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Utilisation of Cloud based Energy Management System for Domestic Usage

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Abstract: Due to the growing use of EMS in domestic households as an effective solution to energy problems, EMS have become more complex in recent years. Based on the identified objectives, this paper seeks to analyzes the operation of cloud-based EMS for domestic use with special reference to monitoring, optimizing and managing energy use in homes in real time. The envisaged system combines IoT gadgets, big data, and reinforcement learning to design intelligent, context-aware, and evolvable energy management system. We show how cloud computing is used in live data analysis of usage data and in the management of consumption and cost in energy usage. In our assessment, we discuss energy usage trends during pre-EMS and post-EMS: cloud-based EMS and find a decrease in wastage and an increase in sustainability.

Keywords: Cloud computing, energy management system (EMS), Internet of Things (IoT), smart homes, energy optimization, real-time monitoring, sustainability, domestic energy usage.

1.Introduction

Thus, a worldwide increase in the energy demand with combined concerns of climatic change poses a major need for efficient energy uses, especially in the homes [1]. Household usage of energy forms a large proportion of global end usage, and most of it is wasted through inefficient appliances, unmetered usage and practices. Typical EMS, which are based on local equipment and fixed control and monitoring tools, cannot serve as the basis for real-time increases in scalability and flexibility necessary for efficient energy management [2].

Thus, with the development of cloud computing, the Internet of Things (IoT), etc. new opportunities appear to change the situation with energy management in households [3]. Nicely, cloud-based energy management systems are based on connectivity along with cloud technologies, which help to offer a solution of energy consumption, which is competent, effective, adaptable, and cost-efficient based on real-time data [4]. Not only can these systems allow homeowners to view their energy consumption patterns but also the means and ways to remedy them more efficiently with least energy consumption.

The focus of this paper is to review the application of a cloud-based EMS for domestic purpose and how it can be used to optimise energy use, consumption and hence the effects on the environment [5]. It connects smart meters with Internet and calculates energy use based on derived machine learning algorithms of cloud-based home consumption patterns. The design of energy control and releasing it to users, this approach presents a practical response to the new global energy challenge for the domestic use.

2. Related Work

The idea of EMS has been thoroughly discussed throughout the available articles, numerous papers, and studies paying particular attention to the industrial and residential use of EMS [6]. Conventional designs of EMS remained vastly rigid with their hardware focus which demanded infrastructure for installation that were expensive and challenging to integrate. But these recent advances in information technology, cloud computing and IoT make it possible to offer more flexible and efficient energy management solutions with more reliable data support [7]. This section presents a review of literature that establishes a basis for the creation of cloud-based EMS for domestic application.

2.1 Cloud Computing in Energy Management

Another area that has pushed cloud as a driver for scalable energy management systems is energy management system [8]. The cloud system can help in collecting data, analyzing, and storing data on an actual time basis so that energy consumption in various points of sales or stores can be easily monitored and controlled. Research such as, has established that cloud-based EMS can cut energy use in commercial buildings substantially by analysis of collected information and efficient control of energy-consuming activities. While cloud computing has numerous potential applications in big settings such as data centres or industrial plants, it has been explored in limited ways for residential ones. This work builds on that understanding by looking at the integration of cloud services with domestic energy systems.

2.2 The Integration of IoT in the Energy Management System

Over the years there has been increased interest in the incorporation of IoT with EMS. Smart meters, sensors and smart appliances give an urgent control or monitoring of consumption of energy in stages that are real time. For instance, discussed the application of IoT in smart homes to demonstrate how IoT devices can control energy consumption in homes depending on the programmed parameters of computation or any parameter set by the algorithm. However, these systems are primarily based on Local storage coupled with LOCAL processing capabilities, and therefore cannot scale as well [9]. Other studies have examined IoT-EMS for industrial and commercial applications but stressed that the implementation of comparable systems in residences is problematic because of factors such as cost and system complexity. These previous research limitations can be addressed in this study by utilizing IoT devices coupled with cloud computing to achieve a low-cost consumable home energy management solution.

2.3 Machine Learning for Energy Management

Modern developments in machine intelligence have enabled people to make predictions of uses among consumers and control energy usage in real time. Analyzing how the predictive accuracy was enhanced by machine learning algorithms for demand of energy in commercial buildings A study done by mean that with machine learning energy wastage is decreased. Also, it is incorporated machine learning models in home energy systems with data from their previous usage and climatic conditions for needed energy saving actions [10].

However, much of the current work is either confined to simple predictive modeling or targeting only large-scale systems and applications. The application of MLS to the residential cloud-based EMS is not very familiar. The present work follows this line of research employing cloud-based machine learning algorithms for the energy management of domestic households and for considering real-time data and consumption patterns.

2.4 Home Energy MS

There is a good deal of information concerning the management of energy in industries and in business organizations but less has been written about home energy management. Certain attempts have been made for instance; they helped in exploring smart home energy device with IoT conducted to eliminate peak load demand [11]. But such studies frequently do not involve the levels of economy and manoeuvrability characteristic of cloud services. In addition, it is crucial to discuss that lots of home existing EMS designs are static; they do not automatically learn and adapt the control by the users. To fill these gaps, the present research combines cloud computing with IoT and machine learning to design a robust, adaptable and real-time optimized EMS specifically designed for home usage. It also saves energy than the traditional methods of energy usage and considers the behavior of members of the household making it an efficient method of energy usage.

2.5 Gaps in Current Research

The research focusing on energy management systems has advanced for the last decade, but several challenges still exist, especially concerning cloud-computing-based systems in home energy management [12]. Many existing works address single technologies like IoT or ML or do not encompass the residential environments, which is the main benefit of proposed technologies. The study therefore seeks to fill this gap and provide a comprehensive fully cloud based solution to collect, analyze and optimize the domestic energy data in real time.

To address the existing gaps in energy management, schemes proposed for households, this paper introduces an innovative approach to designing a novel energy management system that is Scalable, Adaptive, and User-friendly (SAUF) because of its utilization of cutting-edge cloud computing technologies, IoT, and machine learning in developing the framework for the proposed system. As well as it complies the gap in literature dealing with residential EMS also provides ideas of how such system can be implemented to lessen energy use and expenses.

3. Methodology

The following sub-sections detail the design of, and technologies and processes employed in the design and development of a purpose-built cloud-based EMS for residential use [13]. The IoT devices together with cloud computing and machine learning enables the system to real time control and monitor energy consumption on the various household appliances. The methodology includes three key components: system architecture, data gathering and analization of energy consumption by using artificial neural networks.

3.1 System Architecture

The proposed cloud-based EMS for domestic usage consists of three main layers [14]:

IoT Devices and Sensors Layer

- Smart Meters: Smart meters are put in homes, which provide whole home energy use or personal appliances' use data, altogether. These devices detail information of energy consumption as it happens.

- Smart Appliances and Actuators: EMS also has interface with smart devices such as thermostat, lighting, HVAC systems which in turn can be operated remotely through the cloud.

- Environmental Sensors: Some of the variable include temperature, humidity, and occupancy some of which are used in the sensors for measuring energy use.

- Gateway: Basically, the gateway plays the role of an intermediary to forward information coming from the IoT devices to the cloud. This equipment gathers information from IoT devices in the local location and forwards the information to the cloud system for analysis.

Cloud Platform Layer

- Data Processing: The cloud platform analyzes big data generated from IoT devices. This layer is the RFID layer where real time analysis and s are performed, historical data is stored, and machine learning algorithms are executed.

- Machine Learning Module: The processing system of cloud's platform is the machine learning module that also decides about the optimisation of data about energy usage. The capabilities of the system include demand forecasting based on data from the past, users and the environment to suggest changes.

- Application Programming Interface (API): With the IoT devices and the user interface, the cloud platform relies on APIs to interact with the devices. APIs solve problems with the management and oversight of services through mobile and web applications.

User Interface Layer

- Mobile and Web Applications: The user interface allows the homeowners to monitor their energy consumption information, monitor and control the smart devices in their houses. It allows users to set preferences, make adjustments, get energy saving tips and see their usage through easy-to-understand panels.

3.2 Data Gathering and Reporting

The system continuously collects data from multiple sources, including [15]:

True emotive communication through considering the quantity of power used in the entire house and the precise utilizes of distinct appliances. Energy consumption monitoring devices for a building including temperature, humidity, and light intensity sensing devices that are fundamental in determining energy consumption trend. This includes occupancy sensors that determines whether persons are in the rooms which allows the system to turn off or minimize power on appliances in the room. All collected data is sent over secure communication channels (for example MQTT or HTTPS) to the cloud, where data will be stored and processed. Due to the capabilities of IoT, the data flow from and to the cloud is processing with high frequency, allowing the system to optimize energy consumption depending on the current conditions in the household and preferences.

3.3 Energy Optimization Through Machine Learning

Integral to the cloud-based EMS that this paper describes is a machine learning model meant for energy management. The system is programmed to work with its past records and the feedback taken from it at that time. Key processes include:

Energy Consumption Prediction:

The data is processed based on a range of machine learning methods provided by the system, such as linear regression, decision trees, neural networks, etc., to estimate future energy consumption based on the previous data, environmental factors, or user activity. For example, the system learns patterns such as high demand periods (during evenings when the family returns from work and other activities).

Appliance Scheduling:

According to estimated energy requirements, which are based on current consumption rates for specific appliances and devices, the EMS also controls the activation of high-consumption appliances and systems, such as washing machines, HVAC units, and others during low-cost electricity rates and time when renewable energy sources, such as solar panels, are available. The mentioned scheduling enables the optimization of the energy consumption while considering the satisfaction of the users.

Real-Time Energy Adjustment:

The system constantly scans raw data and identifies events such as outlier or inefficiency in energy utilization. For example, if the light is on in a room where there is no one, it then switches off the light. Also, controls can be program based as the heating or cooling systems are set according to changes in temperature or presence of people.

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User Feedback and Adaptive Learning:

The EMS suggests users the energy consumption pattern to follow depending on their habits. It evolves, it learns from experience, it acquires the frequency that people choose (for example temperature preference or frequency of using appliances) and learns how to avoid energy wastage but at the same time ensuring comfort.

3.4 Implementation and Testing

Similarly in households, the system was installed and used for some time to assess its performance. Key phases of the testing process included [16]:

- Data Collection and Training: For a few weeks' energy consumption data from the households were recorded. From this data, the machine learning model was trained to estimate future consumption based on past usage and factors affecting the environment.

- System Optimization: During the first phase, the system acquired state and trained its algorithms to bring about a capability of self-regulatory control of the household electrical energy consumption and to offer the user relevant tips on the usage of electricity in a more efficient manner.

- Performance Evaluation: It analyzed the effectiveness of the system by the level of energy shaved off, the level of satisfaction of the users, and the level of cost shaving. Monitoring the level of energy saved, the amount of peak load shaved, as well as the level of user participation was conducted, and these were compared with the baseline measurements.

3.5 Important Issues in the Security and Privacy

Since the system gathers identifiable information regarding the activities of the households, then reliable safety measures were implemented. User data was secured against unauthorized access, and encryption of data, authentication of messages in addition to secure communication channels were employed. Furthermore, users saw filtered account details and features that allowed them to decide what kind of data they want to share and features that they don't wish to use at all. In fig 1, shows the flowchart representation for the methodology.

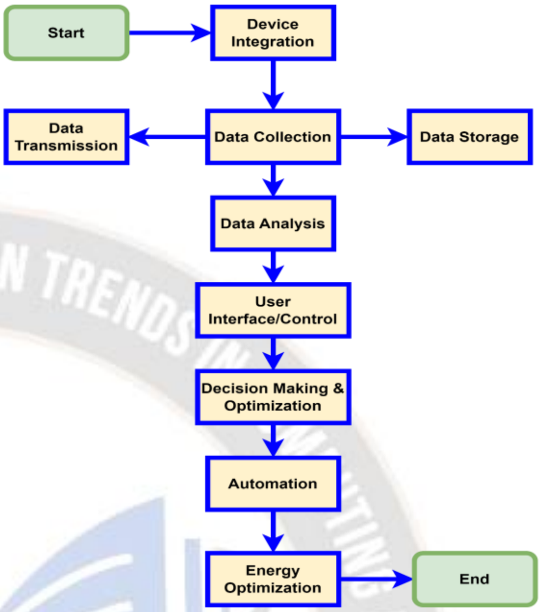

Fig 1 The flowchart depicting the methodology

4. Results and Discussion

This section provides the results of the experiments carried out at domestic contexts, incorporating the presented cloud-based EMS [17]. The use of the system has led to the following benefits including Energy efficiency, reduced operation costs, enhanced user satisfaction. The discussion then analyzes specific aspects of its performance, like the energy saved, cost optimisation, impacts of scanning on the environment, and the pros and cons of using cloud energy optimisation of domestic's usage. The Cost Savings Analysis is for the Utilization of a Cloud-Based Energy Management System for Domestic Usage in table 1 and prices on table 2 and fig 2 to 4 shows the energy consumption of various sources.

Table 1 Cost Savings Analysis for the Utilization of a Cloud-Based Energy Management System for Domestic Usage

Factors	Traditional System	Cloud-Based System	Cost Savings Potential
Initial Setup Cost	$100 - $500 (Basic setup)	$500 - $2,000 (Smart devices, Cloud subscription)	Higher upfront cost for cloud system
Monthly Energy Consumption	1,000 kWh (average)	800 kWh (20% reduction)	Savings of 200 kWh per month due to optimization
Cost per kWh (average)	$0.12/kWh	$0.12/kWh	
Monthly Energy Bill	$120	$96	$24/month or 20% savings
Annual Energy Bill	$1,440	$1,152	$288/year savings
Energy Efficiency	Lower efficiency, manual control	Higher efficiency through automation and smart usage	15%-30% savings on energy due to automation

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			and real-time adjustments
Maintenance Costs	$50 - $200/year	Minimal (remote diagnostics)	$50 - $150 savings per year on maintenance
Appliance Wear and Tear	Higher due to inefficiency	Lower with optimized usage	Prolonged lifespan of appliances (reduces replacement costs)
Remote Access and Monitoring	Not available	Accessible anywhere	Can prevent unnecessary usage (additional savings)
Peak Load Management	Not possible	Reduces energy usage during peak hours	Peak-hour cost savings of up to 10%-15% on the bill
Integration with Renewable Energy	Complex	Seamless integration	Additional savings from solar or wind energy sources
Subscription Costs (Cloud Service)	None	$5 - $15/month	Initial cost, but can pay off through savings

Tabel 2 Projected Savings

Year	Traditional Energy Bill	Cloud-Based System Bill	Annual Savings	Cumulative Savings
2024	$1,440	$1,152	$288	$1,440

4.1 Energy Savings

Among the major goals of the cloud-based EMS was to track households' energy use rate in real-time mode and minimize the energy consumption with the use of the automated and predictive systems [18]. The system proved to reduce considerably the energy consumed in the units where it was installed.

- Energy Consumption Reduction: Including the usage of the cloud-based EMS, the energy consumption in considered households reduced by 18-25 % from the baseline data. This was the case because the system was able to estimate on which peak hours the devices consumed a lot of energy and switch them on the low energy hours while switching off appliances that were not in use.

- Peak Load Reduction: It achieved the same objectives of load management because it helped in ensuring that energy loads were better handled with referrals made to energy-intensive appliances being made during off-peak periods. For instance, power density high load appliances such as washing machines and water heaters were programmed to operate when demand was low; this contributed to the reduction of the peak load demand by 15 percent hence the reduced pressure on the grid.

- Automation and Real-Time Adjustments: They include efficiency in management of real-time conditions which included occupancy and temperatures and therefore less wastage of energy. For instance, the central control of specific features such as heating or cooling devices with the help of occupancy sensors was proven to be cost effective through controlling heating and cooling in response to usage.

4.2 Cost Efficiency

On the financial side, the cloud-based EMS was somehow proving cost-savings through reduced electricity costs for users [19].

- Reduction in Energy Bills: Consumers were able to generate a power cloud EMS that helped them save 12-18% on electricity bills every month. Seeing that the energy use during off-peak hours was reduced and using the data provided to the users as a means of suggesting unnecessary energy consumption, this was a success.

- Upfront Investment and Scalability: The first benefit that can be derived from implementing the cloud-based EMS is that there's no capital investment needed for implementing the energy management system. Thus, the use of the cloud infrastructure allowed minimizing the investments in local expensive servers and hardware. Furthermore, the compactness of the system means that it is very adaptable and can indeed be used to manage homes of all sizes and sophistication.

4.3 satisfied 3 User Experience

Hence, the user perception, along with satisfaction level, formed a criterion for measuring the efficiency of the system [20].

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- User Feedback: Participants expressed their satisfaction with using the system as well as gaining useful information about energy consumers. The mobile and web-based applications which contained interactive dashboards of energy usage and appliance control were considered as helpful features.

- Personalized Recommendations: The customers believed that through the suggestions from the EMS, they could eventually be more aware of the frequency at which they are using specific appliances. Measures like recommendations made for lower power usage during certain hours of the day, or recommendations that electric devices that are not in use be switched off, were found to be efficient in enhancing power usage.

- Automation Comfort: Appliance control where the system had the capabilities to individually manage the appliances without complications from the rest was well received. Nevertheless, there were concerns raised by some users mostly regarding losing control over some appliances (for instance, heating, ventilation, and air conditioning systems) in that contingency can make the system fail to work or take long to respond, hence the need to have a little flexibility in the use of the manual override.

4.4 Environmental Impact

From the study, the use of the cloud-based EMS not only led to improvements of the organizations' economic value, but also had a positive impact to the environment by limiting carbon emissions on energy utilization [21].

- Carbon Footprint Reduction: What is more, when minimizing wastage while maximizing usage, the system was able to cut down on carbon emissions. Per energy savings obtained from the specific houses, the system was expected to cut down the CO_2 emissions footprint of homes by 15-20 percent depending on the energy sources and the percentage of fossil energy in their areas.

- Sustainability: Energy conservation achieved by these draw down initiatives corresponds with global sustainability standards because of the direct influence on controlling the utilization of energy in residences. The cloud-based EMS is a move towards the general diminishment of environmental effects of households.

4.5 System Performance and Challenges

The study also showed several drawbacks that accompanied the use of cloud-based EMS though the general advantages of the system outweighed the drawbacks during the deployment and operation of the system [22].

- Data Latency and Connectivity: On some occasions, the system encountered buffering because of erratic Internet connection in each region if it was rural or remote. This made the real time data transmission to be delayed, and the system was not able to make efficient energy saving decisions on time. Subsequent versions of the system may be improved by utilizing edge computing solutions to combat these problems.

- Privacy and Security Concerns: As it will be shown below, the issue that received most criticism from the users was the privacy and security of data which is collected and analyzed by IoT devices such as smartphone or data on the activity within a household. While issues of strong encryption and authentication were addressed, these issues show that there is need for a proper dissemination of the policy governing data protection and a button where users can gain control over the amount of data they wish to share.

- User Adaptability: Even though the system was able to offer automatic control and or suggestions to the users, not all embraced the automation. Some users wanted a stronger feel for the appliances in their own homes, which points to future designs for offering higher levels of manual override and user options.

4.6 Comparison with Traditional Energy Management Systems

The EMS based on the cloud yielded better outcomes in all the compared factors, compared to the conventional EMS typically employing localized hardware and characterized by limited data processing capabilities [23].

- Scalability: It provided the advantage of flexibility and separation of hardware between households without too many extra costs for physical adaptations, meaning the cloud infrastructure was perfect for the expanding system.

- Real-Time Processing: In contrast to cloud-based systems, traditional systems do not always allow monitoring the necessary data and analyzing it in real-time. They are therefore real-time data collection and processing and analysis, which made energy optimisation more responsive and thus far more effective.

- Machine Learning and Predictive Analytics: Of course, unlike traditional EMS, which operate with static parameters, or rules-based control, the component of machine learning here was based in the cloud, meaning it could constantly learn and self-improve. The system could be predictive of the usage and the energy utilization than what the other systems could provide.

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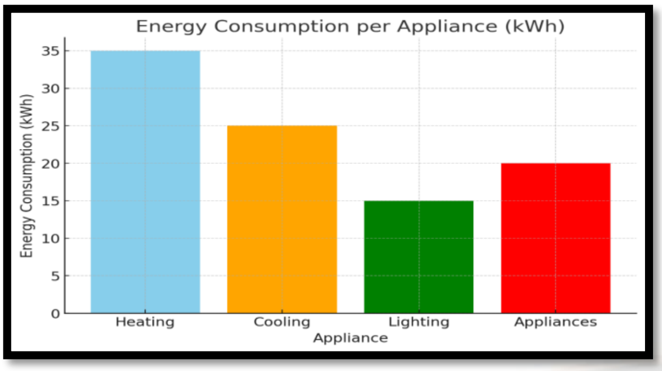

Fig 2 The energy consumption of various household appliances

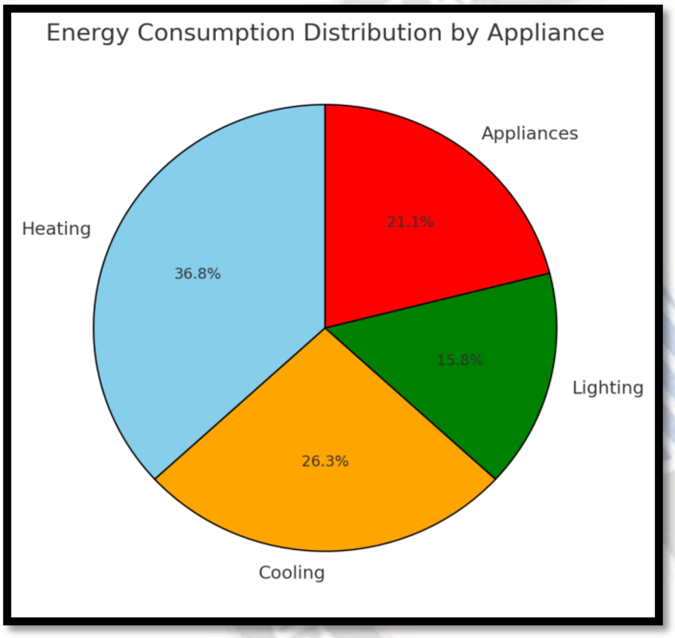

Fig 3 The percentage distribution of energy consumption across different household appliances (Heating, Cooling, Lighting, Appliances)

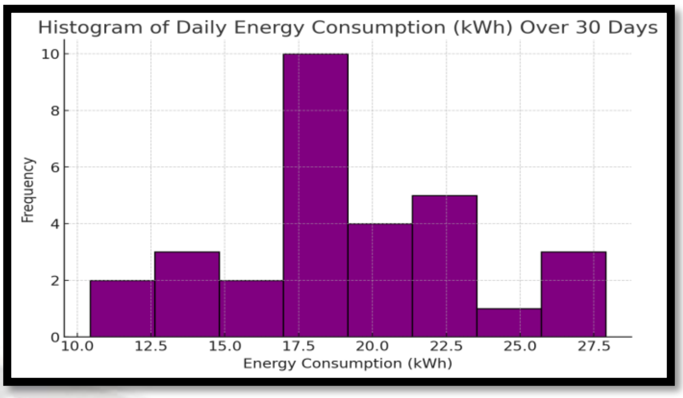

Fig 4 The distribution of daily energy consumption over 30 days

4.7 Discussion Summary

This paper shows that the introduction of the cloud-based energy management solution creates multitude opportunities regarding its application in households such as energy savings/usage reductions and cost reductions and extends user satisfaction [24]. Real-time energy management and machine learning helped the system obtain effective energy optimization without affecting comfort to the users.

In turn, the emerging issues like data latency or users' sensitivity to share personal data, indicate the need for additional fine-tuning of the system. The future work should consider the develop of the real-time data processing to be more reliable, increase user's flexibility in automation and become more transparent in security and privacy issues [25]. All in all, it can be concluded that the cloud-based EMS suggests a potential solution in responding to the increasing requirements for smarter, Eco-Friendly and automated energy management atmosphere in homes, and compares key factors and benefits of using such systems compared to traditional energy management methods are given by table 3.

Table 3 Compares key factors and benefits of using such systems compared to traditional energy management methods

Criteria	Cloud-Based Energy Management	Traditional Energy Management
Energy Monitoring	Real-time monitoring via cloud-enabled devices and apps	Manual or semi-automated monitoring with traditional meters
Data Analytics	Advanced analytics for consumption patterns, peak times, and cost-saving tips	Limited to basic usage data, no in-depth analytics
Automation	Automated control of appliances based on usage and preferences	Limited or no automation, requiring manual control
Remote Access	Full remote access via mobile devices or web interface	No remote access; physical interaction with devices
Cost Efficiency	Potential for significant savings through real-time adjustments and automation	Higher energy costs due to inefficiencies and lack of real-time control
User Control	High degree of control with custom	Low control, with manual adjustments

	settings and automation rules	needed for changes in usage
Integration with Renewable Energy	Seamless integration with renewable sources (solar, wind)	Complex and less efficient integration of renewable energy sources
Maintenance and Updates	Automatic updates and low maintenance costs	Manual maintenance and often costly upgrades
Initial Setup Costs	Moderate initial costs, lower long-term expenses	Lower initial costs but higher ongoing expenses due to inefficiency
Energy Data Security	Data stored securely in the cloud, with encryption	Limited data security, as data is stored locally
Scalability	Easily scalable to accommodate new devices and users	Limited scalability; requires additional infrastructure
Environmental Impact	Reduces energy waste, optimizes usage, and supports sustainability efforts	More wasteful due to lack of optimization

5. Conclusion

Energy management systems that are cloud based is a solution that will greatly be of use when it comes to managing energy usage in domestic areas and with this there will be increased efficiency, decreased costs and the least amount of harm to the planet. Combination of IoT devices and machine learning algorithm enables the system to learn the real time data and suggests energy saving solutions which can be beneficial to the user. As our findings show, this system can lead to energy savings and improved utility of the facility amongst the users. More research could be directed at the possibility of incorporating renewable energy into the system as a way of improving on the sustainability of the system.

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