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Smart Home Energy Management Systems in Internet of Things networks for green cities demands and services

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ABSTRACT

Today, 44% of global energy has been derived from fossil fuel, which currently poses a threat to inhabitants and well-being of the environment. In a recent investigation of the global demand for energy consumption across various energy consumption sectors, the building sector has been shown to be one of the primary energy consumers, with a high percentage of energy consumption deemed as unnecessary. This as a result of poor management practice and implementation of strategies to avoid excess energy consumption. Over the years, researchers in both academia and industries have focused on various techniques to deal with unnecessary energy consumption and ensuring a healthy living environment for green smart cities. Among these techniques is Smart Home Energy Management Systems (SHEMs), which transform electric home appliances, sensor nodes, into autonomous devices in order to manage energy consumption effectively. This study presents an analysis of smart home energy management system with the goal to identify current trends and challenges for future improvement. The result reveals lack of quality attributes such as security, privacy, scalability, interoperability, and difficulty in managing and adapt to the thermal comfort satisfaction of residents, exposing them to health risks. Lastly, the study described opportunities for future research that ensure energy-efficient smart homes free of unnecessary energy consumption, health challenges, and cyber security attacks.

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1. Introduction

The global energy crisis has for decades been one of the significant challenges that pose a threat to the global economy and a healthy living environment. A recent report published in 2020 by Energy Outlook (Outlook, 2019) shows the increase of 2.9% global energy consumption in 2018, which is considered as the fastest increased rates for decades compared to its usual primary yearly average increase of 1.5% (see Fig. 1) and forecasted to increase rapidly in upcoming years. The same report shows the United States of America was the world's largest energy consumer until 2002, when it was overtaken by the Asian region.

The trend shows significant turning point closely related to the ongoing increase in population, and number of industries and infrastructures in the Asian region. Another report also shows government efforts to improve the wellbeing and lifestyle of their citizens partly offset by the substantial gain in energy intensity, which leads to higher energy consumption in the Asian region. A recent report (C., 2018) praised China's effort to manage the supply of energy demand to over 1.3 billion people and thousands of industries. Recently, there has been an unusual increase in ongoing deployment of air condition and heating systems, microwave ovens, televisions, hairdryers, and other home appliances.

Currently the industrial sector is the primary consumer of global energy consumption with increased from 40%–90%, buildings (43%–56%), transport (18%–46%) and the non-combusted accounting for the remainder as shown in Fig. 1. Over the years, researchers have used historical energy consumption to boost the gain in energy efficiency through various technologies. Emerging Smart Grid technologies provide greater save energy, seeking out the lowest energy consumption rates, facilitate and contribute to balance energy generation, supply and consumption across all sectors which marked slowing the energy demand increase in the building and transport sectors to less than half the rate of the previous 20 years. Similarly, the increase of energy demand within industry also lost momentum. Despite the current technological advancement, the non-combusted energy demand particularly in the industry as a feedstock in petrochemicals has not decline.

The global energy peak consumption analysis from global historical energy consumption data pulled from outlook (Outlook, 2019) dated from 1990 to 2020 in Fig. 2 indicates Asian region-building energy consumption demand rose by 95% by 2019, consuming a total of 2.26 billion tonnes, overtaking the US with total consumption equivalent 2.17bn tonnes. Similarly, analysis shows 60% increase in the industrial sector from 1990 to 2019.

Over the years, evidence has shown global warming (Outlook, 2019; Part, 2016; Serra et al., 2014) to be a driving factor that has contributed to a sudden increase in global energy demand, particularly in Canada, China, the US, and Russia in efforts to both cool down and warm extreme cold residential environment that has been experienced since the 1950s.

To curtail the current associated energy and environmental impact, building sector requires a sustainable energy solution in the form of renewable energy sources and energy efficiency technologies. Renewable energy sources provide new occupants with opportunities to generate their own form of electricity. This implies that a standard design for smart home requires that renewable energy sources be taken into consideration. A Smart grid research emerged with new techniques and opportunities to manage energy sources (including generation, storage and supply) and utilization (demand and usage) particularly in building sector as a new frontier for the futuristic smart homes. Today there is increase in adaptation of this trend in practice and research perspective to provide a healthier, more convenient living environment than ever before.

Building sectors are constantly seeking and relaying for new recommendation from researchers in both academic and industry to improve the current building architecture design and SHEMs technologies to attain occupants thermal comfort satisfactory level with higher energy saving potential (Ullah et al., 2020a; Haseeb et al., 2020). While a large number of review studies have been published on SHEM, only a few discussed extensively on issues and challenges faced in current literature, with little emphasis on scope of the literature research limitation. This study, however, takes a step further providing an in-depth critical review analysis aimed to provide the reader with an understanding of research strategies, techniques, constraints used in current SHEMS and various factors which affect its overall functionality and operation. The result of this analysis can be used to improve the current SHEMS state of the art.

This paper is organized as follows: Section 2 provides an overview into Energy Generation and SHEMS, Section 3 SHEMS research quality assessment, Section 4 insight on SHEM's market and product 5 discusses future research and opportunities, Section 6 presents study conclusion.

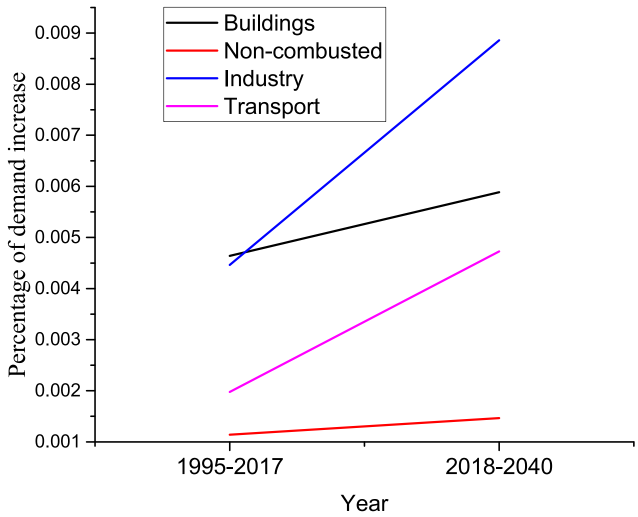

Fig. 1. Expected percentage of global demand for energy consumption in various sectors.

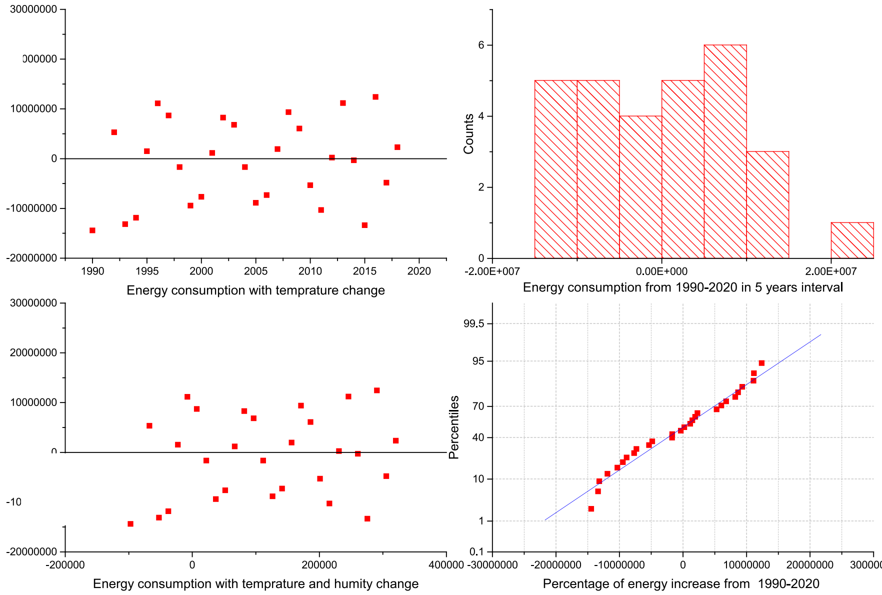

Fig. 2. Global energy peak analysis from 1990–2020.

2. Energy generation and smart grid

Modern technological advancement has positively impacted our lifestyle and, at the same time, led to the progress of environmental concern that poses a threat to the inhabitants. Over the decades, the increase in environmental degradation has become a reality driven by many factors (Haseeb et al., 2020; Chandrasekhar et al., 2020). Increase in world population and industrial activities have led to increase the percentage of unhealthy particles in the outdoor air creating an unhealthy living environment. Electricity is a form of clean energy and safe when it is utilized. However, the transition and generation of electricity has great environmental and health consequences. The generation of electricity from all sources of primary energy has effects on the environment to some extent. Over the decades (Atzeni et al., 2012; Qureshi et al., 2020a,c), fossil fuel (coal, crude oil, and natural gas) contribute 80% of electricity to consumers globally as shown in Fig. 3.

Today the USA, Europe, and Asian countries and other parts of the world use other sources of electricity generation, which include natural gas, coal, and nuclear in the high proportion, which reduces the burning of fossil fuel as shown in Fig. 3. Energy generation is the primary source of greenhouse gas emission GHG. The increasing concentration level of GHG in the atmosphere has led to more energy radiation from the sun resulting in the trend of global warming.

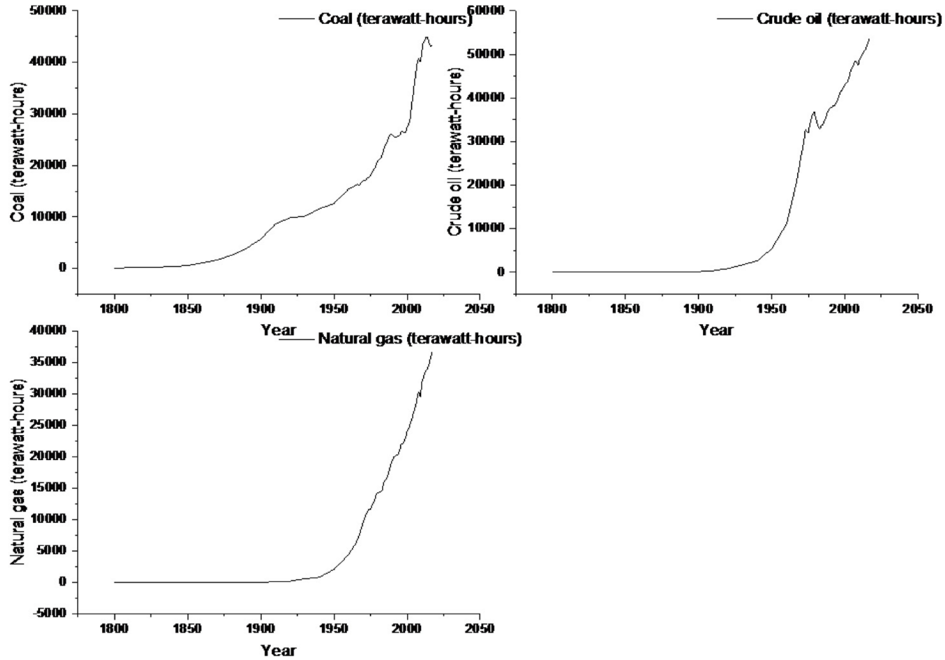

Fig. 3. Fossil Fuel Energy Generation (coal, crude oil, and natural gas).

Study (Hosking et al., 2018; Hussain et al., 2020) shows global fossil fuel energy consumption of coal, crude oil and natural gas have increased coal recently by 28%, 27%, and 38%, respectively in Fig. 3. Burning of fossil poses a greater threat to the atmosphere making earth hotter place. Recent investigations have shown the period 1917–2017 has witnessed a rise in average temperature, wildfire migration shifting of habitat, and draining of sea level, which is linked with increased GHG emission level into the atmosphere.

A key factor that brought all of the emerging Smart Grid technologies to operate together is the synergy between the grid operators, consumer, and utilities (Rathore et al., 2016; Paul and Jeyaraj, 2019). Implementation of automated controls in home and appliances can provide an interface to interact with energy provider to limit energy usage on certain appliance when grid is under stress from peak energy demand, or reschedule demand to use energy when the energy unit at a lower price. Today, smart grid is becoming more attractive building occupants due to its interactive capacity.

Recent research shows (Aswani et al., 2012; Azuatalam et al., 2020) Smart grid provides new opportunity and potential for occupants to optimize energy generation, storage, and consumption in a convenient and automated approach with higher efficiency as shown in Fig. 4. Innovative fit also offers a complete transparent energy budget, avoiding energy purchase at high rates through energy demand scheduling and price forecast. Current trends show global adaptation of renewable energy sources with high decline on fossil fuels generation.

The current adaptation and growth (Manic et al., 2016) of smart grid have subjected building sectors into continuously seeking and demanding for new emerging algorithms and technologies to facilitate and ensure smooth transition of shifting home appliances from traditional utility grids to renewable energy sources to curb the current energy crisis and global warming. In this context, the ideology behind the Smart grid lies upon local generation of energy and with Smart Home. Fig. 4 demonstrates Smart grid synergies harnessing technologies with greater energy supply reliability and sustainability to occupants in comparison to traditional grid utility.

Recent research provides solutions to achieve greater energy saving potential by increasing hosting energy demand for renewable energy to reduce demand for traditional electricity from smart home appliances (see Fig. 4). For example, energy demand on HVAC equipment in the evening when the residents arrive at home can be scheduled to start earlier on the rooftop solar panel to cool down the room before occupants arrive at home.

The architecture displays mutual communication among data distribution centres, smart metres, SHEMS, and home appliances. This communication is essential for SHEMS to analyse, forecast, and predict the cheapest energy source option, time to shift the energy demand on renewable energy of home appliances to reduce the energy costs on traditional electricity, utilize data exchange to decide energy demand priority when the energy demand or cost is at peak and ensure no unnecessary energy consumption. For example, smart metres can assist occupants to cut energy consumption costs by providing useful information such as how much electricity is being used, unit price forecast future price cost.

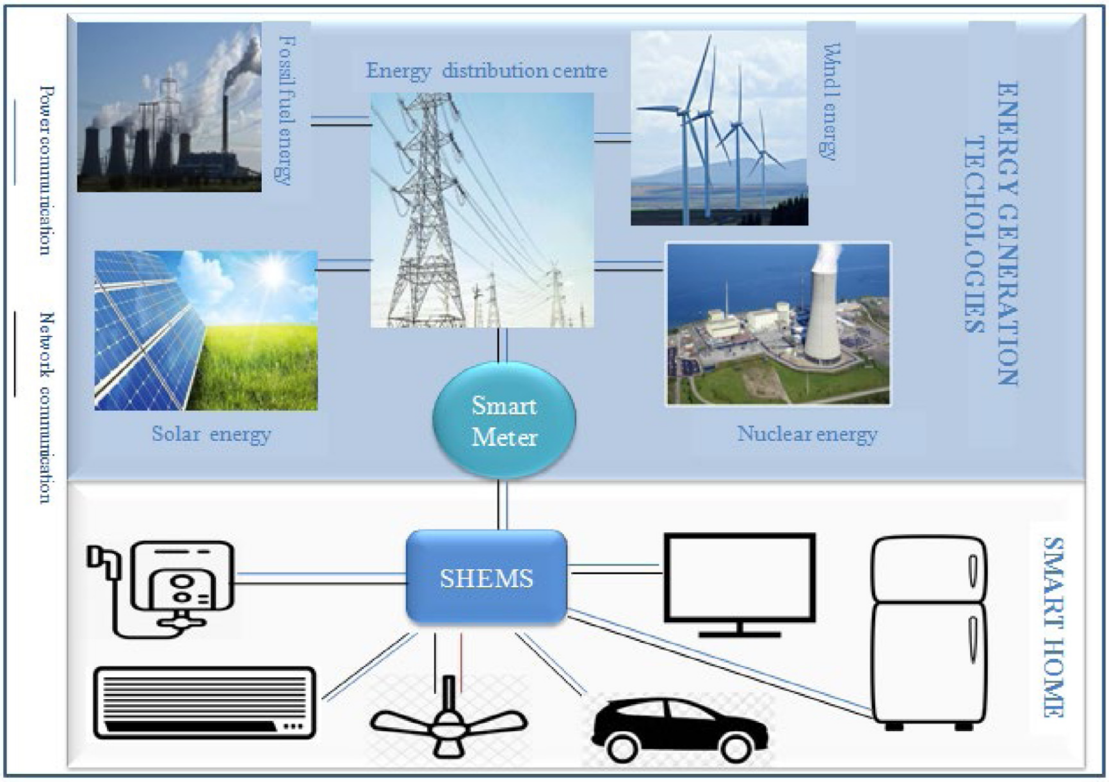

Fig. 4. Typical Architecture of Energy Generation and Smart Grid Ecosystem.

2.1. Energy generation technology

Demand for energy generation sources and technology has increased significantly over the years throughout the world to satisfy consumer energy demand. Energy generation sources and technology have changed over time, and some are often used more than others (Omer, 2009). However, today there are three primary sources of energy generation, which include fossil fuel, renewable and nuclear energy. Studies show fossil fuel energy generation has a great effect on Inhabitant and environmental well-being. Inside data shows international energy regulation sectors have strived to reduce the impact energy generation to the environment through the implementation of specific strategies and policies to protect the environment against harm from energy generation (Omer, 2009; Qureshi et al., 2020d).

Acts such as the Nuclear Safety Authority Strategic Plan and the Waste Act, Nuclear Security, and Transparency Act are some of the policies in place concerning energy generation to environmental hazards which have received broad argument in various dimensions. The majority of the participants agreed that the Acts have played a role in ecological condition stability with the help of a renewable energy approach. As reported in Hosking et al. (2018), Omer (2009) and Qureshi et al. (2020b), the affirmative compliance among various countries has led to a gradual shift to renewable energy sources to reduce the carbon emission to the atmosphere.

2.1.1. Fossil fuel

Fossil fuel (coal crude oil and natural gas), accounted for an estimated 44% of global energy source utilization as shown in Fig. 5. Coal and natural gas account for 28% and 27% of global fossil-fuel utilization, respectively, as reported in Omer (2009). The resulting chemical compound released from the burning of fossil fuel affects environmental health and quality of life. These compounds include methane (CH4), CO2, sulphur dioxide (SO2), and nitrogen oxide (NOx), which are the primary cause of environmental pollution. Mercury (Hg) is another chemical compound released into the environment when fossil fuels and coal are burned, causing trans-boundary pollution. Hg concentration in the air affects water quality. Wildlife exposure to Methyl mercury (CH3Hg) led to a low fertility rate, mortality, congenital disability, an increase of disability, and abnormal development. In many cases, the combination of SO2 and NOx with air vapour led to the production of acid rain from the burning of coal which affects crops and forests, and has led to respiratory challenges among wildlife populations and other severe sicknesses that might lead to mortality in humans. Data in Hosking et al. (2018) and Omer (2009) reveals the emission levels of burning fossil fuel consisting of CO2, water vapour, and CH4 in comparison with the product of oil and coal. The data reveal oil and coal have higher concentration levels of SO2, NOx, and CO2, which lead to environmental pollution.

2.1.2. Nuclear energy

Nuclear energy originated primarily from the use of Uranium through the fission generation process that forms heat in a nuclear energy station. This enables reactor to heat up the water around the fuel rods, which will then have built into stream spins the turbine and allow the generator to generate electricity. Thermal radiation and radioactive particles released from nuclear energy have an impact on environmental survival, reproduction, and growth. The nuclear energy generation combustion products are contained as wastes, and this waste poses a risk and threat to the environment as recently occurred in Japan's Fukushima. The tailing dams are in reach with uranium and cause acid bleaching on the surface, soil, and groundwater when flooded into the ponds. Despite current regulation in place by World Nuclear Association, it was reported that more than 500 commercial nuclear reactors are in operation in 31 countries as a source of energy providing an estimated capacity of 13.5% of global energy production (Sims et al., 2003a). Similarly, nuclear energy plant construction demands an increasing number of roads, traffic flow, the cutting of trees, excavation, which have a significant impact on ecology.

2.1.3. Renewable energy

Renewable energy sources, RES, is the natural process of generating energy restored by means of the earth. This includes energy generated from solar, biomass, and wind, hydroelectric and geothermal. However, the most popular sources of renewable are solar and wind energy.

2.1.4. Wind

Wind energy generation has a long history, apparently originated from Chinese for agricultural irrigation four decades ago. Warm air is the major driving factor to spin large propeller of the turbine, which drive the generator to generate energy. The idle locations for wind energy plants are where speed is about 25 km/h, steady, and reliable, preferably at the top of shaped hills, coastal areas, and open plains (Joos and Staffell, 2018). Wind energy is a form of clean energy that poses no threat or toxicity to human life. However, the biggest challenge faced is community acceptance as it affects reception signals for television and radio. Aluminium and steel consumed by wind energy plant processing emit CO2 during manufacturing, while turbines' concrete foundation range from 15 to 37 tonnes per GWh of energy generated. The percentage of wind energy generation rose from 17% to 29% from the since 2010 (Sims et al., 2003b).

2.1.5. Solar

Sun is another source from which to tap energy using solar cells approach, which transforms light directly into energy. During 1974 energy crisis, the sun was used to heat water panels and solar furnace to tap sun energy into mirrors to generate high temperatures. The solar energy generation was estimated to reach global demand of 9.2% by 2040 (Sims et al., 2003b). Solar cells disposal and radiation emitted by other equipment in transforming solar energy to electricity are the major threats to the environment. The major environmental issues with this fuel cycle are the manufacture and disposal of solar cells and other equipment required to capture the radiation before it is transformed into electricity.

Photovoltaic cells are essential for the panel to function, and the manufacturing process required the involvement of hazardous substances such as cadmium and arsenic. Leftover silicon tetrachloride must be disposed of appropriately and might cause severe environmental pollution due to mismanagement or inappropriate implementation of disposal measures. Solar energy is becoming more popular as it poses less threat to inhabitants in comparison with fossil fuel and nuclear sources of energy. In fact, since the incident in Fukushima Japan, countries such as the UK, France and Germany have stepped forward to minimize the extension of their nuclear energy plant and emphasis renewable energy sources such as solar and wind energy plants as alternatives to meet their energy demand.

For decades, fossil fuel has remained a primary source of energy generation, but with growing concern on the increase of GHG emission and its possible impact on global warming, many countries have to pay attention to tap energy from nature in the form of renewable sources to harness energy to meet the demand for energy consumption. Today countries are focusing on both safeties of the environment and long term adequacy of the energy supply. Information in Fig. 4 shows the increase of momentum in renewable energy supply in recent decades, with high efficiency and potential in the market and without compromising the safety of the environment. Unlike fossil fuel or renewable, the supply of nuclear energy is steady, despite a low amount of carbon emission, and this is mainly due to a lack of nuclear reactor, as they are costly to construct.

2.2. SHEMS review analysis

SHEMS provide advanced IoT technological framework with the potential to transform a traditional home into a smart energy-aware environment to manage the energy resources and demand to reduce excess energy consumption and bills without compromising occupants' comfort and satisfaction. The framework was designed with central intelligence to automate, facilitate and coordinate decision making in the smart home products ecosystem without reliance or participation of the occupants so as to ensure a comfortable and convenient living environment and improve the lifestyle of occupants. So far, the trend (SAULLES, 2017) has shown 15%–23% annual energy bill savings in comparison to traditional home (Grid, 2016). Table 1 presents the summary review analysis on recent literature of SHEMS.

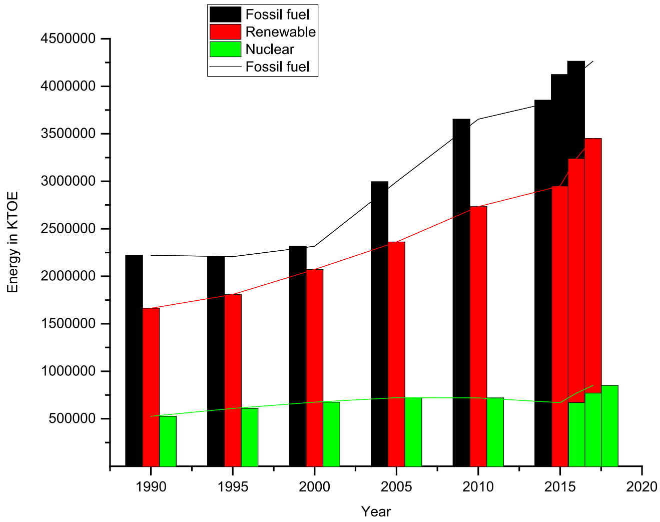

Fig. 5. Analysis of energy generation sources from 1990 to 2020.

Current SHEMS implement different type of intelligent controller that requires external feedback input values such as cost, thermal demand, or PV generation to make appropriate suggestions in response to energy for a customer to choose or perform decisions autonomously. SMHEMS can be classified into two main categories (non-predictive and predictive SHEMS approach) based on the level of the intelligence provided to automate energy demand and control utilization tasks (see Table 1). These controllers are classified into two main categories (predictive and non-predictive controller) based on their maturity level of intelligent provided to the system.

Non-predictive controllers provide SHEMS with the capability to manage home appliance remotely using a mobile application or web service. This is essential when occupants want to use the equipment ahead of time with higher energy saving potential. For example, turning ON HVAC equipment at a low ventilation rate prior to using the space for a specified period, which consumes less energy compared to operating HVAC equipment in a high ventilation rate when the demand arises.

Predictive controllers are designed to automate switching ON/OFF of home appliance without occupants' intervention. Majority of these controllers are trained with machine learning algorithms (see Table 1) to learn the occupant's behaviour towards energy demand and utilization, and are able to perform a precise prediction to respond to occupant's demand without unnecessary energy consumption.

However, majority of SHEMS literature presented in Table 1 greatly rely on occupants fixed schedule activities to derive learning model on occupants' behaviour towards energy demand and utilization. Studies in Qurat ul et al. (2018), Asif et al. (2018), Meana-Llorián et al. (2017b), Javaid et al. (2018) and Yoo et al. (2020) proposed occupants learning behaviour to minimize excess energy consumption by HVAC equipment. The proposed algorithms uses occupants fixed schedule time to be in the building and time to leave the building, occupants energy pattern behaviour, seat point temperature that favour the comfort of the occupants based on the season of the year. The derived model was simulated in EnergyPlus software in comparison with a traditional thermostat, which shows high accuracy in predicting occupants in a space which, in turn, cuts excess energy consumed by HVAC equipment significantly. Energy saving through occupant's schedule activities are essentially practical in commercial buildings such as labs, offices, and business environment where occupants activities are being governed by certain policies.

These proposals are being challenged with flexibility to adjust temperature seat points based on indoor meteorological conditions and the ability to adapt to occupant's behaviour change, which affects the reliability of the occupant's estimation model, especially when occupants decided to go against following the designed fixed schedule.

Dynamic predictive control, on the other hand, does not strictly rely on the occupants fixed schedule to manage home appliance. However, to improve the reliability of SHEMS in some cases, occupants schedule activities are considered in formulating learning model for occupants' behaviours towards energy demand and usage.

Dynamic predictive control implements sensors as source of generating occupants' data for real time processing. Acoustic real-time processing in Huang et al. (2015) and Huang (2018) uses sound frequency received by sensors to control HVAC energy consumption. Camera-based real time image processing in Jung and Jazizadeh (2019) and Cao et al. (2018) proposed a similar approach using the Naive Bayesian algorithm that allows image pixels to be trained based on the desirable threshold predicted number of occupants in the space in order to control HVAC ventilation proportional to number of occupants in a space. Passive infrared using sensor fusion techniques were proposed in Roselyn et al. (2019) and Fayed et al. (2019) to keep track of occupants movement in the space to control occupants demand on HVAC and lighting to avoid excess energy consumption. Carbon Dioxide CO_2 Sensors were used with K-Nearest Neighbour (O'Neill

Table 1
SHEMS literature review analysis.

Reference	Algorithm	Intelligent level	Data set	Validation tool	Appliance	Controller	Observation
Gao et al. (2020)	deep neural network	Predictive control	SG-Singapore-Airp-486980	TRNSYS	Shiftable appliance	Deep learning controller	-Occupants detection ignored -Thermal comfort satisfaction ignored -scheduling control only feasible where demand for energy is shiftable
Lissa et al. (2020)	Markov game	Predictive control	Sensors data	Prototype	Shiftable appliance	deep reinforcement learning controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Ding et al. (2019)	Neural Network	Predictive control	Energy data from ThingSpeak	EnergyPlus	Shiftable and non shiftable appliance	Reinforcement Learning controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Azuatalam et al. (2020)	deep reinforcement learning	Predictive control		EnergyPlus	Shiftable appliance	Markov Decision controller	-Occupants detection ignored -Thermal comfort satisfaction ignored -scheduling policy is required
Zhang et al. (2019)	reinforcement learning	Predictive control		EnergyPlus	Shiftable appliance		-Occupants detection ignored -Thermal comfort satisfaction ignored
AlFaris et al. (2017)	Hidden Markov	Predictive control	Question-naire	eQuest software	Non-Shiftable appliance	Vector support machine	The solution requires extension to consider non-shiftable appliances like HVAC equipment
Qurat ul et al. (2018)	Fuzzy logic	Predictive control	Energy data Data from ThingSpeak	Prototype development	Shiftable appliance	Fuzzy logic controller	Occupants detection and machine learning controller should be considered to improve demand and utilization of energy control and management
Khan et al. (2016)	Binary control	Predictive control	Sensors	Prototype development	Shiftable appliance	Binary/traditional controller	Machine learning controller is required to maintain the life span of home appliance Personalize and collective thermal comfort ignored
Ejaz et al. (2017)	heuristic algorithm	Predictive control	Sensors data	N/A	Shiftable appliance	Hidden Markov controller	Improve the controller intelligence to featured non-shiftable appliances like HVAC.
Arya et al. (2019)	Fuzzy logic	Predictive control	ThingSpeak and Matlab data set	Prototype development	Shiftable appliance	Binary/traditional controller	To maintain life span of appliance binary control should replace. Occupants detection and thermal user comfort should also consider. It is important to control to keep record of data to public to access
Asif et al. (2018)	Strawberry algorithm	Predictive control	Market Clearing Price data set	Matlab	Shiftable appliance	Binary/traditional controller	-Occupants detection ignored -Thermal comfort satisfaction ignored -scheduling control only feasible where demand for energy is shiftable
Filho et al. (2019)	Binary	Predictive control	*Data from Thinksspeak"*	Prototype development	Shiftable appliance	Binary/traditional controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Becker et al. (2018)	Hidden Markov Model	Predictive control	CER data set (Irish company)	Simulation (eQuest software)	Shiftable appliance	Hidden Markov controller	-Difficult to detect occupant in dark -Thermal comfort satisfaction ignored -Simulations are limited to only one type of HVAC
Moreno et al. (2014c)	Binary	Predictive control	Sensors data	Prototype development	Shiftable and non shiftable appliance	Binary/traditional controller	-Occupants detection ignored -Thermal comfort satisfaction ignored

(*continued on next page*)

et al., 2019; Wang et al., 2017; Zuraimi et al., 2017), deep reinforcement learning and Support Vector Machine (SVM) in Rathore et al. (2018), Yazici et al. (2018), Brundu et al. (2017), Oliveira et al. (2017), Meana-Llorián et al. (2017b) and

Table 1 (*continued*).

Reference	Algorithm	Intelligent level	Data set	Validation tool	Appliance	Controller	Observation
Al-Ali et al. (2017)	Binary	Predictive control	Sensors data	Prototype development	Shiftable appliance	Binary/traditional controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Liu et al. (2019)	deep reinforcement learning	Predictive control	Sensors data	N/A	Shiftable appliance	deep reinforcement learning controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Rathore et al. (2018)	hyperellipsoidal model based algorithm	Predictive control	Sensors	Prototype	Shiftable appliance	A Bayesian maximum entropy based controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Qurat ul et al. (2018)	Genetic Algorithm	Predictive control	Sensors	Matlab	Shiftable appliance	Fuzzy logic controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Yazici et al. (2018)	Support Vector Machine	Predictive control	Sensors	Matlab	Shiftable appliance	Random Forests	-Occupants detection ignored -Thermal comfort satisfaction ignored
Brundu et al. (2017)	Fuzzy logic	Predictive control	Sensors	Matlab	Shiftable appliance	Binary/traditional controller	-Occupants detection ignored -Thermal comfort satisfaction ignored
Oliveira et al. (2017)	Fuzzy logic	Predictive control	Question-naire an sensors	Prototype development	Low	Binary/traditional controller	- Occupants detection ignored -Thermal comfort satisfaction ignored

Javaid et al. (2018) to predict the occupants number based on pollutants level in the room to control HVAC equipment to ensure the thermal comfort of occupants were not compromised.

3. SHEMS literature quality assessment

Current literature in the smart home energy management system uses different technique to handle lighting, HVAC, entertainment, kitchen, and other electric home appliance. These techniques are presented in Table 3. To evaluate the level of authors' engagement with audience in order to assess the maturity of the existing proposals, quality evaluation criteria for presented in Table 2 were used for scoring the literature.

The objective of quality assessment analysis is to identify the level of research engagement on the proposed primary objective to the research community. DARE scale presented in Table 2 was used in the assessment and scoring process, and the result of the assessment is summarized in Table 3.

After assessing studies based on quality assessment criteria, it was shown that fifty (50) studies scored 4/4 rating, twenty-three (23) studies score 3.5 out of 4. Likewise, ten (10) score 3 out of 4, and ten (10) studies out of ninety-four (94) score value 2. One study is not relevant, scoring 0 out of 4.

Studies that scored 4 are studies related to both the Internet of Things and energy saving in smart home and building that proposed novel solution together with experimental analysis and evaluation with particular metric or critically and analytically presented a compressive review of the proposed solution. Those that scored 3.5 lack intensive experimental analysis or proper method of evaluation. The majority of studies with 4 and 3.5 score fall within journal articles. Likewise, those with two (2) score presented only proof of concept without any further experimental analysis that does not fully employ the Internet of Things or energy-saving on smart home and building. The majority of these studies are conferences.

In summary, the information in Table 3 reveals that the maximum number of related studies considered have satisfied quality assessment questions.

4. Overview of smart home energy management market

Today the world is in the era of information technology; transforming traditional homes into Smart homes filled with advanced smart networked-based electronic appliances (see Fig. 6). This innovation allows the resident to control several electrical appliances remotely in achieving a convenient living environment (Darianian and Michael, 2008).

Current trends (Markets and Markets, 2020) show the smart home market rapidly gaining momentum with increased shipments of intelligent home electric appliances globally as a result of its affordability and security. With the current energy crisis and an increasing population, smart home has potential to assure quiet, clean, and comfortable environment with available energy supply. Studies show the adaptation of smart homes allows residents to purchase energy at a low price and to utilize it efficiently, thereby supporting its expansion to the global market. The global market reached $76.6 billion in 2018, and the growth is expected to increase by 28% in 2015. This rapid growth is influenced by crucial factors that include accessibility internet, widespread awareness of the benefit of smart home in ensuring a healthy and comfortable lifestyle environment, improved fitness, simplicity in remote home monitoring and energy efficiency offered.

Table 2
Quality assessment procedure.

QA	QA question	Motivation	Evaluation process using DARE	Evolution assessment using DARE
QA1	Are the criteria for inclusion and exclusion well described and appropriately in review?	The aim is to determine whether the inclusion criteria considered are clearly defined and discussed in the study, or partially implicit, or not defined and cannot be readily inferred.	Y (yes) indicates inclusion criteria are clearly defined. P (partly) indicates partially defined. N (no) indicates not defined, and cannot be readily inferred.	The following rating factor are assigned when answering QA1 question Y = 1 P = 0.5 N = 0
QA2	Does the domain search possibly cover all related work as a literature search carried out?	Aim to determine whether four (4) or more digital libraries have been searched and some search strategy are added or all journals addressing the area considered are identified and referenced by authors	Y(yes) indicates either four (4) or more digital libraries have been searched, and some search strategy are added or all journals addressing the area considered are identified and referenced by authors P (partially) indicate only three (3) or four (4) digital libraries have been searched with no addition of any search strategies or defined search used with restriction of set of journals and conference proceedings N (no) indicates the authors have searched up to 2 digital libraries or an extremely restricted set of journals.	The following rating factor are assigned when answering QA2 Y = 1 P = 0.5 N = 0
QA3	Has the quality and validity of included studies been assessed by the reviewers?	The aim is to determine whether quality criteria considered are clearly defined and separated from the result.	Y (yes)indicates Quality criteria considered are clearly defined and separated P (partially) indicates that the research question involves quality issues that are addressed by the study; N (no) indicates that quality assessment of first result was not clearly attempted.	The following rating factor is assigned when answering QA3 Y = 1 P = 0.5 N = 0
QA4	Does the information/studies of concern were described adequately?	The aim is to determine the detail information presented in study	Y (yes) indicates detailed Information about study is presented; P (partially) indicates summary information about first studies is presented; N (no) indicates no results of individual primary studies are specified	The following rating factor are assigned when answering QA4 Y = 1, P = 0.5 N = 0

A SHEMS can be divided into independent segments (see Fig. 6) serving its purpose (Markets and Markets, 2020) as described below:

Smart life entertaining appliances: (Markets and Markets, 2020) the key-driven factors that boost the capacity of the smart home market include smart life entertainment appliances. The convenient sound and visual effect, as well as a remote controlling option offered by these appliances contribute to an increasing number of sales from $170 million to $ $225 billion and is expected to increase by 6.3% from 2019 to 2040. The report shows a larger rise in the share market for the home theatre control system in 2018 than ever before. The companies with the global market share in smart entertainment include LG Electronics Inc., Panasonic Corporation, Samsung Electronics Co. Ltd., Sony Corporation, and Mitsubishi Electric Corporation. These major market players adopt acquisition strategies that include partnership collaborations to maintain their position in the global market, and product launches to build trust and gain a worldwide reputation. In 2019, Samsung Electronics revealed that all 2018 and 2019 Samsung Smart TV models would enjoy features offered by Apple TV app launched in 2019 in more than 100 countries. With this, Samsung was able to build strong collaboration between Samsung and international investors.

Challenge: The current smart entertainment appliances are not featured to perform proactive, intelligent communication towards the customers. Customers are restricted from getting basic knowledge of both real-time and historical energy data consumptions. Integrating proactive features in the upcoming appliances would attract both international and local investors, which help to boost the market share of the smart home in the global market.

Smart lighting system (Markets and Markets, 2020): lighting accounts for large residential energy consumption; however, the current provision of energy-efficient connected lighting controls available in the market reveals the increase in demand for smart lighting system especially for upcoming smart city projects in developing economies. The current

Table 3
Quality evaluation using DARE scale.

Author/year	ID	Type	QA1	QA2	QA3	QA4	S-CATEGORY	TOTAL
Kitchenham et al. (2009)	S1	Journal	0	0	0	0	Policy	0
Revel et al. (2015)	S2	Journal	Y	Y	Y	Y	Algorithm	4
Shah and Mishra (2016)	S3	Conference	Y	Y	P	P	Platform	3
Guo et al. (2016)	S5	Journal	Y	Y	Y	Y	Architecture	3.5
Curi et al. (2017)	S6	Journal	Y	Y	Y	Y	Algorithm	4
Hafeez et al. (2017)	S7	Journal	Y	Y	Y	Y	Algorithm	4
Risteska Stojkoska et al. (2017)	S8	Journal	Y	Y	Y	Y	Algorithm	4
Kontes et al. (2017)	S9	Journal	Y	Y	Y	P	Review	3.5
Tsui and Chan (2012)	S10	Journal	Y	Y	Y	Y	Model	4S
Pan et al. (2015)	S11	Journal	Y	Y	Y	P	Model	3.5
Brundu et al. (2017)	S12	Journal	Y	Y	Y	P	Framework	3.5
Feldmeier and Paradiso (2010)	S13	Journal	Y	Y	Y	P	Algorithm	3.5
Tsai et al. (2016)	S14	Journal	Y	Y	Y	P	Architecture	3.5
Khan et al. (2016)	S15	Journal	Y	Y	Y	P	Platform	4
Serra et al. (2014)	S16	Journal	Y	Y	Y	Y	Algorithm	4
Moreno et al. (2014b)	S17	Journal	Y	Y	Y	Y	Architecture	4
Asif et al. (2018)	S18	Journal	Y	Y	Y	P	Algorithm	4
Aswani et al. (2012)	S19	Journal	Y	Y	Y	Y	Model	4
Bujdei and Moraru (2011)	S20	Conference	Y	Y	Y	P	Model	3.5
Velusamy et al. (2013)	S21	Journal	Y	Y	P	P	Model	3
Salamone et al. (2016a)	S22	Conference	Y	Y	P	P	Model	3
Han et al. (2014)	S23	Journal	Y	Y	Y	P	Architecture	3.5
Zeiler et al. (2013)	S24	Journal	Y	Y	Y	Y	Review	4
Barata and Silva (2013)	S25	Journal	Y	Y	Y	Y	Model	4
Kumar (2014)	S26	Journal	Y	Y	Y	P	Platform	3.5
Gateau and Rykowski (2015)	S27	Conference	Y	Y	Y	Y	Architecture	3.5
Bari et al. (2015)	S28	Journal	Y	Y	P	P	N/A	3
Sehar et al. (2017)	S29	Journal	Y	Y	Y	Y	Algorithm	4
Moreno et al. (2014c)	S30	Journal	Y	Y	Y	Y	Algorithm	4
Uribe et al. (2015)	S31	Journal	Y	Y	Y	Y	Architecture	4
Salamone et al. (2016b)	S32	Journal	Y	Y	Y	Y	Platform	4
Salamone et al. (2017b)	S33	Journal	Y	Y	Y	P	Platform	3.5
Salamone et al. (2017a)	S34	Journal	P	P	P	P	Platform	3
Robles and Kim (2010)	S35	Journal	Y	Y	Y	P	Review	3.5
Fischer and Madani (2017)	S36	Journal	Y	Y	Y	Y	Review	4
Darby (2017)	S37	Journal	Y	Y	Y	P	Review	3.5
Thomas et al. (2013)	S38	Journal	Y	Y	Y	P	Review	3.5
Piyare and Lee (2013)	S39	Conference	Y	Y	P	P	Architecture	3
Baig et al. (2013)	S40	Journal	Y	Y	P	P	Platform	3
Rabbani and Keshav (2016)	S41	Journal	Y	Y	Y	Y	Algorithm	4
Zheng et al. (2013)	S42	Journal	Y	Y	P	P	Review	3
Yamauchi et al. (2015)	S43	Journal	Y	Y	P	P	Platform	3
Moreno et al. (2014d)	S44	Journal	Y	Y	Y	Y	Model	4
Javed et al. (2017)	S45	Journal	Y	Y	Y	Y	Platform	4
Luo et al. (2016)	S46	Journal	Y	Y	Y	Y	Model	4
Chen et al. (2013b)	S47	Journal	Y	Y	Y	P	Algorithm	3.5
Kim et al. (2015)	S48	Conference	P	P	P	P	Model	2
Drungilas and Bielskis (2012)	S49	Journal	P	P	Y	Y	Algorithm	3
Meana-Llorián et al. (2017a)	S50	Journal	Y	Y	Y	Y	Algorithm	4
Walker et al. (2016)	S51	Journal	Y	Y	Y	Y	Review	4
Chen et al. (2013a)	S52	Journal	Y	Y	P	P	Platform	3
Ciabattoni et al. (2016)	S53	Conference	Y	Y	P	P	Platform	3
Han et al. (2011)	S54	Journal	Y	Y	Y	Y	Architecture	4
Rehman et al. (2018)	S55	Journal	Y	Y	Y	Y	Algorithm	4
Patti et al. (2013)	S56	Journal	Y	Y	Y	Y	Infrastructure	4
Talari et al. (2017)	S57	Journal	Y	Y	Y	Y	Review	4
Jahn et al. (2010)	S58	Journal	Y	Y	Y	Y	Platform	4
Pan et al. (2012)	S59	Journal	Y	Y	Y	P	Review	3.5
Tereshchenko and Nord (2018)	S60	Journal	Y	N	P	P	Framework	2
Giuseppina and Salvatore (2015)	S61	Journal	Y	Y	Y	P	Review	3.5
Haider et al. (2016)	S62	Journal	Y	Y	Y	Y	Review	4-
Hang-yat and Wang (2013)	S63	Journal	Y	Y	Y	Y	Platform	4
Harfield and Rattanongphisat (2017)	S64	Journal	Y	Y	Y	P	Framework	3.5
Hargreaves et al. (2015)	S65	Journal	Y	Y	Y	P	Review	3.5
Manic et al. (2016)	S66	Journal	Y	Y	Y	Y	Review	4

(*continued on next page*)

Table 3 (*continued*).

Author/year	ID	Type	QA1	QA2	QA3	QA4	S-CATEGORY	TOTAL
Altayeva et al. (2016)	S67	Journal	Y	Y	Y	Y	Review	4
Lockton et al. (2013)	S68	Journal	P	P	P	P	Review	2
Kumar (2014)	S69	Journal	Y	Y	P	N	Platform	2
Mansur et al. (2014)	S70	Journal	Y	Y	Y	P	Algorithm	3.5
Langevin et al. (2013)	S71	Journal	Y	Y	Y	P	Review	3.5
Meinke et al. (2016)	S72	Journal	Y	Y	Y	P	Review	3.5
Moreno et al. (2014a)	S73	Journal	Y	Y	Y	P	Model	3.5
Kathiravelu et al. (2015)	S74	Journal	Y	Y	Y	Y	Architecture	4
Alan et al. (2016)	S75	Journal	Y	Y	Y	P	Algorithm	3.5
Zhu et al. (2015)	S76	Journal	Y	Y	Y	P	Review	3.5
Tila and Kim (2015)	S77	Journal	Y	Y	Y	P	Algorithm	3.5
Pritoni et al. (2017)	S78	Journal	Y	Y	Y	Y	Review	4
Huang et al. (2015)	S79	Journal	Y	Y	Y	Y	Algorithm	4
Brager et al. (2015)	S80	Journal	Y	Y	Y	Y	Review	4
Peffer et al. (2016)	S81	Journal	Y	Y	Y	P	Review	3.5
Rostampour and Keviczky (2018)	S82	Journal	Y	Y	Y	P	Framework	3.5
Royapoor and Roskilly (2015)	S83	Journal	Y	Y	Y	Y	Model	4
Michailidis et al. (2018)	S84	Journal	Y	Y	Y	P	Algorithm	3.5
Wei et al. (2018)	S85	Journal	P	P	P	P	Review	2
Wei et al. (2018)	S86	Journal	Y	Y	Y	Y	Algorithm	4
Jia et al. (2018)	S87	Journal	Y	Y	Y	Y	Review	4
Park and Rhee (2018)	S88	Journal	Y	Y	Y	Y	Review	4
AlFaris et al. (2017)	S89	Journal	Y	Y	Y	Y	Algorithm	4
Singh et al. (2017)	S90	Journal	Y	Y	Y	Y	Algorithm	4
Matsui (2018)	S91	Journal	Y	Y	P	P	Review	4
Ejaz et al. (2017)	S92	Journal	Y	Y	Y	P	Algorithm	3.5
Shakeri et al. (2017)	S93	Journal	Y	Y	Y	Y	Algorithm	4
Lu et al. (2017)	S94	Journal	Y	Y	P	P	Algorithm	3
Chellamani and Chandramani (2020)	S95	Journal	Y	Y	Y	Y	Algorithm	4
Samadi et al. (2020)	S96	Journal	Y	Y	Y	Y	Algorithm	4
Li et al. (2020)	S98	Journal	Y	Y	Y	P	Framework	3.5
Hakimi and Hasankhani (2020)	S99	Journal	Y	Y	Y	Y	Algorithm	4
Kerboua et al. (2020)	S100	Journal	Y	Y	Y	Y	Algorithm	4
Chamandoust et al. (2020)	S101	Journal	Y	Y	P	P	Infrastructure	3
Choo et al. (2018)	S102	Conference	Y	Y	P	P	Architecture	3
Qurat ul et al. (2018)	S103	Journal	Y	Y	Y	Y	Infrastructure	4
Ullah et al. (2020b)	S104	Journal	Y	Y	Y	Y	Architecture	4
Hassan et al. (2013)	S105	Journal	Y	Y	Y	Y	Framework	4
Hussain et al. (2018)	S106	Journal	Y	Y	Y	Y	Algorithm	4
Nadeem et al. (2018)	S107	Journal	Y	Y	Y	Y	Algorithm	4
Javaid et al. (2018)	S108	Journal	Y	Y	Y	Y	Algorithm	4
de Castro Tomé et al. (2020)	S109	Journal	Y	Y	Y	Y	Framework	4
Filho et al. (2019)	S110	Journal	Y	Y	P	P	Algorithm	3
Jamaludin et al. (2013)	S111	Journal	Y	Y	Y	Y	Model	4
Rodriguez et al. (2019)	S112	Journal	Y	Y	Y	Y	Algorithm	4
Khemakhem et al. (2020)	S113	Journal	Y	Y	Y	Y	Algorithm	4
Pawar et al. (2020)	S114	Journal	Y	Y	Y	Y	Algorithm	4
Ejaz et al. (2017)	S115	Journal	Y	Y	Y	Y	Algorithm	4
Arya et al. (2019)	S116	Journal	Y	Y	Y	Y	Algorithm	4
Becker et al. (2018)	S117	Journal	Y	Y	Y	Y	Model	4
Al-Ali et al. (2017)	S118	Journal	Y	Y	P	P	Algorithm	3
Liu et al. (2019)	S119	Journal	Y	Y	Y	Y	Algorithm	4
Jo and Yoon (2018)	S120	Journal	Y	Y	Y	Y	Infrastructure	4
Arya et al. (2019)	S121	Journal	Y	Y	Y	Y	Architecture	4
Yuliansyah et al. (2019)	S122	Conference	Y	Y	Y	Y	Infrastructure	3
Chandramohan et al. (2017)	S123	Journal	Y	Y	Y	Y	Algorithm	4

market stability has given the home resident the opportunity to plug smart LEDs together with modernized light infrastructure to minimize energy cost and consumption. Today the smart lighting system growth has reached over $20 billion and is estimated to reach $40 billion by 2024. Some of the industries with the highest smart lighting system include Signify Holding (Netherlands), Legrand SA (France) Eaton Corporation (Ireland), General Electric Company (US), and OSRAM Licht AG (Germany). These industries strive to make smart lighting systems are, investing in a greater share of smart lighting control-related system through adapting acquisition strategy. In 2019, the majority of these industries acquired technology developers of the Wiz Wi-Fi lighting control system. This helps to expand the leadership position and maintain the position in competition with the regional supplier and control the lighting ecosystem price.

*Challenge***:** smart lighting control is one of the fastest growing segments in the smart home market due to rising demand in automated street lighting, LED occupant lighting systems in developed and Asian Pacific countries. One of the major

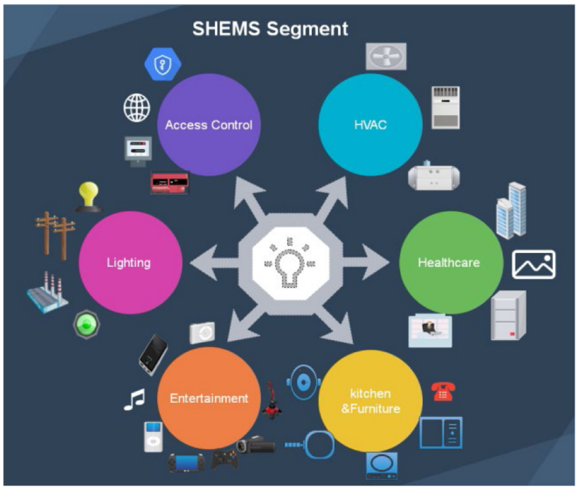

Fig. 6. SHEMS segments.

challenges faced by the smart lighting segment is the compatibility issue. The report showed that in 2018, end-users have experienced connectivity issues while connecting their appliance with Google Wi-Fi setup, and it seems the company is aware of the challenge. To survive the market competition, the smart lighting system has to overcome interoperability and allow connectivity issues across a wide range of technologies.

Integration of smart lighting with other lighting systems into smart cities such as parking-lot lights, traffic lights, pollution detection sensors, and energy metres is a logical approach to boost the smart lighting share in the market. However, current products available in the market offer only a few devices and accessories to be integrated, which poses a more significant threat to the development of future smart cities. Furthermore, with increased magnitude in voice controlling research, the industry could consider voice control lighting system development solutions together with other innovative lighting applications such as horticulture, speciality, solar, and human-centric lighting. Another opportunity is the integration of LED wireless-based technology into an automobile. This could serve as a significant advancement for a luxury car to be incorporated with smart lighting.

Smart Access Control: Conventional access cards remain the biggest player in the market. However, today many industries have focused on smart application Bluetooth based technology to offer residents remote access control over secured elevators, doors, and turnstiles (Markets and Markets, 2020). This innovative technology has the potential to revolutionize the digital security market industry eliminating the burden of security access card management and maintenance through the provision of smart access security control via mobile application. Lack of security standard and security architecture requirements to suit current smart devices is one key factor that is slowing the market of smart access control. Even though the smart access control market is still young, recently, the market observed increased demand in smart locks and smart cameras to record and monitor both customer and employee activities. According to the recent forecast on the global crime rate, the estimated market growth is expected to rise from $7.5 billion to $12 billion by 2025. Reliability and affordability of smart access control over traditional proximity and magnetic stripe cards are key driving factors bringing a new investor on board. The key market player of smart access control includes ASSA ABLOY AB (Sweden), Johnson Controls International Plc (Ireland), Dormakaba Holding AG (Switzerland), Allegion Plc (Ireland), Honeywell Security Group (US), Identiv, Inc. (US), Nedap N.V. (Netherlands), Suprema HQ Inc. (South Korea). These market players use product acquisitions, partnerships, and product launches as competition strategies to keep and bring new foreign and local investors to the market.

*Challenge***:** Although research on IoT in academia and industries is still in its infancy, most of the current access control provides authentication and validation of resident identity without securing end-to-end communication broadcasting resident credentials, among other smart home appliances. Therefore, there is a need for an upgrade on current smart access control to ensure end-to-end security encryption solution to achieve an adequate level of security for the user credentials.

Smart HVAC (Markets and Markets, 2020): is one of the advanced achievements in smart aimed at providing thermal comfort satisfaction to the resident as well as purchasing energy at a low price and avoid unnecessary energy consumption. Today different smart thermos, including occupants' detection, sensors, light, and thermal-based control are available at the global market to ensure stakeholders achieve substantial energy saving and help to obtain real-time information on energy consumption. Recently there is the increased deployment of a smart HVAC platform equipped with sensors that offered remote sensing to regulate the thermostat. This remote sensing application can be configured to monitor and manage room temperature, humidity, and refrigerator. The global market for HVAC control accounted for $14 billion in 2018 and is estimated to reach $27 billion by 2023. The major driving factor for share growth is the ongoing demand for building automation and the efficiency of the products. The major market player for smart HVAC control includes Jonson (US), Siemens (Germany) and Honeywell (US).

*Challenge***:** Researchers in Serra et al. (2014) have shown concern regarding practice employed to regulate smart HVAC thermostat, which has been proven to reduce the life span of smart home energy products. For example, the current method for handling temperature control is mainly based on the classical binary approach, which tends to cause frequent OFF and ON of the appliance when the desire value set is not stable, especially in the afternoon period, which in turn tends to reduce their lifespan. An alternate method should be considered, such as a fuzzy control algorithm that would help to regulate temperature efficiently even in a situation where the temperature in the room is not stable.

Another challenge is maintaining thermal satisfaction of resident, which is a significant factor that influences the market of smart HVAC system for healthy living and higher productivities at the workplace. Future designs for smart HVAC systems should feature a technique that manages and maintains the thermal comfort satisfaction level of the resident to avoid health challenges.

The Smart Healthcare System: is one of the important IoT technologies that exist today. The technology allows a doctor to treat and care for the patient at home. There is a wide range of applications in the market that enable doctors to examine the health status of the patient at home, such as potential heart attack, drug usage, the blood pressure level of the patient. Other advancements include mechanical applications such as a smart robot, the ambient assistant agent should be a research focal point that would assisting treating viral disease remotely without the risk of being infected. Recently, the University of Tsinghua China developed an automated robot (Gangtie, 2020) to reduce the spread of Corona virus among the citizens of China. The robot can determine the potential victim, deliver food and water to quarantine patients, provide oral treatment. This is one of the major factors that the Chinese government has adopted to reduce the spread of Corona virus to medical personal.

Today there is increased demand for smart mechanical healthcare assistant agents to monitor and assist patients suffering from diabetes, heart ailments, asthma, and joint pain. The global market for smart healthcare system already hit \$6 billion and forecast to reach \$30 billion by 2026. The major key players in this sector include Health Care Originals, Apple, Google, and Medical Guardian LLC.

*Challenge***:** The smart healthcare industry is one of the fastest-growing segments in the smart home market today. This is driven by improving ease of access to healthcare application cost. However, with the current increase in the world population, the outbreak of viral disease and an increasing number of older people requires an ambient assistant. There is a need to increase the number of innovative applications to provide autonomous assistant to treat the patient and assist older people.

Current smart healthcare applications require integration of many technologies to connect patient with doctors, and on many occasions, these applications face interoperability challenges. Researchers in academia and industries must focus on developing cross-platform layers that address interoperability issues in smart healthcare applications.

Privacy has a long history in the smart healthcare system and has become a bottleneck for global acceptance of this advancement to society. A smart healthcare system usually communicates and shares data among various platforms and technologies to establish mutual communication between doctor and patient.

Recent studies show patient data are being shared with the public domain for research and analytic purpose without other technologies of concealment of patient privacy. This practice poses threat to patient privacy, and it is necessary to integrate techniques for privacy-preserving in the future smart healthcare system for the broad acceptance of this innovation into society. Imaging smart security in healthcare applications is essential for today's era of the connected world accessible by a different type of criminals with different intentions (Aliero et al., 2019): imaging hijacking, disruption, interception of healthcare application in the middle of the operating theatre by cybercriminals.

A recent study shows smart healthcare system has become a prime target of worldwide cyber-attack in recent years. These applications are designed without security considerations. Therefore, smart healthcare research must focus on modelling classes of advanced traditional security mechanisms to suit smart healthcare applications and integrate them in the next generation of smart healthcare applications to avoid cyber murder.

Smart kitchen (Markets and Markets, 2020): uses different sensors designed to provide comfortable and convenient kitchen activities. These appliances are well equipped with wireless and Bluetooth based connectivity features to provide communication with other smart house appliances such as tablets and other remote handheld appliances. Today, academia and industries are focusing on smart kitchen integration and other start-up products with several smart kitchen appliances available in the market equipped with sensors for easy operation and to help residents regulate kitchen activities remotely. Smart kitchen appliances are energy efficient compared to conventional kitchen appliances, which is expected to raise their demand in the market in coming years. The global market growth for the smart kitchen has already reached \$2.7 million and expected to reach \$8.5 million by 2027. The major participants in the market include LG (US) and Tovala.

Challenge: Whenever we talk about the smart kitchen, everyone will think of a phenomenon where you have kitchen system control by artificial intelligence to prepare a favourite resident meal. A number of smart kitchen appliances available at the market today are handy. With today's reliance on technology, it is a big opportunity for smart kitchen industries to consider a more sophisticated smart kitchen that would adapt to a favourite resident meal based on resident historical data for more straightforward preparations. Featuring the next smart kitchen generation with the ability to recognize your favourite meal, order recipe and ingredient and cooked resident favourite food will the game-changer in the smart home market.

Smart Furniture (Markets and Markets, 2020): is the segment of smart home solutions that monitor residents surrounding information to ensure comfort satisfaction and integrated functionality. An increase in individual income and the nation's economy is a key factor influencing individual lifestyle change. The technology mainly monitors resident fitness such as bedtime, nutrition, hygiene, and total burned calories. Additionally, smart furniture has features that provide wireless charging to smartphones and Bluetooth speakers. Recently it was announced the upcoming smart furniture would feature technology that monitors employee work productivities, the status of the closet, and alarm for the messy environment. The global market for smart furniture has reached $174 million and estimated to hit $795 million by 2026. The market players in smart furniture include Smart Living LLC, Ori Systems, and Ikea Group.

*Challenge***:** The current smart Furniture available in the market can monitor the status activity style of the resident within the surrounding which includes standing, seating, sleeping and eating, and this information is being shared among other smart home appliances such as smart home metre autonomously without any authentication mechanism. This practice also can introduce a privacy challenge that can lead to theft or committing a high-level crime since criminals can manage to gain access to smart furniture and deduce the time the resident is at sleep or not present at home. The industries should consider advanced security mechanisms in future smart furniture to ensure proper identification before the establishment of communication between smart home and outsider.

4.1. SHEMS products

A smart home energy management system is the platform that handles mutual communication between energy providers and consumers as well as manages energy consumption by smart home appliances. The platform provides functions such as checking the energy purchase price, energy purchase, managing appliance energy demand, and eliminating excess energy usage. There is ongoing research on smart home energy management systems in both academia and industries. This section study described the top 10 smart home energy management systems available (IoTLineup, 2020) in the market.

Philips Hue-Hue Go: is the smart light control emitting different exiting colours of light. The Hue lighting system is not bright enough to replace the lamp that lights up the room and does not work without Hue Bridge, which the resident has to acquire separately as standalone or purchase Hue kit. The platform has a mobile application that can be used by the resident to control the light remotely. Amazon Echo is technology implementing a similar approach with Hue Goand can recognize Hue light build; however, the Hue Go does not support Amazon Echo.

Smart Nest thermostat: is one of the smart home energy management systems you can find in the market that can learn from resident energy patterns used and adapt to it autonomously without having to specify it. The device allows the resident to view historical energy consumption and manage connected smart home appliances remotely via the internet. Current Smart Nest Thermostat in the market does not have the feature to predict the time or best time for energy purchase so that the shift able appliances need to be scheduled ahead for cheaper energy consumption rates.

Logitech POP smart button provide a resident with three gestures to perform different functions and come with colourful light similar to Hue-Hue Go. POP allows a resident to connect and manage other smart home appliances such as door lock, HVAC system with a simple push-button. Additionally, the device offers the resident the sleep mode option that automatically adjusts the room temperature and turns off the home lights with the press of a button. To boost the market opportunity of the POP, smart button should feature techniques that can establish communication with other smart furniture to learn the sleep schedule of the resident so that everything goes automatically without having to touch sleep mode.

Norm Smart Thermostat: Isa smart home energy management device that connects with the HVAC system via Wi-Fi to allow a resident to manage room temperature. It has a feature that can learn from resident thermal satisfaction, such as cooling and heating preferences, and automatically adjust it for residents before arriving at home. Even though the device cannot connect and manage other smart home appliances, it is one of the best smart devices in the market to ensure the thermal satisfaction of the resident. One of the glitches observed by customer review is that Norm Smart Thermostat does not give accurate temperature reading. Still, the resident can alternatively use Wink mobile application or Wink wall-mounted relay to view and adjust the temperature of the room with additional expenses.

Honeywell smart home thermostat and Norm smart home thermostat implement a similar approach in terms of functionality. Additionally, Norm allows the resident to connect and manage lighting systems on mobile applications, schedule energy utilization among devices, and provide a resident with energy-saving mode. Unlike Norm, Honeywell delivers an accurate reading on the touch screen and allows the resident to check outside temperature.

Ambi Climate: is a smart temperature controller that replaces Air-condition infrared remote control with something more intelligent. The technology allows a resident to sync Air-condition with mobile application giving full control access to manage and monitor room temperature anywhere. The device offers an additional feature to ensure comfort satisfaction of residents by continues monitoring of resident preference to the precise temperature set point on the cloud for the future prediction. Ambi Climate ensures resident thermal comfort satisfaction by considering indoor temperature, outside temperature, and resident historical data from cloud to set his temperature set point automatically tailored to his comfort satisfaction, which helps to save more energy than a traditional approach. Looking deeper into this practice, we can realize the device will face a challenge to balance the thermal comfort satisfaction for more than three residents of different thermal comfort preferences.

ZEN Thermostat: is a smart home energy management device that uses a programmable thermostat to regulate the HVAC system and maintain resident thermal satisfaction and avoid excess energy usage. ZEN features scheduling options based on resident preferences to use energy such as time to leave and arrive at home. This enables the device to easily develop a resident profile for better energy utilization. For example, ZEN reduces energy consumption by the HVAC system through the use of low-temperature minutes before the resident arrives at home, which is more energy-efficient to stabilize the room with comfort temperature than starting with high temperature on the arrival of resident at home.

Keen Home: is SHEMS that offers ventilation regulation and is efficient in place that is not frequently used in the house. The device is very easy to be installed on the wall to regulate the room temperature by creating zone within the house such as Bedroom, Dining, or kitchen instead of cooling or heating the whole house to avoid the challenge of some rooms being too hot or too cold. It allows the resident to schedule the operation and also have mobile control capability anywhere. The idea behind this is to have personalized particular room temperature within the house, especially in summer, when individual rooms tend to be hotter; Keen can direct cold to it or allow you to divert warm air away.

Foobot: is another type of smart home device rather than smart home energy management devices that can be placed in the room to monitor the air quality. It keeps the resident up to date about temperature and humidity values and sends an alarm whenever the air quality level is not healthy. There is a variety of diseases that infect home residents are a result of bad air quality. This health concern includes dementia, cerebrospinal meningitis, among other diseases mostly caused by bacteria Neisseria meningitides covering the brain and spinal cord, which results in a stiff neck, high fever, rash, severe headache, vomiting, and confusion. The device can also detect air pollutants such as carbon dioxide and other volatile organic compounds that can endanger the life of residents even at low concentrations.

5. Research opportunity

Improve occupants' thermal comfort through smart sensing and intelligent control: The thermal comfort satisfaction of occupants is one of the primary goals of the SHEMS. However, recent researches are constantly and extensively focusing towards energy saving without much given emphasis on occupant's thermal comfort. Current Smart home sensing technologies are seeking for new intelligent learning algorithms to promote HVAC occupants responsive research under various active states on occupant's skin temperature utilizing the wearable device and contactless sensing to infer personalized and adaptive thermal comfort.

Improve occupants' thermal comfort through building design: improving the current building envelop (basement wall, sidewall, slab) through the accounting of energy efficiency in the building design to eliminate the issue of heat loss resulting in excess heating or heat gain, which results in excess cooling. Efficient quality insulation on the attic, walls, doors, and windows should be accounted similar to having efficient heating and cooling equipment to reduce follow of heat into the room as well as keep the indoor cold from seeping outside, is one of the logical ways to cut unnecessary heating or cooling. Similarly, careful positioning of the HVAC equipment and other optical factors influencing how thermal radiation of the building are key factors to consider to achieve thermal energy-efficient home.

Standard pricing scheme: Another research opportunity in the smart home energy management system is the introduction of an energy pricing scheme based on energy demand from customers and the ability of distribution centres to satisfy their order to reduce irregularity in energy consumption bills. The current smart home energy management system cannot provide actual pricing for energy for a day or a specific time interval, even with communication with energy providers ahead of energy usage. This is one of the factors that drive high energy costs, especially at an event of peak demand from customers.

To handle this, it is essential that energy providers should make historical energy consumption data available to an energy control system to ease development of price estimation of the model based on assumption using dependent variables such as meteorological data that can be used to predict the level of energy demand and previous pricing scheme patterns. Presenting the estimated pricing will help the resident to make a decision on scheduling time to use energy at a low cost rate for shift able appliances. For example, pumping water on storage tanker can be scheduled at any time in a day as long as storage is not empty, heating water storage for future use such as bathing, kitchen purpose or any other relevant heating or cooling can be scheduled when the cost of energy is at low price which will help save money in the long run.

Lighting system: Research has made a tremendous contribution in the lighting system to ensure feasible and efficient energy consumption which include smart lighting technology improved lumen, dimmers, and LEDs. However, today, lighting system is one of contributing factors that account for excess energy consumption as a result of poor lighting control management practice and bad building design. One way to reduce energy consumption in a lighting system is to consider an ideal approach that allows optical lighting parameters to be managed independently. Similarly, window insulation and position should be considered to achieve efficient transparency to the sun in such a way that it can absorb brightness into the room without threatening the skin or damage to materials. Placing daylight sensors and motion detection sensor lights on less frequent use areas will reduce unnecessary lighting. Good window insulation and right skylight positioning combined with dimmers will help to cut energy consumption by an average of 40%.

Security: Security has been a real issue since the inception of smart home, particularly on ensuring availability and secure communication of smart home appliances. Today smart home energy management systems are among the top target interest by cybercriminals which shows the rapid increase of attack threats and vectors ranging from denial of service to breach of confidentiality and integrity of the resident personal information due to lack of adequate level implementation of security mechanisms and infrastructure to ensure an end to end communication between smart home energy management appliances (Qureshi et al., 2017).

The dimension of new vulnerabilities and attack-vectors are likely to increase in the future as a result of the ongoing deployment of smart home energy management system without accounting for security requirements. A few security schemes lack universality and are usually applied to secure special communication or applications domain. To ensure global acceptance of smart home energy management system products, industries have to ensure smart home devices are secure against any form of attack that security breaches are immediately reported upon detection. The primary way to manage this problem is through research funding and collaboration among researchers in academia and industries.

Privacy: Another challenge is privacy; for example, smart metre connected with smart appliance responsible for tracking resident behaviour patterns, vital body signs such blood pressure, heart rate, body temperature, drug overdose, muscle strength, sleeping hours, medical prescription. It is essential to know this information is dynamically processed in real-time and shared with energy providers and other relevant service providers or in the cloud for data analytic. Current practice exposed notable resident personal data directly without preserving its privacy. This became particularly dangerous when occupants' activities or medical status can be personally identified by cybercriminals or unintended individuals as it poses threat to resident personal privacy (Aliero et al., 2020; Babar et al., 2018; Bai et al., 2019; Kong et al., 2020; Qureshi et al., 2020e; Chehri and Jeon, 2018; Iqbal et al., 0000; Slalmi et al., 2019).

Scalability: scalability is a major factor that ensures the universal expansion of the smart home energy management system. Today there is a high demand for smart energy management system infrastructure that can accumulate newly added smart appliances for better energy management operation. Current lighting technology in the market has a limited number of lighting bulbs and accessories they can accommodate at a time, for example, replacing traditional lighting within the building that is not often used. For instance, bathroom, kitchen hallway, garage, and store with motion sensor lights, while two other spots, such as living room and bedroom can be equipped with dimmer lights in order efficiently use energy, thereby cutting the energy consumption bill.

Imaging using a single Hue goes for this type of configuration as it can only handle 50 lights and 12 dimmers or motion sensors. Fixing five sensor switches in the first configuration take 47% of the Hue Go hub capacity, setting six dimmers, three in living room and three in the bedroom; will take 96% of capacity, which makes it impossible to add other accessories in the future. What if the resident suddenly has to deal with three bedrooms, entrance, and backdoors with motion sensors? This is why scalability matters in the development of a smart home energy management system to reduce the technical and management operation of the smart home lighting system.

Interoperability: Current smart home energy management systems provide a resident with limited functionalities; for example, smart light system cannot communicate with the HVAC system or smart access control to ensure the security of resident. This implies that residents that are away from home would not be able to know the status of home security through the smart lighting system. The smart home is an environment that brought together a number of smart appliances of different manufacturers without sharing mutual standard communication protocols.

The interoperability issue is one of the obstacles that hinder the rapid growth and development of complex smart home energy management systems with broader functionalities. The issue can be expressed as a language barrier among smart home appliances. For example, communication between lighting system and HVAC system requires language understanding, and image lighting system speak only designated language by its manufacturer. HVAC system also understands only its own language designated by a different manufacturer so in this case, it would be difficult for these appliances to communicate with each other without a common language. This is a very challenging factor that needs to be resolved to ensure the expansion of smart home energy management systems with wider functionalities; otherwise, the future growth of the smart energy management system will collapse and be compromised.

However, there are some initiative projects and proposals aimed ate common understanding among participating smart appliances in smart home environments, and these initiatives include IEEE P2413, ZigBee Alliance, X10, and Z-Wave. This shows providing standardize unified architecture models suitable to support interoperability among a diversity of smart appliances regardless of their specification or manufacturers will promote universal growth for future smart home energy management systems.

6. Conclusion

Today, global energy demand is increasing faster than the expected annual rate, which is driven by an increasing number of world population, production industries, transportation, building, and many other sectors. Study shows building sectors account for an average of 35% of energy demand worldwide due to the new, improved standard of living of individuals around the world. Subsequently, energy prices in the market impacted negatively posing a threat to the thermal comfort satisfaction of home residents.

Fossil fuel accounts for 44% of global energy sources which currently poses a threat to Inhabitant and well-being of the environment. Today, more emphasis is placed on other sources of energy, such as renewable to harness energy from nature, which has been less concerned about global warming in order to satisfy the energy consumer demand. Building sector is among high energy demand with a large percentage of energy waste. This is a result of poor energy utilization and operational policy control practice and implementation.

Over the years, researchers in industries and academia have attempted to deal with this problem through implantation of renewable energy sources, Smart grid and SHEM's solutions to reduce energy demand, waste and ensure reliability of energy supply in building sectors and provide healthy and convenient living environment. The solutions implement various sensing technologies used in home appliances jointly connected via a network to provide synergy to facilitate smooth autonomous communications.

The study investigates different forms of energy generation technology and how it can be coupled with SHEM's system to balance the energy demand supply in building sectors. The study shows fossil fuel is major source of world energy which implies demand for expansion and adaptation of renewable energy sources to curtail the rising issue of global warming and provide healthy living environment.

Similarly, this study critically analyses and synthesizes the recent SHEMS literature to control and manage energy demand and utilization of home appliances. The review analysis of a large number of literature have reached the certain level of smartness proving automatic prediction of occupant's behaviour towards energy consumption, implementing occupants fixed occupants schedules, real-time occupants data processing technology. Furthermore, study provides overview on SHEM's market and products reporting the progress and challenges.

Finally, the study concludes with results finding and future recommendations on current literature of SHEMS which includes special intervention to increase the maturity level of home appliances (entertainment, kitchen, furniture, security lock, and HVAC) through machine learning and artificial intelligence, promote research collaboration among industries and academia to develop new occupants thermal comfort responsive approach to improve current building design, and sensing technologies to ensure occupants thermal comfort level is within the acceptable level. The remaining technical findings shows less emphasis on security, privacy, scalability, and interoperability considerations on current deployed SHEMS products.

Declaration of competing 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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