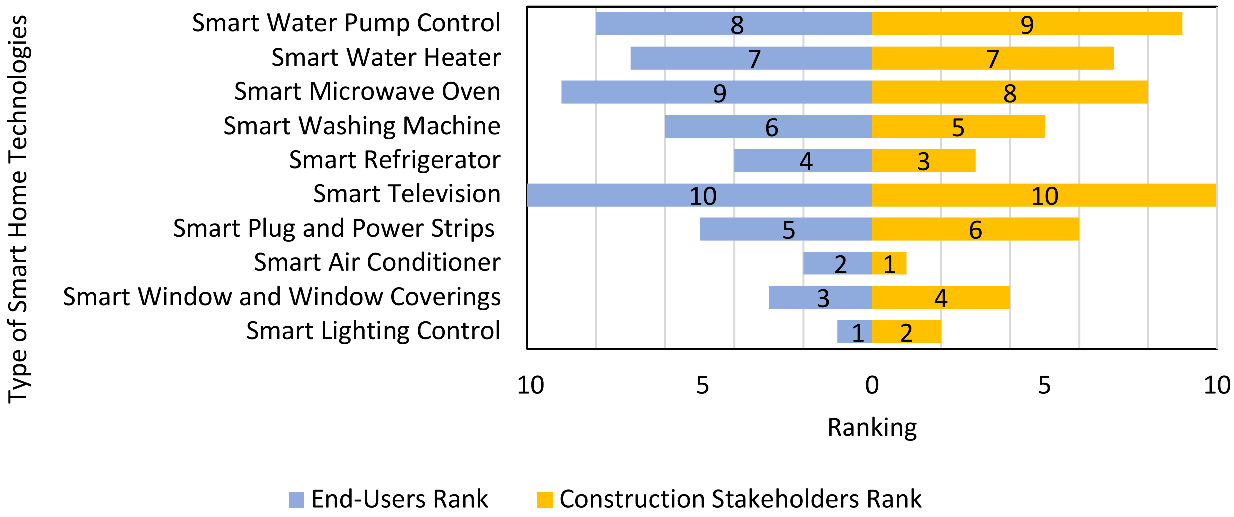


Fig. 10. Comparison of ranking for the potential of SHTs in reducing energy between end-users' and construction stakeholders' perspectives

The smart refrigerator is perceived to have significant potential for energy savings by both end-users and construction stakeholders, ranking fourth and third, respectively. This perception is likely due to the refrigerator's longer operating hours and smart features, which enable energy savings over an extended timeframe. This finding is consistent with literature review, which notes the potential for smart refrigerators to save energy [51]. Similarly, the smart washing machine is also highly ranked by both end-users and construction stakeholders for its potential in reducing energy consumption. The delay starts function and load shifting and control strategies that can help reduce energy consumption [52]. The smart washing machine has troubleshooting features that can detect and notify end-users of issues or required maintenance, reducing unnecessary operation or water leakage. Another smart appliance perceived to have potential in reducing energy consumption is the smart plug and power strip. These devices can reduce energy consumption by 26% to 50% [53]. Automated receptacles or smart plugs, can interact with controllers such as occupancy sensors or timers to remotely turn off receptacles, increasing energy savings [40]. Advanced power strips go a step further by monitoring inactive devices and shutting off power to the strip entirely, further reducing energy consumption.

3.5 Challenges and Barriers in the Adoption of SHTs

According to Figure 11 and Figure 12, the top challenges such as privacy and security, high cost and complexity/ease of use show only a one- or two-rank difference between end-users and construction stakeholders. In contrast, challenges like limited customer demand, administration, interoperability and energy rebound differ by five ranks. Interestingly, government support and internet access hold the same low rankings for both groups. Privacy and security are top concerns for both end-users and construction stakeholders regarding adopting smart home technologies (SHTs), ranking first for end-users and second for construction stakeholders. Authors Sovacool *et al.,* [36]; Balta-Ozkan *et al.,* [38]; Junior *et al.,* [41]; Gazzawe *et al.,* [42] and King [54] support the idea that privacy and security concerns significantly impact the adoption of SHTs. SHTs can collect various types of information data, such as movement, energy use, bills, music preferences and purchase records, to tailor the requirements of the occupant. However, the potential threat of exposing this information to others is a major concern. A Cyber Security Breaches Survey 2020 by the UK Department for Business, Innovation and Skills and conducted by (PWC) revealed that 46% of businesses and 26% of charities in the UK experienced security breaches in the past 12 months. Cybercrime is increasingly becoming more sophisticated and destructive [55].

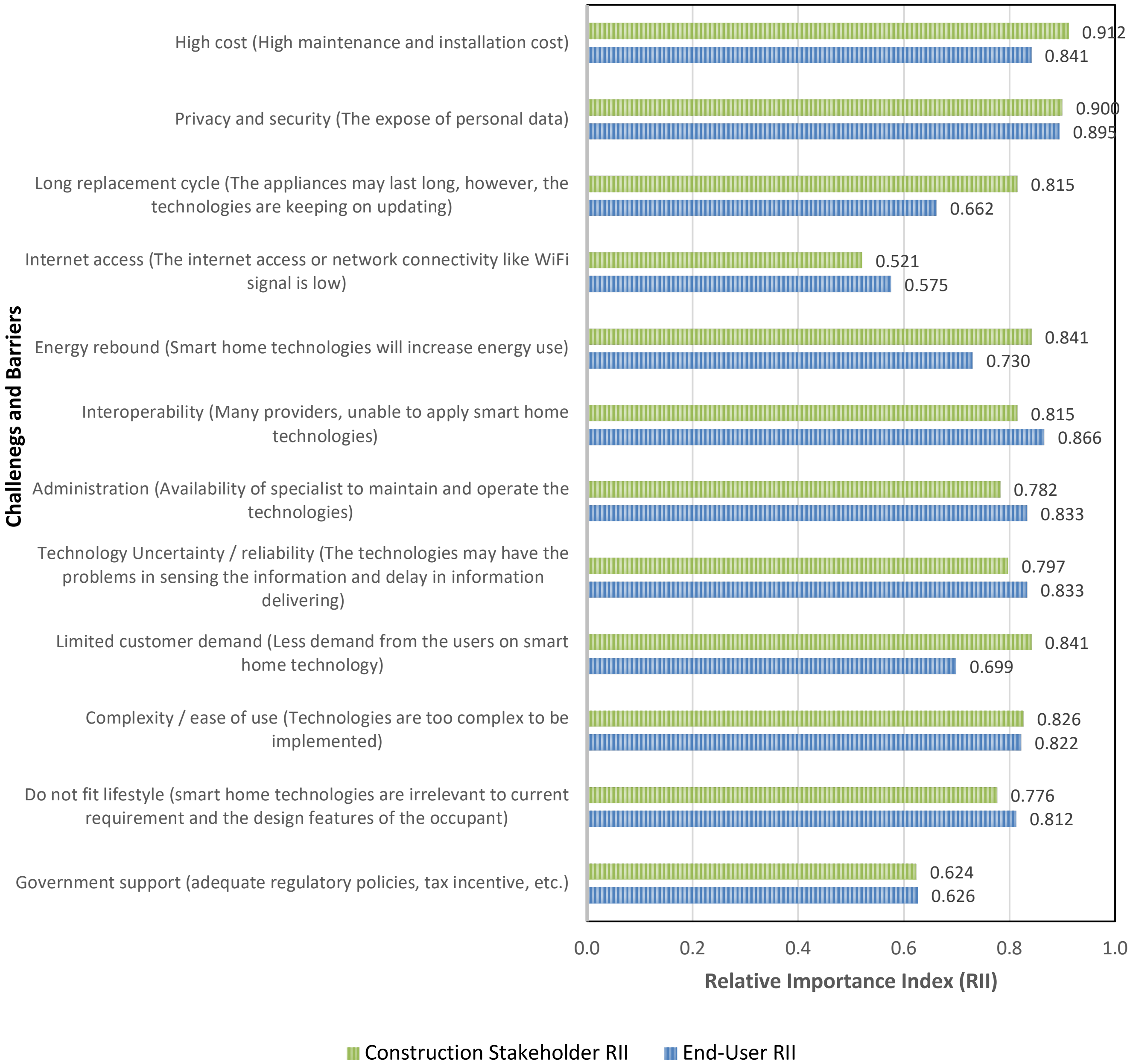


Fig. 11. Comparison of RII value towards the challenges and barriers in the adoption of SHTs between end-users' and construction stakeholders' perspectives

One of the major challenges to adopting smart home technologies (SHTs) is their high cost, ranked third by end-users and first by construction stakeholders. This finding aligns with previous research, as noted in studies by other scholars such as Sovacool *et al.,* [36]; Greenough *et al.,* [39]; King *et al.,*

[40] and Junior *et al.,* [41]. The high initial installation cost is a barrier to adoption for some people and financial factors such as the cost of technology, installation, maintenance and repair can affect the value proposition for potential adopters [56]. Even though awareness of environmental consequences and energy-efficient appliances may be high, the high cost of adoption may discourage potential buyers. For example, a study conducted by Ramayah *et al.,* [57] found that Malaysians were aware of the benefits of energy-efficient appliances, but the high implementation cost reduced their intention to purchase them. Thus, while both end-users and construction stakeholders may be aware of the benefits of SHTs and their environmental impact, the high cost of adoption can affect their decision to implement them.

Both end-users and construction stakeholders have a similar view on the ranking of complexity/ease of use of SHTs, which is 5th and 6th, respectively. The design and function of SHTs should be self-explanatory and easy to use. Additionally, both end-users and construction stakeholders have similar views on the lowest ranking factors, which are government support and internet access, ranked 11th and 12th, respectively. This is due to the government's support, as Malaysia's government has implemented various programs and plans to improve smart appliances' adoption and smart city development (Green Technology Master Plan 2017-2030, National Physical Plan 3, etc.). Moreover, internet access may not be significant as some SHTs can be controlled through Bluetooth and internet coverage in Malaysia is relatively high, with 90.1% of households having internet access.

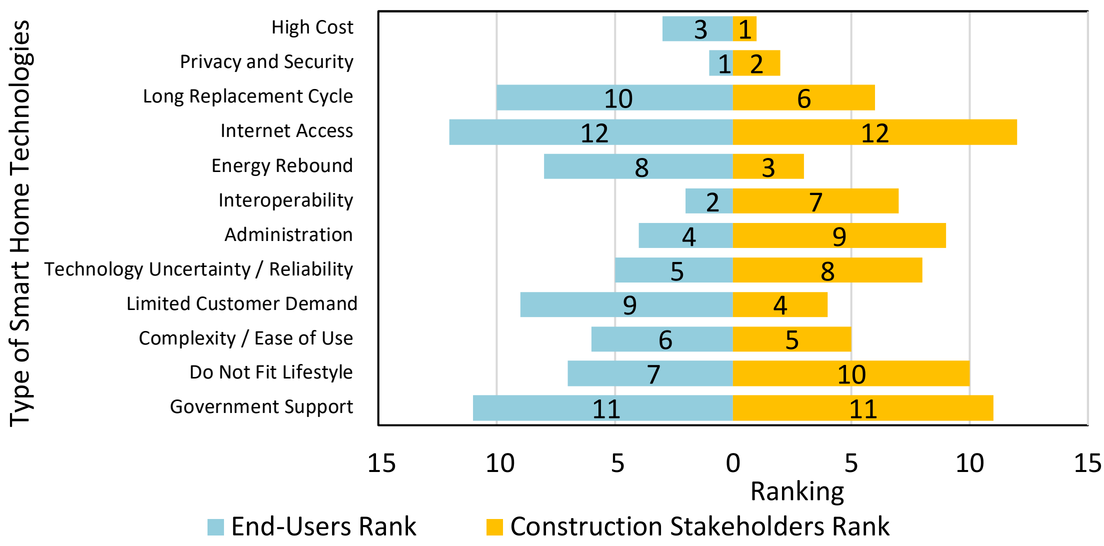


Fig. 12. Rankings of the challenges and barriers in the adoption of SHTs between end-users and construction stakeholders

Interoperability is ranked as the 2nd most important factor by end-users but only 7th by construction stakeholders, whereas administration is 4th for end-users and 9th for construction stakeholders. This difference may stem from construction stakeholders perceiving smart home technologies (SHTs) as a cohesive set of smart appliances installed together, while end-users see them as individual, separate devices. Both interoperability and administration are noted as challenges in the adoption of SHTs [37]. The proliferation of connected home devices and the use of different networks, media and communication protocols by different manufacturers contribute to interoperability challenges. Skilled specialists are needed for the operation and maintenance of SHTs, which can be difficult for end-users to find. Third-party service providers or developers may not be able to fully handle operational and maintenance issues due to the subjective nature of some devices and services. Sufficient management functionalities like monitoring, maintenance and remote control can help reduce errors and assist in maintenance activities.

The prioritization of energy consumption related to smart home technologies (SHTs) differs significantly between end-users and construction stakeholders, ranking 8th among end-users but 3rd for construction stakeholders. This discrepancy may arise from construction stakeholders' awareness that the standby mode of SHTs can increase energy consumption-something that end-users might overlook. Additionally, construction stakeholders understand that SHTs can intensify energy use during pre-warming phases, potentially leading to an energy rebound effect. Another notable divergence is seen in the ranking of limited customer demand, which construction stakeholders rate 4th, while end-users place it at 9th. Limited customer demand is also recognized as a key challenge in the adoption of SHTs [39].

4. Conclusion

The research findings reveal a relatively high level of awareness about smart home technologies (SHTs) among end-users in Iskandar Puteri, with most familiar with the features and sustainability benefits of SHTs. Among these benefits, energy saving received the highest level of agreement from end-users. Additionally, most construction stakeholders perceive the adoption of SHTs in Iskandar Puteri to be relatively high and are actively engaged in smart home projects, often providing smart home design training through their companies. This indicates a strong awareness of sustainability among construction stakeholders in Malaysia. However, the literature review reflects mixed perspectives on whether adopting SHTs effectively reduces energy consumption. The research results indicate that most construction stakeholders agree on the energy-saving potential of smart home technologies (SHTs). Both end-users and construction stakeholders similarly recognize the energy-saving benefits of individual smart appliances. However, various challenges and barriers hinder the adoption of SHTs, with perspectives differing based on each group's role in the process. For end-users, privacy and security are the main concerns, while construction stakeholders primarily view high costs as the key challenge.

Acknowledgement
This research was not funded by any grant.

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