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Research Article

SMART HOME ENERGY SAVING WITH BIG DATA AND MACHINE LEARNING

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Abstract
In response to escalating energy consumption, particularly within the housing sector, a global imperative to reduce energy usage has emerged, propelling the concept of "smart houses" to the forefront of innovation. This paradigm shift owes its genesis to the convergence of advancements in energy conversion, communication networks, and information technology, catalyzing the emergence of the Internet of Things (IoT). The IoT facilitates seamless connectivity of devices via the World Wide Web, enabling remote management, monitoring, and detection capabilities. Capitalizing on this technological synergy, the integration of IoT, big data, and machine learning with home automation systems holds immense promise for enhancing energy efficiency. This paper introduces HEMS-IoT, a groundbreaking energy control system for intelligent homes, underpinned by big data analytics and machine learning algorithms, prioritizing security, convenience, and energy conservation. Leveraging J48 neural network technology and the Weka API, the study illuminates user behaviors and energy consumption patterns, enabling household classification based on energy usage profiles. Moreover, to ensure user comfort and safety, RuleML and Apache Mahout are deployed to customize energy-saving recommendations tailored to individual preferences. By presenting a practical demonstration of smart home monitoring, this paper validates the effectiveness of the proposed approach in enhancing security, comfort, and energy conservation. This pioneering research not only showcases the transformative potential of IoT-driven energy management systems but also sets the stage for a sustainable and interconnected future.

Keywords: Big Data, Internet of Things, HEMS-IoT, Smart Home

INTRODUCTION

New developments in information, communication, and power conversion technologies have led to the emergence of the "smart home," a new housing paradigm. These homes improve comfort, security, usability, and entertainment features while enabling homeowners to reduce energy consumption. As the market for smart homes continues to grow quickly, Home the management of energy Systems (HEMS) are essential to achieving the goals of smart energy houses. Energy-efficient systems, pleasure, lighting, the detection of fires, and other areas are where progress is most noticeable (Elkhorchani, & Grayaa, 2016; Al-Ali et al., 2017; Marinakis et al., 2020; Abdulqadir et al., 2021).

Interior comfort and ecological responsibility are becoming more and more integrated into domestic action plans as measures to conserve energy gain global traction. It is critical to acknowledge the diversity of demands and lifestyles that impact consumer behaviour patterns when it comes to energy use. In order to develop effective resource-saving strategies, it is imperative that one recognises the interplay between ease of use, electrical usage, and occupant needs (Salman et al., 2016; Li et al., 2018; Sadeeq et al., 2021). This can be achieved by balancing the priority of interior comfort vs power conservation. Because Internet of Things (IoT) equipment in smart homes have limited capabilities, adding more data processing choices is necessary to ensure effective data handling, collecting, and analysis. Big data technologies and machine learning stand out as essential elements among these options. Tasks requiring previous knowledge are addressed by machine learning, which is divided into three categories: learning under supervision, unsupervised learning, and reinforcement learning.

For our system to evaluate and classify energy consumption efficiency, identify user activity patterns, and improve home comfort, we must use machine learning techniques and big data technologies. The paper's following parts are arranged as follows: This section explores works on the Internet of Things, big data technologies, machine learning, intelligent agents, and energy-saving methods for smart homes. The Internet with Things architecture is then presented in Section, which includes a case study that shows how to monitor a smart home for energy efficiency, comfort, and safety. The results of the particular case study discussed earlier are presented in Part 4, and the research's conclusions and future prospects are outlined in Section.

LITERATURE REVIEW

The Internet of Things, also known as the IoT, has made it easier for people to transition from conventional houses to smart homes by enabling them to monitor, control, and manage energy usage according to their lifestyles (Adiono et al., 2015; Chauhan & Barbar, 2017; Hossain et al., 2017). An overview of pertinent studies on Internet of Things initiatives targeted at improving the use of energy in smart homes is given in this section. We pay attention to initiatives that use big data and machine learning for monitoring.

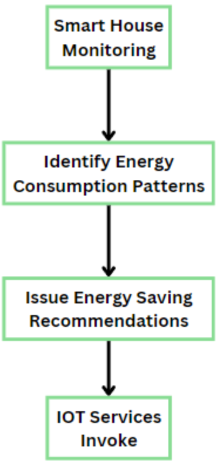

Figure 1. Flowchart of the System

An Intelligent Administrative System (IMS) was created in the context of the Internet of Things using open-source software and equipment (figure 1). Two scenarios were used to evaluate the system: a disaster management service and a smart home medical system. Three layers make up the architecture: the information, management, and presentation layers. An entry point connects the internal and external environments. With a smartphone, users may remotely operate their houses. The SQLite database system was used in the implementation, and it was verified by many tests. In the context of the Internet of Things, this research presents a unique service composition that builds a service overlay network.

A big data and online computing system for monitoring senior citizens' at-home energy saving is provided (Kang et al., 2015; Lee et al., 2015; Matsui et al., 2019; Maulud et al., 2021). Furthermore, an intelligent audiovisual intermediate assistant is shown that can send and receive multi-media messages, visualise energy-saving procedures, get notifications about the status of domotic devices, and control smart devices using gestures. Similar to our solution, HEMS-IoT aggregates data from several IoT providers, smart home appliances, and sensors.

PROPOSED METHODOLOGY

Home automation appears as a potential area for the development of novel and useful applications within the Internet of Things (IoT) space, which includes both public and private application sectors. "Home automation" refers to a collection of approaches that are intended to incorporate technology into areas like security, welfare, and energy management in a home.

Algorithm

STEP 1: Identify key energy consumption points within the home such as HVAC systems, lighting, and appliances.
STEP 2: Deploy IoT sensors and devices throughout the home to collect real-time energy usage data.
STEP 3: Integrate collected data into a centralized big data platform for storage and processing.
STEP 4: Apply machine learning algorithms to analyze energy usage patterns and identify opportunities for optimization.
STEP 5: Develop predictive models to anticipate energy demand based on historical usage and external factors like weather forecasts.
STEP 6: Implement automated control systems to adjust energy usage in real-time, optimizing for efficiency while maintaining user comfort.
STEP 7: Continuously monitor and refine the system's performance based on feedback and new data.
STEP 8: Provide insights and recommendations to homeowners for further energy-saving opportunities.
STEP 9: Ensure system security and privacy measures are in place to protect sensitive data.
STEP 10: Scale and adapt the system to accommodate different types of homes and user preferences.

Architecture Description

A home energy management system called HEMS-IoT aims to help homeowners save energy while also enhancing the security and comfort of smart homes (Samuel, 2016; Thema et al., 2019). In order to accomplish this goal, energy usage must be controlled by using big data, machine learning, and Internet of Things (IoT) devices. Furthermore, real-time home sensor and domotic device monitoring is made possible by HEMS-IoT. Utilising machine learning techniques, the system examines and deciphers the gathered data to find trends in user behaviour and energy use (Baker et al., 2017; Alarifi, & Tolba, 2019; Almufti et al., 2021; Asaad, & Abdulhakim, 2021). It then offers pertinent recommendations to reduce energy waste.

HEMS-IoT: Architecture and Functionality

The seven-layered architecture of HEMS-IoT is intended for great scalability and simplified maintenance (Schuelke-Leech et al., 2015; Matsui, 2017; Huang, & Yu, 2019; Yazdeen et al., 2021). The Appearance Layer, IoT Services Layer, which is Security Layer, Governance Layer, Transmission Layer, Data Layer, and Device Layer make up the overall structure. Each layer has a distinct component and serves a particular function.

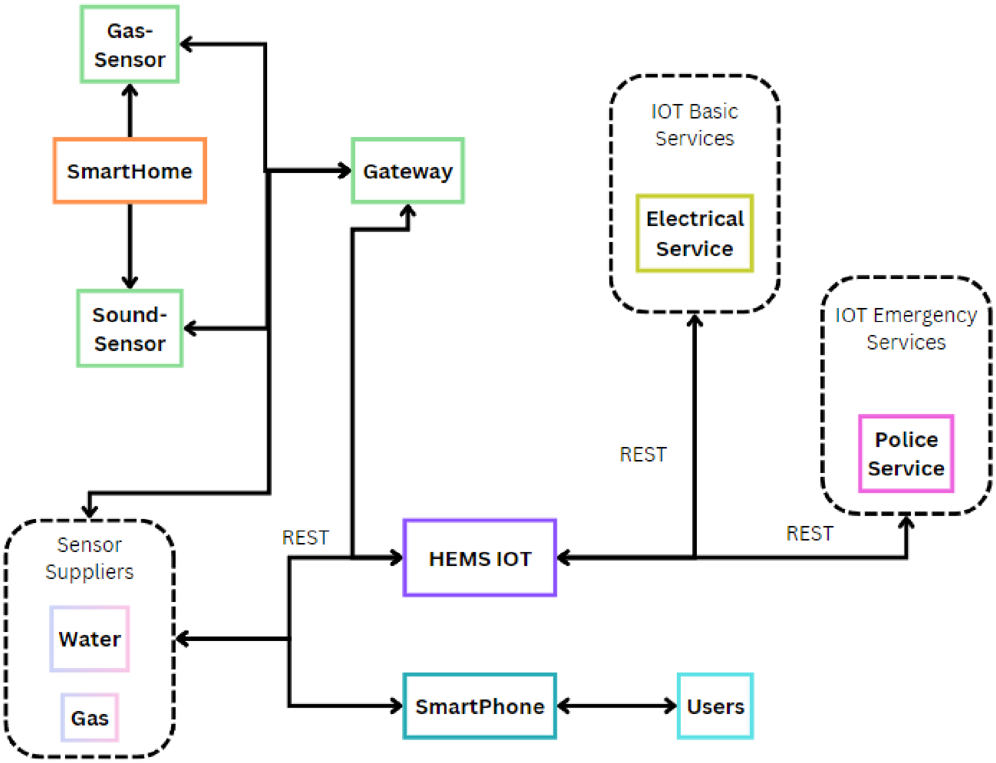

Figure 2. Workflow Methodology of The System

• Presentation Layer: Enables online or mobile apps to facilitate user-system interaction. Users have access to energy use information, accessible IoT services, history power usage, and suggestions. On a daily, weekly, and monthly basis, the layer offers energy-saving recommendations and displays energy use patterns (Bandyopadhyay, & Sen, 2011; Chilipirea et al., 2016).
• Security Layer: Provides safe data collection from the device layer, data security, and data secrecy. Through interaction with the management and communication levels, the layer serves as a bridge between the medical device and security layers (Atzori et al., 2010; Fensel et al., 2017; Ageed et al., 2021).
• IoT Services Layer: Provides a range of REST APIs to enable customers to fully use HEMS-IoT capabilities by bridging the management layer and application layer (Contreras et al., 2015 Iqbal et al., 2018).
• Managers Layer: Executes and supervises essential procedures to meet user requests stated at the software layer. The REST API is used by the IoT layer to ease interactions among the front end and the leadership layer (Ageed et al., 2021; Asaad, 2021).
• Data Layer: Maintains observed data, sensor profiles, user profiles, recommendations, and service profiles. Stores data created in the device layer. Modules manage user profiles, device profiles, sensed data from gadgets for the smart home system providing services data, and recommendations relating to comfort and energy conservation (Kibria et al., 2017; Lanfor et al., 2017).
• connectivity Layer: Chooses how sensors, the Internet, TCP/IP, and 4G connectivity are used to communicate with domotic devices. facilitates connection between various architectural levels (Bonomi et al., 2012; Gawali, & Deshmukh, 2019).
• Device Layer: Oversees sensors as well as home automation equipment, facilitating connections and data receiving from a variety of domotic devices (Geraldo et al., 2019).

Device Layer

Controlling the use of domotic equipment in the home is essential for an efficient energy-saving system that takes into account the preferences of the residents. However, various additional elements impact a house's energy usage, such as the residents' age, natural ventilation, seasonal temperature changes, and the external surroundings (figure 3). Several devices are considered by the HEMS-IoT device layer, including:

• Operating Devices: These devices, which come in a variety of shapes and sizes and are placed all over the house, have distinct purposes. Domotic devices and other domestic appliances are controlled by actuators, a kind of operational device. For instance, actuators may cut off energy and water supplies, provide notifications about possible faults or crises, modify air conditioner settings, and regulate the brightness of smart lighting.

Communication Layer

Smart houses have different energy requirements, but common ones are for hot water, lighting, and interior air conditioning and heating. Reliable communication networks are critical to accurately collecting data on energy use and user behavior in HEMS-IoT. The HEMS-IoT connection layer incorporates a number of technologies, including: IP/TCP: Developed by the United States Bureau of Defense, the Transfer Controlling Network/Internet Network (TCP) facilitates communication between computers running different operating systems across LANs and WANs, or local area networks.

IoT Services Layer

This layer provides a range of REST-based web-based services to enable communication between the administrative and software layers. HEMS-IoT features are easy for consumers to interact with. RESTful API: REST collects or processes data in any that can be represented format, such as XML and JSON, via HTTP. When weighed against alternative information transmission protocols, such the complex yet highly-capable Simple Object Access Protocol, REST is a solid choice. Service selector: This module selects the required services and checks the parameters passed on by the presentation layer. Additionally, based on the parameters and information regarding authentication it has received, the service selector may accept or reject services.

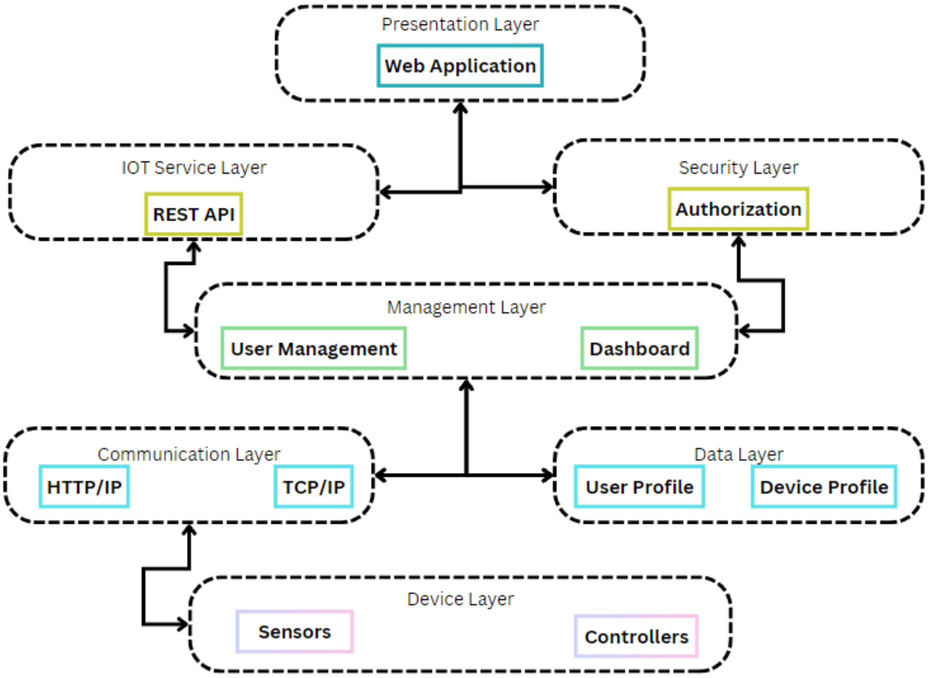

Figure 3. Architecture of the system

Security Layer

This layer securely gathers data from the customer and the device layer while maintaining data confidentiality. Increased interaction between the device layer and the defense layer is facilitated by the administration and communication layers. Within this layer, two crucial security components authorization and authentication are taken into account:

Presentation Layer

With its simple UI, HEMS-IoT functions as a smartphone app for Android. Options for managing the home, favorites, energy information, room settings, and device control are available from the main menu. Within the application, users may examine existing accounts, add or remove devices and rooms, adjust program parameters, and end the program. Using IoT and machine learning, HEMS-IoT provides real-time monitoring of smart home devices together with recommendations for energy-saving measures depending on user behavior. Additionally, technology increases home safety by promptly alerting occupants to potential threats like fires or other security risks and by simplifying the process of obtaining emergency assistance when needed.

Case Study: Monitoring a Smart Home to Ensure Indoor Comfort and Safety and Reduce

Energy Consumption

This section describes the case research that demonstrates how HEMS-IoT in intelligent houses may improve security, convenience, and energy efficiency. The study demonstrates how homeowners with connected homes may monitor overall energy use as well as user energy patterns. HEMS-IoT uses these insights to recommend energy-saving measures, which contributes to the creation of the shortened instance scenario that follows: In a six-sensor smart home (water move, energy authority, gas, motion, sound, & interior temperature), constant monitoring is required to provide optimal environment, security, and energy efficiency. To allow HEMS-IoT to gather data about homes and offer resident-approved energy-saving recommendations, the system ensures that every sensor provider provides accurate data.

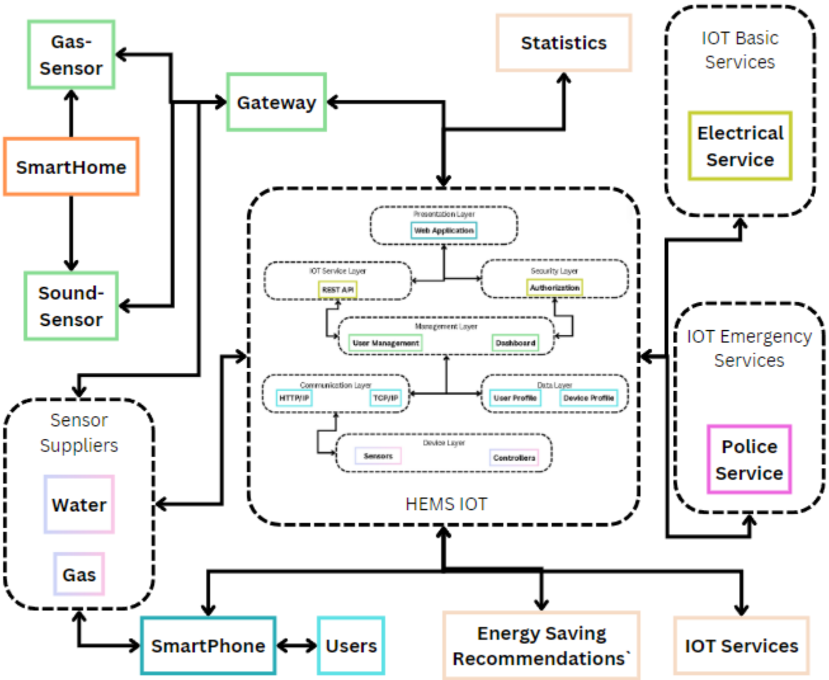

Figure 4. Implementation Of the System

Techniques

The main goals of the case study are to evaluate how much power smart homes use and categorise consumption patterns according to the average energy consumption levels set by HEMS-IoT. Ten separate dwellings with unique features were part of a Mexican cooperative community where a case study was carried out (figure 4). The principal differentiation between the two dwelling designs is their dimensions, which may be ascribed to differences in the quantity of bedrooms: the first design has two bedrooms, whilst the subsequent design has three. There are also differences in occupancy; the first design can house three people, while the second can accommodate four. At least two smart plugs are included in every residence, and all ten have sensors thoughtfully placed throughout to record and display information on lighting, temperature, motion, and room placements.

RESULTS AND DISCUSSIONS

Homeowners may anticipate more from the smart homes as HEMS-IoT integrates big data and machine learning techniques into its service layer, especially with regard to energy management (table 1). In order to spot trends in energy use and learn more about the variables affecting these patterns, this part examines the data that HEMS-IoT gathered for the case study.

Data Analysis

We thoroughly analysed the data on a daily, weekly, and monthly schedule in order to spot trends in energy use. We used the average aggregation strategy, which involves averaging the initial values, to resolve missing data. Specialists support this approach in sensor networks, with impressive results. Next, we examined the recommendations that HEMS-IoT had offered.

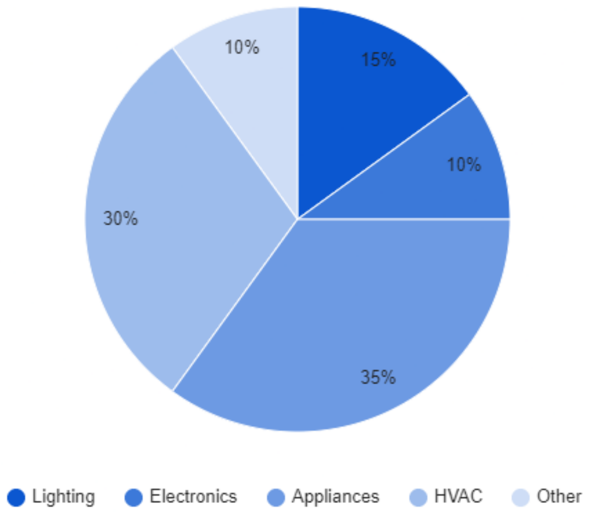

Figure 5. Energy Consumption Breakdown In A Smart Home (HEMS-IoT) For The System Application

Table 1. System Feature and Their Description and Benefits

Feature	Description	Benefits
Data acquisition	Monitors domotic devices and sensors in real-time. collecting data on energy consumption, appliance usage, environmental conditions. and user behavior.	Provides comprehensive understanding of home energy dynamics.
Big data processing	Stores and manages large datasets using big data technologies like Hadoop or Spark	Enables efficient data analysis and pattern recognition.
Machine learning algorithms	Utilizes techniques like J48 decision trees and RuleML to learn user behavior and energy consumption patterns, classify homes based on energy usage, and generate personalized recommendations	Identifies opportunities for energy savings and tailors solutions to specific needs.
Real-time monitoring and control	Enables real-time visualization of energy consumption data and remote control of devices for optimizing usage.	Allows for immediate adjustments and proactive energy management.
User Interaction and feedback	Provides personalized energy-saving recommendations and facilitates user interaction through dashboards and mobile apps.	Empowers users to actively participate in energy savings and track progress.
Scalability and adaptability	Designed to be scalable and adaptable to different home configurations and user preferences.	Ensures flexibility and applicability to diverse scenarios.
Security and privacy	Securely collects, stores, and processes data, adhering to privacy regulations and user consent	Builds trust and transparency with users regarding data handling

During the first few months of the following monitoring period, our study found instances of overuse of cooling systems and lights left on in vacant rooms, suggesting that the inhabitants were not paying attention to how much power they were using. In addition, we saw that smart houses continued to consume more energy even when their occupants were not there, which was especially evident in homes with kids. These homes were placed in the low/poor energy efficiency use category via cluster analysis. Furthermore, we discovered two smart houses that used excessive amounts of energy in comparison to how occupied they were; this might be related to the use of air conditioners.

A daily investigation was carried out to identify patterns in energy use, with a focus on seasonal differences (spring, the summertime, autumn, and winter). According to our data, energy use was greater at night and in the afternoon than it was in the morning. Certain hours were shown to be important indicators of daily usage of energy in smart homes. There was a noticeable seasonal difference in the amount of energy used, with winter demand being greater and summer demand being lower. Finally, our results confirmed that during the educational institution summer vacation, video game consoles considerably increased the amount of energy used in households with both designs.

We collected energy consumption information for our case study both before to and during the residents' use of the HEMS-IoT software. Using a before-and-after comparison, our goal was to find differences between the two observation periods. Consistent with Mexico's bimonthly power bill issue schedule, our data supports this pattern. The observed alterations may be ascribed to smart house occupants following HEMS-IoT's energy-saving advice.

CONCLUSION

The study of energy conservation has become more important due to the rise in energy use, especially in residential settings. There is a lot of promise for energy-saving solutions when home automation systems and the growing Internet of Things (IoT) are integrated. Despite their limited resources, IoT devices for connected residences efficiently collect, share, and analyse data to turn it into insightful information. To get over this restriction, other data processing techniques like big data and machine learning must be taken into account in order to manage enormous volumes of data. Massive amounts of data, machine learning and the Internet of Things together provide a lot of promise for addressing the housing sector's present energy-related issues. Our research suggested the HEMS-IoT, a smart home power management system that prioritises security, energy efficiency, and peace of mind. Big data and machine learning technologies are used by this system. Ensuring home comfort, spotting patterns in user behaviour, and classifying energy consumption efficiency all depend heavily on the use of machine learning techniques and big data technology. HEMS-IoT was verified via an investigation that kept an eye on a smart home to ensure safety and comfort while reducing energy consumption. Three essential elements contributed to the reduction of energy usage in this case study: the residents' commitment to altering energy-consuming behaviors, the system's ability to further investigate energy-saving suggestions, and the ability to adjust domotic device operating settings. We think that HEMS-IoT will soon be able to predict when inhabitants will arrive and proactively adjust features like the air conditioning or music based on user preferences, hence increasing comfort. Additionally, attempts will be made to include solar panels and employ cutting-edge security measures like cryptocurrencies and electronic safety in order to further reduce the amount of electrical energy used.

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AUTHOR CONTRIBUTIONS

Author 1-2 creates articles and creates instruments and is responsible for research, author 3-4 Analyzes research data that has been collected, author 5-6 assists in research data analysis, instrument validation and input research data.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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