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Review

Design and Implementation of Smart Buildings: A Review of Current Research Trend

Dongsu Kim [1], Yeobeom Yoon [2], Jongman Lee [3], Pedro J. Mago [4], Kwangho Lee [3,*] and Heejin Cho [5,*]

[1] Department of Architecture Engineering, Hanbat National University, Daejeon 34158, Korea; dongsu.kim@hanbat.ac.kr
[2] Building Technologies Research and Integration Center, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831, USA; yoony@ornl.gov
[3] Department of Architecture, College of Engineering, Korea University, Seoul 08308, Korea; leejongman93@gmail.com
[4] Department of Mechanical and Aerospace Engineering, Statler College of Engineering and Mineral Resources, West Virginia University, Morgantown, WV 26506, USA; pedro.mago@mail.wvu.edu
[5] Department of Mechanical Engineering, Mississippi State University, Starkville, MS 39759, USA
* Correspondence: kwhlee@korea.ac.kr (K.L.); cho@me.msstate.edu (H.C.)

Abstract: The building sector is one of the largest contributors to the world's total energy use and greenhouse gas emissions. Advancements in building energy technologies have played a critical role in enhancing the energy sustainability of the built environment. Extensive research and new techniques in energy and environmental systems for buildings have recently emerged to address the global challenges. This study reviews existing articles in the literature, mostly since 2000, to explore technological advancement in building energy and environmental systems that can be applied to smart homes and buildings. This review study focuses on an overview of the design and implementation of energy-related smart building technologies, including energy management systems, renewable energy applications, and current advanced smart technologies for optimal function and energy-efficient performance. To review the advancement in building energy-related technologies, a systematic review process is adopted based on available published reviews and research types of articles. Review-type articles are first assessed to explore the current literature on the relevant keywords and to capture major research scopes. Research-type papers are then examined to investigate associated keywords and work scopes, including objectives, focuses, limitations, and future needs. Throughout the comprehensive literature review, this study identifies various techniques of smart home/building applications that have provided detailed solutions or guidelines in different applications to enhance the quality of people's daily activities and the sustainability of the built environmental system. This paper shows trends in human activities and technology advancements in digital solutions with energy management systems and practical designs. Understanding the overall energy flow between a building and its environmentally connected systems is also important for future buildings and community levels. This paper assists in understanding the pathway toward future smart homes/buildings and their technologies for researchers in related research fields.

Keywords: smart home; smart building; energy management system; building-to-grid integration; renewable system integration; electric vehicle integration

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1. Introduction

The rapid growth of energy consumption globally has led to concerns about greenhouse gas emissions (GHG) and, thus, global warming. Global energy consumption grew by 2.3% in 2018, at nearly twice the average growth rate since 2010 [1]. The building sector has been considered a major contributor to fossil fuel energy consumption and carbon gas emissions. Increased heating and cooling demands in the building sector are one of the main reasons for increasing energy consumption and emissions worldwide. Energy-related emissions contribute as much as 80% of the EU's total GHG emissions, and the building sector accounts for about 40% of the EU's total final energy consumption [2]. The U.S. Energy Information Administration (EIA) [3] reported that the building sector's share of the global delivered energy consumption would increase from about 20% in 2018 to 22% in 2050. As the building sector is one of the largest contributors to the world's total energy use, it also offers the greatest energy savings potential compared to other sectors [4]. According to the U.S. EIA [3], electricity used for appliances, lighting, cooling, heating, and other equipment in buildings is the primary source of energy consumption in both residential and commercial building sectors. Understanding energy consumption and the environmental impact of the building sector is crucial to reducing the energy and the associated issues [5].

Various building energy-related technologies have been introduced and developed to support these global challenges of reducing building energy consumption and GHG emissions, including passive design and active system measures. Those technologies should consider various indoor environmental factors in parallels, such as room temperature and air quality, in the design and operation to achieve a high-quality indoor environment with low energy consumption [4]. The energy-efficient technologies could be classified into several categories from different perspectives, including passive system design (e.g., building geometry design, external wall insulation, and window systems), building service devices (e.g., lighting and electrical appliances), active systems (e.g., heating, ventilation, and air-conditioning (HVAC), domestic hot water systems, and renewable energy systems), and operation design (e.g., building energy management and control) [6]. Those technologies are designed to accomplish energy reductions and energy-efficient management under built-environment conditions by minimizing building energy demands and balancing them with on-site distributed power supply. Various smart building and control concepts can be considered to enable flexible and sustainable operations. Many literature review studies have been conducted, e.g., [7–12]. Research and technology development in the energy and environmental system for buildings has rapidly evolved, and many recent advancements have not been reviewed in the existing literature. This study provides a state-of-the-art review of the energy and built-environmental system and relevant techniques by focusing on aspects of smart home/building(s)-related systems and their operation, including smart energy management systems, smart technologies for optimal function and energy-efficient performance, and renewable energy applications for smart buildings and their integration with energy grids or within the community.

This study critically reviews scientific publications on designing, modeling, and optimizing energy and environmental systems for building applications, focusing on the smartness of building energy and environment management, and reducing building energy consumption and GHG emissions. This study adopts a systematic review approach to retrieve the available literature to overview recent advancements and revolutions. The detailed review methodology is addressed in Section 2. Section 3 focuses on the design and applications of smart home/building(s) based on the published articles. This section describes smart home and building concepts and definitions, mostly using review-type articles first, and then discusses the research articles concerning smart energy management and associated technologies in the smart home/building. In Section 4, discussions on research papers on building-to-grid integration, renewable energy integration, and electric vehicle (EV) integration with smart home management systems are provided. Finally, the Conclusions Section summarizes research gaps and future trends in designing and implementing advanced energy-related technologies that can be applied to smart homes and buildings under built-environmental systems.

2. Review Methodology

The review explores and searches relevant articles based on related keywords. The research articles published in reputable scientific peer-reviewed journals based on MDPI's and Elsevier's database (e.g., Open Access [8], Scopus, and ScienceDirect [9] journals) mostly since 2000 have been reviewed with focused topics, including smart home/building(s), smart grid and community, as well as smart-building-related technologies. The literature search associated with the keywords is conducted by identifying article types and scopes through an iterative process using the publication databases. Figure 1 shows the workflow of the systematic review process for this study. The word-cloud statistical analysis using Python's word cloud statistics library is first conducted to explore the review-type articles based on the keywords, and then major research scopes associated with smart buildings' design and implementation and their technologies are captured. The cited articles from the review-type articles are also examined to explore the research-type articles. The review of the searched research-type articles is carried out to investigate major research objectives, focuses, limitations, and future considerations.

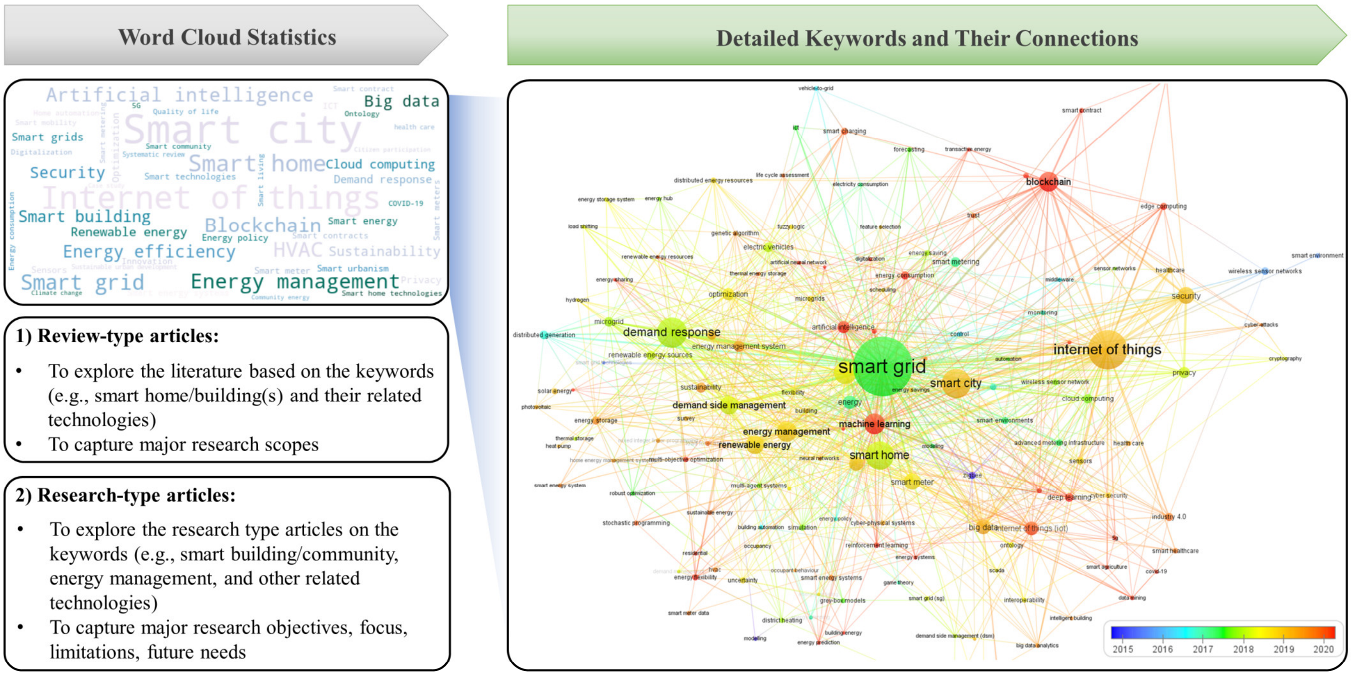

Figure 1. Workflow of the systematic review process for the study.

Figure 1 also presents the detailed keywords and their network connections regarding research-type articles' keywords. The connection map is created using the VOSviewer [10], developed by Leiden University. The connection map depicts research trends throughout the years of 2015 to 2020 by keywords.

3. Smart Home/Building Design and Application

The smart home/building concept has become a prominent theme in recent years. The transformation in the smart product market and energy management service industry has led the growth of smart home technologies globally [11]. Many advantages of smart home/building systems have been reported through many studies, e.g., increased personal thermal comfort and safety, energy cost reduction, and flexibility [12], and various definitions of smart homes have been conceptualized and defined. Table 1 summarizes definitions of a "smart home" dating back to 1992.

Table 1. Literature review of representative definitions regarding smart homes.

Source	Year	Definition
Lutolf [12]	1992	*"The integration of different services within a home by using a common communication system. It assures an economical, secure, and comfortable operation of the house and includes a high degree of intelligent functionality and flexibility."*
Aldrich [13]	2003	*"A residence equipped with computing and information technology, which anticipates and responds to the needs of the occupants, working to promote their comfort convenience, security, and entertainment through the management of technology within the home and connections to the world beyond.*
Chan et al. [14]	2008	*"A house, which promises to provide cost-effective home care for the aging population and vulnerable users."*
De Silva et al. [15]	2012	*"A home-like environment that possesses ambient intelligence and automatic control, which allow it to respond to the behavior of residents and provide them with various facilities."*
Balta-Ozkan et al. [16]	2013	*"A residence equipped with a high-tech network, linking sensors and domestic devices, applications, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the need of its inhabitants."*
Saul-Rinaldi et al. [17]	2014	*"Inclusive two-way communication systems between the house and its occupants."*
Buildings performance institute Europe [18]	2017	*"Is highly energy-efficient and covers its very low energy demand to a large extent by on-site or district-system-driven renewable energy sources. A smart building (i) stabilizes and drives faster decarburization of the energy system through energy storage and demand-side flexibility; (ii) empowers its users and occupants with control over the energy flows; (iii) recognizes and reacts to users' and occupants' needs in terms of comfort, health, indoor air quality, safety as well as operational requirements."*
Hargreaves and Wilson [19]	2017	*"Collects and analyses data on the domestic environment relays information to users (and service providers) and enhances the potential for managing different domestic systems (e.g., heating, lighting, entertainment)."*
Strengers and Nicholls [20]	2017	*"Encompasses home ICTs, connected and automated devices and appliances, and the Internet of Things."*
Shin et al. [21]	2018	*"An intelligent environment that can acquire and apply knowledge about its inhabitants and their surroundings to adapt and meet the goals of comfort and efficiency."*
Gram-Hanssen and Darby [22]	2018	*"One in which a communications network links sensors, appliances, controls and other devices to allow for remote monitoring and control by occupants and others, to provide frequent and regular services to occupants and the electricity system."*
Marikyan et al. [23]	2019	*"A residence equipped with smart technologies to provide tailored services for users."*

Although numerous articles have defined a smart home/building, there are no standardized definitions [22]. The area is still being expanded based on different aspects of home/building and their associated technologies. Through comprehensive reviews of the existing literature on smart home/building applications, it is determined that the critical attributes of such technologies are based on the data and communication network that link various technological devices and systems with energy management systems and end-users [16]. Those network devices and services enable enhanced daily activities of occupants (e.g., comfort, energy conservation, healthcare, and security) by incorporating smartness into the spaces [11]. There are many categorized types of smart services that offer a better quality of life and work environment in these places. Those types depend on the needs of the target and preferred technical applications in homes and buildings. Balta-Ozkan's study [16] was grouped into three categories (see Figure 2): energy consumption and management; safety; and lifestyle support from a holistic approach.

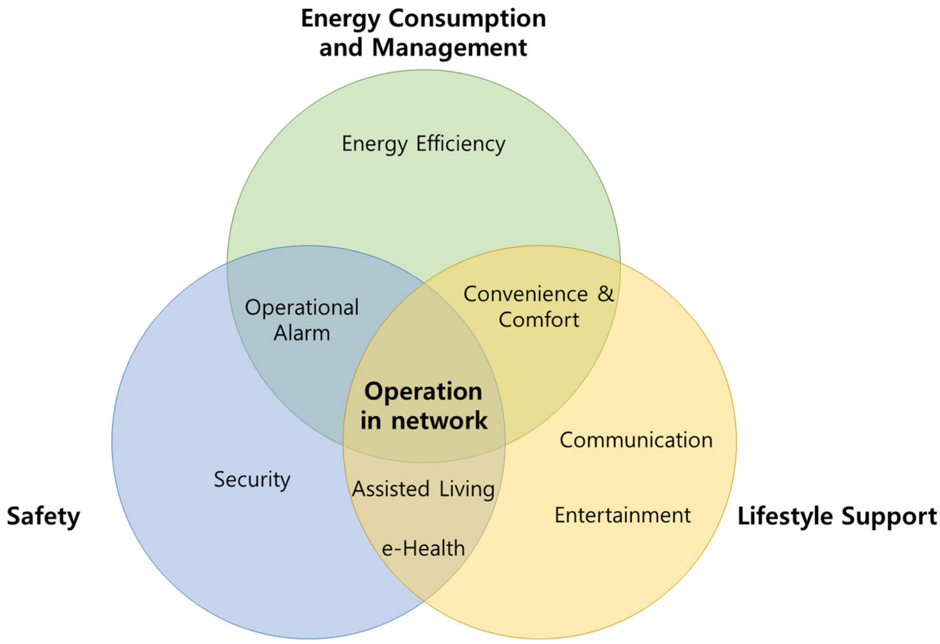

Figure 2. Types of smart home services reprinted with permission from Ref. [16].

Figure 2 depicts the related categories containing associated keywords according to the intended services. Related devices and systems in each category are operated in a network by enabling sensors, actuators, and monitors and connecting them to a local energy management system or web-based server/application [14]. The energy management system diagnoses the ongoing situation and initiates assistance procedures, relying on several vital aspects [16]: (1) a fast and reliable communications network, (2) intelligent controls to manage each device based on information from sensors or users, and (3) data/information collected from smart sensors and actuators. Note that among these categories, energy consumption and system management are considered as the core of services supporting the development of smart grids [16]. A systematic literature review is conducted based on the various review and research articles regarding smart home/building(s) and their related technologies, which have been published since 1992. Table 2 summarizes review-type journal articles based on smart home/building, technologies, applications, and case studies.

Table 2. Summary of review-type journal articles regarding smart home/building(s) and their related technologies.

Source	Year	Review Focus of Article	Major Contents
Lutolf [12]	1992	*"Major contribution is to describe general aspects of "Smart Home" systems, including application examples and customer benefits."*	• Definition • Typical application areas • Customer benefits and advantages
Aldrich [13]	2003	*"This study aims to provide the motivation and the background for social scientists to become involved with the emerging phenomenon of the smart home."*	• The past, the present, and the future of the smart home: - The historical definition and context about the smart home - The social science of domestic technology in general for smart home/buildings - Future aspects of smart home/buildings

Table 2. *Cont.*

Source	Year	Review Focus of Article	Major Contents
Chan et al. [14]	2008	*"This article presents an international selection of leading smart home projects and the associated technologies of implantable monitoring systems."*	• The smart home projects review: In the U.S., Asia, Europe, Australia, and New Zealand • Wearable and implantable systems review: In the U.S., Asia, Europe, Australia, and New Zealand • Future challenges
Silva et al. [15]	2012	*"A review of the state-of-the-art of smart homes: the viewpoint of specific techniques utilizing computer vision-based techniques and audio-based techniques and smart homes."*	• Video-based techniques in smart homes • Audio-based techniques in smart homes • Multimodal-based techniques in smart homes • Smart homes for eldercare • Smart homes for energy efficiency • Future challenges
G. Hoseini et al. [24]	2013	*"This study attempts to theoretically analyze case models of smart homes to identify their essence and characteristics."*	• Review of smart house cases: - The gator tech smart home - Matilda smart house - Duke university smart house - MIT smart house - The aware home developed at Georgia Institute of Technology - Smart home lab at Iowa state university - Toyota dream house PAPI
S. Al-Sumaiti et al. [25]	2014	*"This article reviews the goals of a smart home energy management system, along with related definitions, applications, and information about the manufacturing of its components."*	• Smart home energy management systems: - Optimization (Scheduling) - Control and Automation - Communication systems - Research topic areas
Wilson et al. [19]	2015	*"This paper reviews the dominant research themes and the linkages through a systematic analysis of peer-reviewed literature on smart home/buildings and their users."*	• Views of the smart homes: - Functional - Instrumental - Socio-technical • Users and the use of the smart homes: - Prospective users - Interactions and decisions using technologies in the home • Challenges for realizing the smart homes: - Hardware and software
Zhou et al. [26]	2016	*"This paper presents an overview on the architecture and functional modules of smart home energy management systems (SHEMS) by thoroughly analyzing the advanced SHEMS infrastructures and home appliances."*	• SHEMS overview: - Concepts - Architecture - Functionalities • SHEMS infrastructures: - Communication and networking - Smart meters - SHEMS center and home appliances • Renewable energy resources with SHEMS • Energy scheduling strategies
Abubakar et al. [27]	2017	*"This article presents the current state of the art of appliances' energy management through intrusive load monitoring (ILM) and non-intrusive load monitoring (NILM)."*	• The load monitoring concepts: - ILM - NILM • Energy monitoring devices: - Measuring devices - Optimization tools - Communication devices - Control devices - Display devices • Techniques for energy and cost reductions • Future research directions

Table 2. *Cont.*

Source	Year	Review Focus of Article	Major Contents
G-Hanssen and Darby [22]	2018	*"This review paper focuses on the aspects of smart home technologies related to energy management within the home (end-uses) and at network or grid level systems."*	• Concepts of a smart home • Home and smartness technologies: - Security and control - Smart homes as places for activity - Places for relationships and continuity - Smart homes and reflection of identity and social status
Marikyan et al. [23]	2018	*"The aim of this paper is to systematically review the smart home literature and survey the current state of play from the users' perspective."*	• Analysis steps: - Planning stage - Conducting stage - Reporting stage • Definition and characteristics of smart homes • Types of smart home technology services • User benefits of smart homes: - Health-related benefits - Environmental benefits - Financial benefits • Smart home implementation and barriers
Sovacool et al. [28]	2019	*"This study critically reviews the promise and peril of smart home technologies."*	• Research design: - Interviews - Retailer visits • Historicizing, defining, and conceptualizing technologies • Plentiful commercial options • Identifying potential benefits, barriers and risks to smart homes
F. D. Rio et al. [29]	2020	*"This study presents data from semi-structured expert interviews and reviews the recent literature regarding smart home technologies and policy discussions."*	• Energy sustainability and the business implications of smart home technologies: - Definitions and applications - Benefits and barriers - Business models • Business models for achieving smart homes: - Energy services provision - Household data and surveillance capitalism - Digital platforms - Health care and assisted living - Demand response - Security and safety
F. D. Rio et al. [30]	2021	*"This paper elaborates on an array of social, technical, political, economic and environmental dimensions of smart home technology diffusion."*	• Research design: - Conceptualizing smart homes - Case selection - Research methods • Four steams of scholarship on smart homes: - The intrinsic environmental sustainability - The role of culture in smart home adoption and risk assessment - Specific cultural dimensions in four case countries • Cultural applications and uses: - Aging and living with the elderly - The pursuit of luxury and status - Enthusiasm for new technology - Trust, safety, and security - Culturally different uses • Cultural barriers to adoption

Table 2. *Cont.*

Source	Year	Review Focus of Article	Major Contents
Kim et al. [31]	2021	*"this paper investigates the research themes on smart homes and cities through quantitative review and identified barriers to the progression of smart homes to sustainable smart cities."*	• Current technical phase of smart energy conservation systems: - Smart home domain - Smart city domain • Technical and functional barriers towards sustainable smart cities: - Interoperability - Flexibility - Decentralization • Innovative solutions in future smart cities: - Construction of infrastructure - New strategies for energy trading in distributed energy systems
Malagnino et al. [32]	2021	*"This study reviews existing research works and technological solutions that integrate important topics (e.g., BIM-based data sharing and management of the infrastructure life-cycle through 3D informative virtual model."*	• Application areas for smart and sustainable environments • Architectures and information flow for the BIM-IoT integration • Integration methods and tools - BIM solutions - IoT systems - Central database, brain, and GUI systems • Main limitations of the integration

Although various review-type papers have been published covering those associated categories from different perspectives, this paper focuses on the design and implementation of related technologies and applications associated with smart home/building/city energy and their environment. In recent years, building energy management systems to optimize energy usage within a home/building have become one of the most important parts of smart home applications. Smart home energy management systems (SHEMSs) integrate electrical devices and energy systems into a communication network as a homogeneous system and enable smart homes, which can be controlled by devices, such as smartphones and voice-enabled controllers [26,33–36].

Zhou's study [26] provided a good overview of the architecture and functional modules of SHEMSs. Figure 3 depicts the overall architecture of a representative SHEMS obtained from the study [26]. The SHEMS operates as a central optimal system, monitoring and controlling various related home appliances and energy devices in real-time to provide energy management services efficiently. With the SHEMS, many smart technologies are available on the marketplace for innovative home/building applications. According to Sovacool and Rio's study [28], many smart technologies enabled in electrical appliances, safety and security, home robots, energy and utility, lighting control systems, and entertainment can be controlled and managed by SHEMSs. Among those technologies, the benefit associated with energy consumption and savings was identified as the most prominent aspect of smart home/building technology based on survey responses [28].

As seen in Figure 3, there are various components of the SHEMS, including monitoring meter, sensing devices, electrical appliances controller/optimization management, and renewable energy systems and their energy storage with linked communication and electrical power networks. Each of those components can be utilized to manage the energy flow within a home network domain. For example, a smart meter monitors home energy usage consumed by electrical appliances and/or heating/cooling systems. This consumption information from sensing devices transmits to the utility through the communication network of the SHEMS. An optimizer/controller makes the best decisions for optimal coordination and operation schedules by reflecting the input of home energy consumption and on-site power generation.

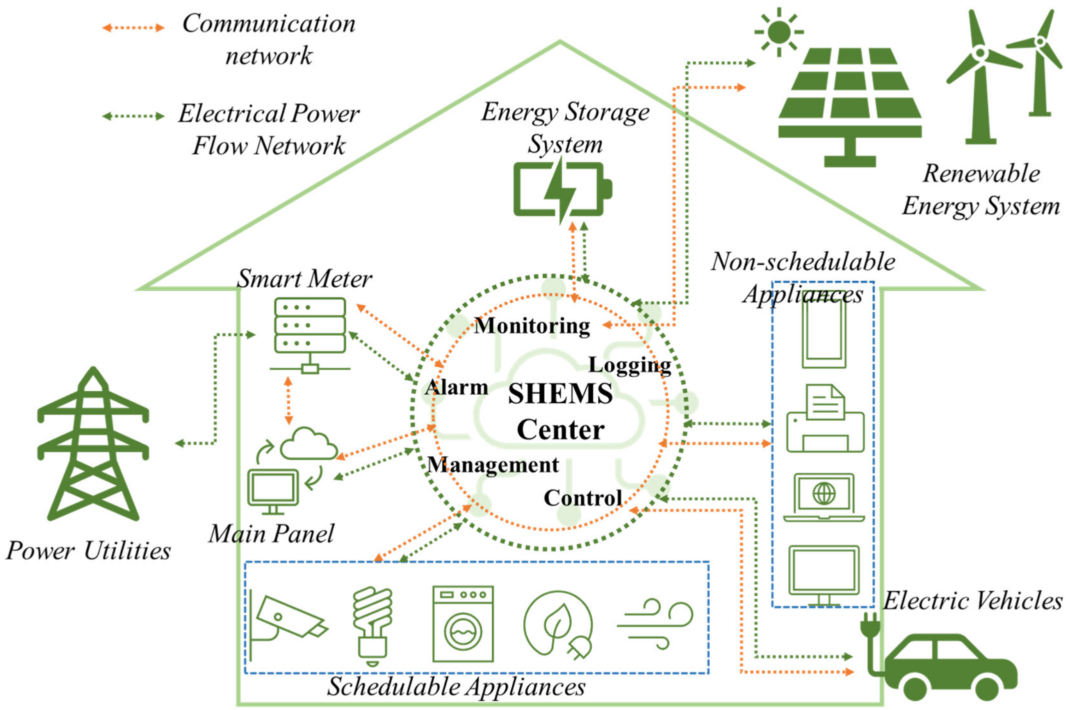

Figure 3. The overall architecture of a representative SHEMS reprinted with permission from Ref. [26].

In addition, the SHEMS can maximize the advantages of the occupant's comfort levels, including thermal, visual, and air quality comforts. As it is challenging to satisfy both energy-efficient and comfort perspectives practically [32], many studies have been actively conducted on the SHEMS by considering both performances to respond to the the occupant's desires and expectations in smart building technologies. Amjad Anvari-Moghaddam et al. [37] developed multiple objective optimization models for optimal energy management control in smart homes based on balancing energy conservation and the occupant's comfortable lifestyle. SHEMS also enables an economic opportunity for a smart home to facilitate demand-side resources by shifting their electricity peak usage in response to the changes in an electrical grid. The following section discusses integration efforts between smart buildings and the electric grid.

4. Smart Building-to-Grid Integration

The technology to identify energy use patterns of individual smart homes provides excellent opportunities to understand how much imported and exported energy flow is currently occurring in a grid community [38]. There are diverse components associated with smart homes and buildings, impacting energy flow between the grid and buildings. These include distributed energy generation systems, energy storage systems, intelligent switches, smart sensors, smart electric appliances, and plug-in electric vehicles [39]. The increased usages of those components could significantly affect changes in patterns of the energy flow and, thus, have potential impacts on the overall power grid stability and reliability [40–42]. According to the literature [43], the large-scale implementation of zero energy buildings with renewable energy systems could affect the current electricity demand patterns due to lower purchased electricity and increased surplus power generations from on-site to the electrical grid. For the successful design and integration of smart and net-zero energy buildings into grid infrastructure, various input/output parameters and resources, including electric/thermal efficiency, geolocation characteristics, energy prices, energy demand, thermal comfort, and security, need to be carefully considered [44–47]. A case study [48] demonstrates the importance of a well-thought-out plan to integrate smart technologies in smart homes into public services and utilities in a smart grid.

Energy-related applications of smart homes are considered to be one of the core elements in developing and expanding a smart grid/city. Wang et al. [49] proposed an energy-efficient integrated planning framework for green smart cities to enhance energy efficiency and performance. Their proposed planning framework model was used to improve smart homes' energy efficiency and perform systematic cost analysis for a smart city. Khalil et al. [50] introduced a hybrid smart grid system with various energy resources based on energy-efficient power management control using an energy optimization method in real-time operation. They developed optimized energy distribution systems for the energy-efficient operation in a smart city based on the occupant's actions and probabilities models. Liu and Zhang [51] proposed a long short-term memory-assisted staked auto-encoder (LSTM-SAE) model to predict the air quality in smart building environment design planning in a smart city. Their method with the LSTM-SAE model provided a useful insight into air quality prediction in a smart city according to overpopulation and industrialization growth. It was also revealed that this prediction model could efficiently be used in intelligent environment-based smart cities for air quality prediction.

The internet of things (IoT) technology and related big data applications are key components to developing the infrastructure of smart and sustainable cities [52–57]. Hui et al. [58] presented the essential requirements for smart homes/buildings in a smart city based on IoT technologies based on a recent research survey. They demonstrated a typical integration of various smart technologies in a smart city, as depicted in Figure 4. Under this typical smart city architecture, their proposed smart home/building requirements with IoT technologies were heterogeneity, self-configurable, extensibility, context awareness, usability, security and privacy protection, and intelligence.

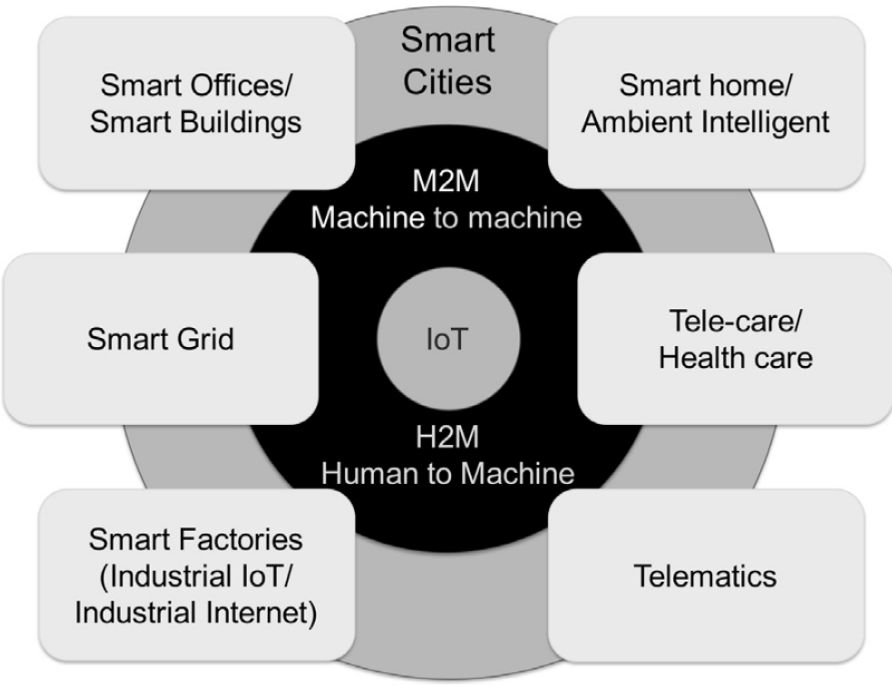

Figure 4. Typical architecture of a smart city adapted with permission from Ref. [58].

Regarding energy-efficiency perspectives of IoT technologies, Rathore et al. [54] proposed a combined IoT-based system for an energy management system and urban planning in a smart city. A four-tier architecture was proposed to implement the combined system with various steps, including data generation, collection, aggregation, filtration, classification, preprocessing, and decision making. In their study, IoT-based datasets generated by smart homes and environmental elements were essential for effective analysis and evaluation. Silva et al. [56] proposed a smart city framework based on big-data analytics. Their proposed framework considered three steps to operate and improve the smart city architecture, including (1) data generation and acquisition, (2) data management and processing, and (3) application to make decisions. Fugini et al. [59] presented an approach to develop big-data analytics for smart cities in Italy. Their proposed infrastructure and data platforms are intended to provide users with shared data and hardware and software components for data storage and analysis. In addition, Aliero et al. [34] presented research on smart home energy management systems in IoT networks for future improvement regarding smart city demands and services.

Demand response (DR) energy management also has a high potential to improve building energy system flexibility by shifting peak load hours to other times in response to variations in electricity prices over time [31,60–62]. Numerous studies have been conducted to improve DR technologies with smart home/building applications. Zhao et al. [63] proposed an energy-efficient scheduling method in a home area network based on DR information, indicating the real-time electricity price. With their DR-based proposed method, all-electric appliances in a smart home operate automatically in the most cost-effective way. Their proposed scheduling model would also reduce the electricity operation cost and the power peak-to-average ratio. Geneidy and Howard [64] presented factors affecting contracted energy flexibility potential based on a generalizable incentive-based DR scheme. Through participation in the contracted energy flexibility (i.e., DR programs), the control strategy was able to archive energy reductions in sustained demand while keeping acceptable thermal comfort in homes using a preheating system. The DR potential of the smart home community was discussed in their study with operation and configuration characteristics by the building and their systems, the physical environment, and behaviors and performance of occupants. Chen et al. [65] presented the optimal energy management of smart building energy systems with multi-energy flexibility measures. Dynamic demand-side control was modeled for the energy recovery process using an optimized operation scheme between smart buildings and their grid. Their study concluded that the optimized multi-load recovery strategies could improve the DR potential of a smart building energy system by offsetting energy payback effects. Munankarmi et al. [66] used all-electric smart home community models to investigate the relationships between different demand-side management measures, such as system energy efficiency, envelope upgrades, smart appliances, and DR measures. The combination of energy efficiency upgrades and demand flexibility was able to save on electric utility bills while increasing community load flexibility. Utama et al. [67] investigated the demand-side flexibility potential of Singapore's building stock. Their analysis indicated that a demand-side bidding program could help users utilize the demand flexibility potential by encouraging more energy-efficient usage and saving their electricity utility cost.

To enhance the demand flexibility strategies for DR controls in smart-grid-interactive buildings, both energy demand and supply sides must be carefully designed and managed to balance better energy flow variations between the energy supply and demand [68]. Figure 5 illustrates the demand flexibility sources of a smart home, considering both energy supply and demand sides. On the supply side, distributed energy generation resources are a significant consideration for smart home/building applications within smart grids/cities. With DR operation combined with a storage system, renewable energy systems can be utilized to increase energy flow flexibility during peak load time. Hakimi et al. [69] presented a new method for DR with high renewable energy resources based on load conditions in smart homes and a microgrid. Their study demonstrated that the peak loads could be shifted to other times when the difference between loads and on-site power generation was maximum considering the consumer's welfare. Thus, the flexibility of energy consumption and generation was increased in an intelligent grid. The subsequent section addresses the integration of renewable applications with a smart home/building.

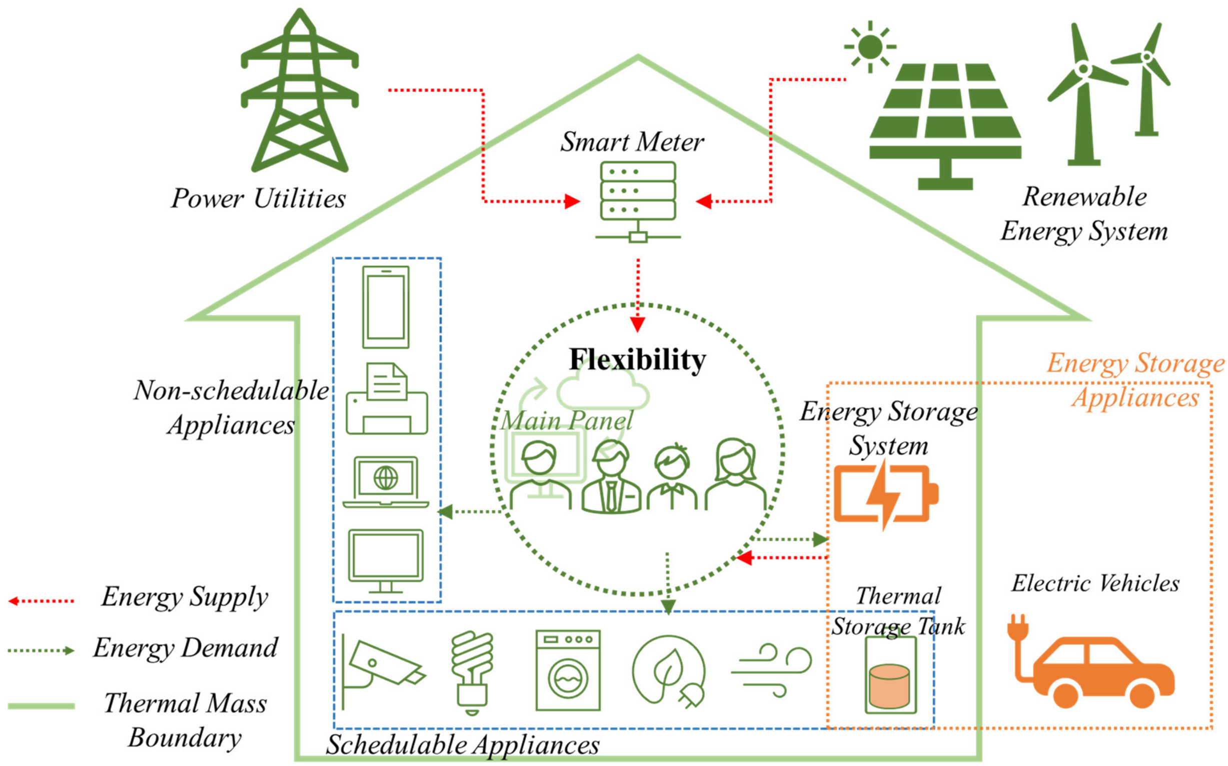

Figure 5. Energy flexibility sources of a smart home/building reprinted with permission from Ref. [66].

Integrating on-site renewable energy systems with SHEMSs can offer various opportunities to improve energy efficiency, reliability, and operation quality of a smart grid/city, with a balanced interaction through the electrical distribution network [70,71]. As seen in Figures 4 and 5, renewable energy systems can be used to reduce greenhouse gas emissions by offsetting electricity imported from the grid [72] when an appropriate dispatch schedule is adopted and applied. Sharda et al. [73] proposed an IoT-based automated SHEMS method using a stochastic real-time scheduling algorithm for electricity cost minimization. Their optimized schedules in response to different load request patterns and pricing scenarios were applied to integrate a renewable energy system (e.g., photovoltaics) with an automated SHEMS control. Their study demonstrated that using their proposed algorithm, cost savings were achieved under different DR programs, such as real-time pricing (RTP) and time-of-use (TOU). Toopshekan et al. [74] also investigated the performance of on-grid renewable energy systems with a battery system for a residential sector based on different load demand patterns. Their results indicated that when their proposed dispatch strategy was used with a 24 h foresight for the power grid's cut-off, upcoming demand, and weather conditions, there was cost saving in the energy system operation compared to strategies without forecasting, such as load following and cycle charging. Hoang et al. [75] introduced renewable energy systems' primary components and roles for smart cities based on technical and economic criteria. They concluded that although the integration of renewable energy systems into the smart home and city was an essential solution to reach more sustainable development, the optimization of the integrated energy systems with renewable components should be critically embraced to ensure good stability and optimize operational performance to achieve cost savings while maintaining the demand/supply-side flexibility. Han et al. [76] proposed a SHEMS framework by considering both energy supply and demand sides at the same time. Their study used ZigBee-based energy measurement modules and a power line communication (PLC) to optimize the energy consumption of smart home appliances and manage on-site renewable energy generation systems. Their proposed SHEMS architecture was expected to maximize home energy reduction and achieve home energy cost savings. Nezhad et al. [77] also proposed a new model, employing a self-scheduling method using a SHEMS, considering both renewable energy systems and air conditioner systems. Their proposed model used a TOU tariff to minimize daily electricity bills. Based on the electrical and thermal loads from a smart home, a PV system combined with electrical energy storage (EES) was considered in their study to balance the energy flow between required demands and on-site energy generation. When the proposed model was applied to a smart home, the optimal operation could present savings in home energy consumption. Mahmood et al. [78] discussed the integration engineering efforts of renewable energy applications for optimization strategies toward green energy cities. Their study demonstrated that dealing with the uncertainty factors of smart home renewable energy generation is an important aspect to operate a networked grid to be optimized within its full capacity for a more sustainable environment.

Several studies, e.g., [29,60,79], indicated that the ability to deal with electrical vehicles (EVs) at smart homes has significant impacts on both electricity demand and supply sides when using the EV batteries as mobile electrical energy storage (EES). There have been many investigations on EV integration to smart homes and buildings with various concepts, such as vehicle-to-grid (V2G), vehicle-to-home (V2H), grid integration-to-vehicle (G2V), and their performance and efficiency improvements [80–83]. Duman et al. [84] introduced the mixed-integer linear programming-based SHEMS control. Their proposed control scheme predicted day-ahead load scheduling for cost minimization based on good thermal comfort, optimal DR, renewable energy generation, and EV loads. The proposed control scheme achieved daily cost reductions under the TOU and feed-in tariff DR programs. Wu et al. [85] proposed an optimization framework for the energy-efficient management of a smart home with EES and PV systems and a plug-in electric vehicle (PEV) integration. Based on their convex programming control in a smart home-to-vehicle mode and V2H mode, they demonstrated that energy savings could be achieved while satisfying home demands by reducing electricity purchases from the grid during electric price peak periods. Alilou et al. [86] used a multi-objective scheduling method based on intelligent algorithms for a SHEMS integrated with home electric appliances, a PV system, and PEVs. Their multi-objective algorithm and analytical hierarchy process method enabled suitable performance, which provided savings in the electricity bill of smart homes and reduced the peak demand of a smart microgrid. Tostado-Veliz et al. [87] developed a mixed-integer linear programming formulation to optimize electrification systems' operation for off-grid smart homes. Their developed framework was applied to an off-grid smart home by incorporating advanced demand-side strategies over various time horizons. Their proposed approach reduced utility costs by enabling flexible demand and V2H capabilities.

5. Conclusions and Discussion

The appropriate design and implementation of energy and built-environment technologies are important to enhance the energy-efficient and cost-effective performance of buildings and their connected systems, so as to resolve global energy and environmental issues. Therefore, suitable techniques and designs need to be selected to achieve goals by facilitating the existing technologies in parallel, while meeting people's needs and comforts inside buildings. In this context, a comprehensive review of the design and implementation of smart building energy and environmental systems was performed and presented in this paper. From the detailed literature review, the major conclusions and overlooks for future work can be highlighted as follows:

- From smart home/building-related review articles, this study identified that the technologies in the smart home/buildings applications are becoming mature, and the current research trend in smart homes/buildings has moved towards detailed system integration or guidelines to enhance people's daily activities and the sustainability of the built environment by utilizing the recent advancements in digital solutions (e.g., IoT), practical designs and implications in a cost-effective manner, addressing changes in people's lives and technologies, and building connected systems (e.g., an electrical grid and EV).

- To enable smart and sustainable homes/buildings in an energy-efficient manner, understanding overall energy flow details between a building and its connected systems (e.g., distributed renewable energy, energy storage, and electric vehicles systems) could be an essential part of future buildings and their community levels.
- In addition, future smart buildings would essentially require advanced energy control and management systems that can provide energy-efficient and cost-effective operations of relevant energy subsystems in parallel and can integrate them into a communication network to exchange the information in real-time with others within the community and regional levels within various constraints, such as net-metering, demand response, carbon tax or credit, etc.

Based on the current review study, it is recommended that future work focuses on the implementation and case study of smart energy technologies in building, town, and city-level communities together in a practical application with considerations of economic and environmental life-cycle benefits.

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