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Integrating Smart Energy Management System with Internet of Things and Cloud Computing for Efficient Demand Side Management in Smart Grids

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Abstract: The increasing price of and demand for energy have prompted several organizations to develop intelligent strategies for energy tracking, control, and conservation. Demand side management is a critical strategy for averting substantial supply disruptions and improving energy efficiency. A vital part of demand side management is a smart energy management system that can aid in cutting expenditures while still satisfying energy needs; produce customers’ energy consumption patterns; and react to energy-saving algorithms and directives. The Internet of Things is an emerging technology that can be employed to effectively manage energy usage in industrial, commercial, and residential sectors in the smart environment. This paper presents a smart energy management system for smart environments that integrates the Energy Controller and IoT middleware module for efficient demand side management. Each device is connected to an energy controller, which is the inculcation of numerous sensors and actuators with an IoT object, collects the data of energy consumption from each smart device through various time-slots that are designed to optimize the energy consumption of air conditioning systems based on ambient temperature conditions and operational dynamics of buildings and then communicate it to a centralized middleware module (cloud server) for management, processing, and further analysis. Since air conditioning systems contribute more than 50% of the electricity consumption in Pakistan, for validation of the proposed system, the air conditioning units have been taken as a proof of concept. The presented approach offers several advantages over traditional controllers by leveraging real-time monitoring, advanced algorithms, and user-friendly interfaces. The evaluation process involves comparing electricity consumption before and after the installation of the SEMS. The proposed system is tested and implemented in four buildings. The results demonstrate significant energy savings ranging from 15% to 49% and highlight the significant benefits of the system. The smart energy management system offers real-time monitoring, better control over the air conditioning systems, cost savings, environmental benefits, and longer equipment life. The ultimate goal is to provide a practical solution for reducing energy consumption in buildings, which can contribute to sustainable and efficient use of energy resources and goes beyond simpler controllers to address the specific needs of energy management in buildings.

Keywords: cloud computing; demand side management (DSM); energy conservation; energy efficiency; smart grid (SG); smart energy management system (SEMS); internet of things (IOT)

1. Introduction

The traditional electric grid (TEG) is a network of power generating stations, transmission lines, and distribution systems that are used to generate, transmit, and distribute
electricity. However, with the increasing demand for energy and the need for a more efficient and reliable power supply, there has been a shift towards the development of smart grids (SG) [1]. According to a report published by International Energy Agency (IEA), a 30% increase in worldwide energy demand will be observed during 2017 and 2040 [2]. Another report of IEA revealed that the monthly electricity demand in Pakistan in FY 2019–2020 was around 120,000 GWh, and it is estimated to increase to around 200,000 GWh by FY 2024–2025 [3]. Further, there is a significant gap between the demand and supply of electricity in Pakistan, which results in frequent power outages or load shedding. The duration of load shedding varies depending on the region and time of year, but it can range from a few hours to more than 12 h per day. Developing nations such as Pakistan frequently struggle with issues including poor infrastructure, minimal access to power, and extreme poverty. Therefore, the effective use of power may improve access to electricity, lessen the strain on the nation’s limited resources, and accelerate economic growth [4–6]. For instance, SG installation can help to lower energy losses, increase power supply dependability, and lower the price of electricity [7]. This may be accomplished by taking a number of steps, such as installing smart meters (SMs), which can aid with monitoring and limiting power consumption, and using renewable energy sources (RES), which may reduce the nation’s reliance on fossil fuels [8]. The adaptability and stability of the power supply can also be improved with the inclusion of an energy storage system (ESS) [9–11].

A smart grid (SG) is an improved electric infrastructure that controls, regulates, and optimizes the usage of power using digital technology. In order to increase the effectiveness, dependability, and flexibility of the electricity supply, it involves the inculcation/integration of several technologies, including SMs, RES, and ESS [12]. Demand-side management (DSM) and energy conservation (EC) strategies are also made possible by SG, which can help to lower the demand for power and encourage the effective use of energy. The Energy Management System (EMS) is a crucial component of DSM [13]. Figure 1 displays a representation of the SG, which is composed of multiple power sources, transmission lines, RES, EMSs, and a central control center [12].

![Figure 1. Representation of the Smart Grid [12].](image-url)
Demand-side management (DSM) and smart-energy-management-systems (SEMS) are related ideas in the field of energy management (EM). Monitoring, managing, and energy conservation in an organization, facility, or industrial process are all parts of EM. The goal of EM is to save on expenses, maximize efficacy, and decrease energy usage while maintaining a comfortable and productive atmosphere [14]. Energy managers can employ demand-side management (DSM) and smart EM systems (SEMS) as two critical tools to accomplish these objectives [13,14]. Real-time (RT) data on energy use are gathered by SEMS, processed, and analyzed to reveal useful information on how and where to make changes. SEMS employs cutting-edge technologies, including automation and sensors, to maximize energy efficiency (EE) and minimize waste [15]. DSM, on the other hand, is a collection of methods and tactics that put emphasis on controlling energy demand by scheduling consumption for off-peak times, modifying temperature setpoints, and controlling lighting and other equipment. SEMS may be used as a tool to implement DSM techniques; hence the two concepts are closely connected. Energy managers can consider EM holistically when SEMS and DSM are used together [16]. SEMS offers RT data on energy use, enabling managers to spot areas of inefficiency and waste. It is therefore possible to put DSM methods into practice to lower energy consumption at peak periods, when energy is most expensive and carbon intensive [17].

Demand-side management is a strategy that focuses on reducing the overall demand for energy by encouraging the efficient use of energy. It involves a range of measures, such as EC, and demand-side response, which aim to decrease electricity demand and enhance its efficiency [18]. This can be achieved through various measures, such as RT monitoring and control of all electrical appliances, promoting energy-efficient technologies, encouraging the usage of RES, and providing incentives for EC. Energy conservation, on the other hand, refers to the practice of reducing the use of energy through various measures. EC can help reduce the maximum demand of electrical distribution networks and enhance the efficacy of the electricity supply [19]. The implementation of DSM/EC strategies can provide a cost-effective means to attain energy security and independence, particularly in developing nations where a complete overhaul of infrastructure from TEG to modern SG may not be a feasible alternative due to its substantial cost [13]. Energy efficiency represents the most economical approach to cater to the expanding energy demands, while also constituting a fundamental component of sustainable development, in line with the United Nations Sustainable Development Goals (SDGs) agenda [20,21] DSM plays a significant role in accomplishing this objective by enabling the monitoring and control of loads, thereby facilitating improved EE. Furthermore, DSM and EC can help reduce the strain on the country’s limited resources, improve access to electricity, and promote economic growth. DSM in SG must take advantage of the latest/smart technologies such as the Internet of Things (IoT) to achieve better efficacy and reliability in SG environments [15]. Figure 2 shows various DSM techniques [13].

The IoT encompasses a network of interconnected physical devices, including vehicles, buildings, and objects, equipped with sensors, software, and other technologies to facilitate data collection and exchange. The evolution of the IoT has provided numerous benefits to the electric grid. With IoT-enabled SEMS, we can more efficiently track and control the energy utilization in our homes, buildings, and cities. The primary advantage of IoT-based SEMS is their ability to automate certain processes. For example, a smart thermostat can automatically regulate the temperature in a home or building based on the time of day, the number of people present, and other factors. Implementing IoT technologies can lead to EE by reducing energy consumption, thereby resulting in cost savings associated with heating and cooling expenses. Another benefit is to provide RT information on energy usage. This can help individuals and organizations make more informed decisions about how to use energy more efficiently. By automating processes, providing RT information, and enhancing the resilience and reliability of the TEG, these systems can help us use energy more efficiently and sustainably [22–26].
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If energy consumption in homes utilizes efficiently, energy can be conserved, sustainability can be enhanced and carbon emissions can be minimized to a noteworthy level [27,28]. Buildings in the United States contribute to a significant portion of energy consumption, accounting for around 40% of total energy usage and 75% of electricity consumption. Heating, Ventilation and Air Conditioning (HVAC) systems are a significant contributor to this energy usage, accounting for around 30% of the energy consumption in commercial buildings and 50% in residential buildings [29]. In UAE, HVAC contributes almost 60% of energy consumption [30], whereas in Pakistan it contributes almost 49% [13]. As buildings and HVAC consume a lot of power in the electric grid, efforts to reduce their load can have a significant impact on the total demand of national electric grid; consequently, significant priority in energy conservation (EC) may be given to the HVAC and buildings. The presented study emphasizes the importance of control and surveillance in the DSM component of the SG while offering the RT deployment of an IoT-based SEMS. The work incorporates SMs for monitoring, command, control and efficient data processing, as well as IoT middleware modules. The presented system is deployed at different locations, allowing users to monitor, control and send commands to various electrical appliances such as HVAC systems.

The main contributions of this research work are as follows:

Development of a multilayered architecture for EMS: This study proposes a comprehensive multilayered architecture that enables effective monitoring and control of electrical appliances.

Integration of ECON and middleware module for efficient EM: The architecture incorporates inculcation of ECON and a middleware module to enhance the EM capabilities that further employs optimization algorithms and load control techniques alongside the EMS.

Figure 2. Demand Side Management Techniques [13].
Performance evaluation of the EMS in multiple locations: The presented EMS is deployed and evaluated in various locations to assess its performance and effectiveness. The study validates the applicability and scalability of the EMS.

Real-time energy savings: One of the primary objectives of the study is to achieve significant energy savings in RT. By implementing the proposed EMS and leveraging its advanced features, the study demonstrates the potential for substantial energy reduction without compromising the comfort or functionality of the monitored systems.

2. Literature Review

A smart energy management system covers three areas: wireless sensor network (WSN), smart appliances, and EMS. The EMS requires a robust communication channel for the transmission of data related to power usage and the power consumption pattern during peak hours. This communication channel is developed using wireless sensor network techniques. The architecture of EMS is explained in [31,32]. The ZigBee module is used to connect with the sensor modes. During peak load hours, the system tracks device usage statistics and communicates control signals to end nodes. However, over time, when new sensors are implemented in the network, the lifetime of the WSN network decreases.

Moreover, Han et al. in [33] discussed the mechanism in which the ZigBee protocol for WSN is used, which is vital for communication and tracking purposes. However, the data processed and accumulated in this method exclusively for the server of the residential units may result in loss of data in the event of any discrepancy. Besides, to achieve two-way communication between sensor and control systems of household devices, the ZigBee protocol is interfaced with the Internet Protocol stack. For interfacing between ZigBee and Internet Protocol stack, a link is needed to fill the gap from the connection of the digital device to numerous homes.

The WSN networks which are mentioned above were expanded to wider ranges in the IoT framework; the end devices were remotely controlled utilizing the GSM/GPRS networks described in [34,35]. IoT technologies are used to monitor and control the method of HVAC systems. In this way, HVAC energy usage is regulated and explained in [36,37]. This research work proposes an optimal EM approach for HVAC systems in commercial buildings with thermal energy-storage using the strategy of model-predictive-control. The proposed approach uses a model predictive control algorithm to optimize the HVAC operation. A defined structure of smart home services design is implemented for user interface with several house displays, as summarized in [38]. In this analysis, a centralized controller monitors all the active devices in homes with the help of sensors and it is responsible for accumulating all the energy consumption and telemetry for homeowners. In a large community, a centralized regional broker unit is established to accommodate the different home network appliances; for instance, security cameras.

This paper [39] proposes a smart control strategy for HVAC system in commercial buildings that can maintain the indoor air quality and thermal comfort while minimizing the energy consumption. The proposed approach uses an energy scheduler with comfort constraints (DES-CC) and a dynamic energy scheduler with a comfort constraints relaxation (DES-CCR) algorithm to find the optimal setpoints for temperature [40]. This paper proposes an approach for reducing peak power demand in residential HVAC systems by integrating HVAC management and optimal scheduling of smart appliances. The focus is on implementing a smart thermostat scheduling technique to achieve community-wide peak load reduction [41]. The proposed method is based on a mixed-integer linear programming model which accommodates the users’ preferences, electricity pricing and the thermal dynamics of the building. This paper [42] proposes an energy-saving control approach for HVAC systems in commercial buildings using a hybrid model predictive control and artificial neural network. The proposed approach uses an artificial neural network to model a predictive control algorithm to optimize the HVAC operation in RT and achieve the desired indoor temperature. The authors of [43] present the development of an EMS, LoBEMS, that integrates IoT components to optimize building efficiency, resulting in a 20% energy saving by controlling
Air Conditioning (AC), lighting, and monitoring systems. This paper [44] proposes an EM strategy for HVAC systems in commercial buildings using model predictive control and weather forecasting. The proposed strategy utilizes a model predictive control algorithm to optimize the HVAC operation in RT. The proposed approach aims to reduce the ultimate electricity demand while maintaining the indoor thermal comfort within a predefined range. For monitoring of the household devices [38], two types of protocol are used alternately: one is Message Queuing Telemetry Transport Protocol (MQTT) and the second is Hypertext Transfer Protocol (HTTP). Big Data is extremely influential when organizing and examining a sheer amount of data gathered through household sensor networks, but the framework of the new suggested design is incapable of integrating the Big Data. The importance of a SG in managing electricity usage, as well as proposals for IoT-based SEMS that will generate consumer load profiles to be remotely accessed by utility companies has been discussed in [12,13]. They proposed a SEMS that monitors energy consumption, uploads data to the cloud, and provides load profiles through a web portal for effective DSM. The authors of [15] discuss the need for smart metering systems to track energy consumption, enable smart equipment control, and integrate users and networks for improved EE. They propose a cost-effective SM with IoT capabilities and demonstrates its effectiveness in real-life environments.

However, the researchers in [45] recommended IoT-based DC-driven homes and the development of the distribution network developed on the DC infrastructure that can incorporate the data of all residential DC loads in a community. The DC power system is the appropriate replacement for the AC power system, but inefficient formalized protocols and regulations were the main hurdles to the implementation of a smart DC power system. However, these challenges can be overcome by IoT, which can provide a more reliable and efficient energy distribution of DC-powered technologies.

In the framework of providing telemetry on EM, In-Home Energy Displays [46] are used to provide several opportunities to monitor and control energy consumption and cost. Automatic meter reading (AMR) is used in the proposed design to record usage data and to communicate these data to the datacenter for assessment and payment. The smart home system based on the atmospheric condition can choose the correct user interface, such as TV, smartphone, tablets and computers, accordingly. However, a standard user interface is absent in this architecture, which could satisfy multiple monitor displays. A proposed EMS architecture using communication from power lines was addressed in [47]. Realtime information from the home appliances is obtained for tracking and monitoring purposes with the help of EMS, thereby allowing its customers to be aware of their power consumption status using smart meter data. With the help of this information, consumers can control their devices remotely. The suggested architecture is built in such a way that it is designed on HTTP protocol but it is not compatible to assist MQTT, which is a vital ingredient for the scaling of the system to compensate multiple community areas. A centralized gateway controller in [48] is implemented with a management system that could control all the operation plans of nodes connected in the home network of residential areas. This gateway controller is dependent on weather conditions. The information on power usage is then fed to the internet via Extensible Markup Language (XML) which encrypts information in both human-readable and machine-readable formats. Because XML files appear to be big on data transmission for both client and server, sending such large files across the network would pose major bandwidth challenges for the architecture [48].

Moreover, a cost modeling scheme was introduced by the researchers in [49] to utilize the EM system to its full potential, which aims to reduce the consumer’s energy expenses. Factors such as electricity generation capacity at the regional level, highest electricity demand hours and tariffs dependent on the consumer demand were considered for the application’s RT pricing for each scenario, as compared with no EM approach, the application was recorded to reduce energy costs. For sustainable and effective solutions, EMS can be used. Using accredited EMS [50], long-term savings of over 20% can be achieved. Another study showed that Home-Energy-Management-System (HEMS) would theoretically mini-
mize power usage, with reasonable discomfort, by almost 20% [51]. The work [30] revealed the importance of SEMS by utilizing IoT and Big Data technologies to monitor energy. The authors present a SEMS for smart homes, where devices are connected via an IoT mesh network, collecting energy consumption data for centralized processing and analysis. The proposed system employs Big Data analytics and Business Intelligence software to manage energy consumption effectively, with HVAC units as a case study for validation. The research work in [52] presents the development and validation of ‘EnerMon’, an IoT LoRa system based on edge computing, for monitoring power consumption. It provides RT information and descriptive analytics to identify energy waste over time. Prakash et al. [53] emphasizes the importance of demand-side energy management to address the growing concerns of increased power appliance usage and the imbalance between demand and supply. The system incorporates cost optimization algorithms, sensory information, ZigBee communication and an IoT environment for data analytics storage. In another work [54], the authors highlight the need for the framework to control and track electricity utilization due to the increasing number of household appliances. They propose an IoT-enabled SM that provides device-level energy consumption data, aiding consumers in managing energy effectively. The research work [55] focuses on creating an innovative ICT ecosystem tailored for school environments to raise awareness among young people and promote EE. Karthick et al. [56] presents the proposal for a Commercial-Building-Energy-Management-System (CBEMS) by utilizing IoT-based Smart-Compact-Energy meters (SCEMs) to monitor and control energy usage and power quality in commercial buildings. Soliman et al. [57] proposed a supervisory EMS for a hybrid battery/PV/tidal/wind sources integrated in a DC-microgrid energy storage system. Sahri et al. [58] presented an EMS for a hybrid RES in a microgrid-based network. Another study [59] explores the potential of automated Demand Response through SG technologies to improve the comparing capacity of distribution systems and enhance grid stability, as evidenced by European case studies. The work in [60] provides a comprehensive review of the energy-internet (EI) inculcated with SG, highlighting its concepts, challenges, and future directions, including utility energy services, DSM, and potential improvements for sustainable operation and management. These studies [57–60] contribute to the field by addressing specific EM challenges. However, they differ from our research, which focuses on the inculcation/integration of IoT and cloud computing for DSM in buildings. Energy-saving behavior has been identified as a potential strategy for DSM for developing economies, with the literature suggesting that it can minimize the energy demand up to 21.9%. Now, consumers can become more efficient and control their electricity consumption to a greater extent by using the new suggested architecture.

The following research gaps are identified in the field of SEMS:

Insufficient Integration with Cloud: Many previous research works lack integration with cloud platforms, which limits their ability to efficiently manage and analyze large volumes of data. This gap highlights the need for systems that seamlessly connect with cloud-based solutions to enhance data management and analysis capabilities.

Optimization Algorithms: Many existing studies lack comprehensive and efficient optimization algorithms for EM. There is a need for advanced algorithms that can effectively optimize energy consumption while considering the ambient temperature conditions and operational dynamics of buildings.

Load Control: The ability to control and manage loads effectively is a significant research gap. Previous works may not adequately address load control strategies, which are crucial for optimizing energy usage, reducing peak demand and achieving overall energy savings.

Practical Application in Multiple Locations: While some references focus on individual buildings or locations, there is a lack of emphasis on practical implementation in multiple locations or a larger-scale context. Extending the application and testing of SEMS to multiple locations is necessary to assess scalability, interoperability, and overall system performance.
Real-Time Energy Savings: Many existing systems may not fully leverage RT data with load control strategies to achieve optimal energy savings. RT monitoring, analysis, and adaptive control mechanisms are essential for continuously optimizing energy consumption and adapting to dynamic conditions in RT.

By addressing these research gaps in a comprehensive manner, this work builds upon previous research works [12,30] to integrate advanced optimization algorithms, incorporate effective load control strategies, demonstrate practical application in multiple locations, and enable real-time energy savings. In doing so, this work presents a single integrated approach that encompasses all the mentioned functionalities and contributes to the development of efficient, scalable, and practical SEMS. Table 1 compares the various SEMS with the presented work, that clearly displays the contributions and significance of the work.

The suggested design work is expected to initiate exciting opportunities in IoT-based SEMS. The findings of a case study show that overall energy usage in a building can be minimized. The program enables users to track and manage devices remotely through a user-friendly mobile application interface.

3. System Model

The presented SEMS design includes hardware components composed of ECON which inculcate current and temperature sensors, a Data Acquisition (DA) System on Chip (SOC) microcontroller, relays and System software components that further include web-application and a cloud-based-IoT middle ware module. They are explained in the next subsections. First, we present multilayered Architecture of SEMS.

Table 1. The comparison of various SEMS, with a specific focus on analyzing their features and functionalities.

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3.1. Multilayered Architecture of SEMS

Based on Cloud Computing and IoT, we present multi-layered generic architecture of SEMS. The layers are defined as follows:

The bottom layer, Energy Monitoring and Data Collection (EMDC), comprises actuators, sensors, and other smart devices that capture data. It is responsible for data collection and monitoring. The Energy Control (ECN) layer is responsible for data collection from the integrated sensors and transmitting that to the actuators to act based on the commands received from the cloud (middleware module). EMDC and ECN layers can be located in various places, such as homes, factories, or cities, and can be used for different purposes, such as monitoring energy consumption, controlling temperature, or detecting motion. The third layer is the communication layer that provides connectivity between devices and enables bidirectional communication of data and commands between cloud (middleware module) and SEMS via IP/TCP protocol. This layer includes internet gateways and DA systems that collect raw data from smart sensors and convert it from analog to digital format. These three layers are applied at the consumer end. Cloud layer (CL) offers the infrastructure for data storage and processing, data analytics and execution of EC directives. The application layer is where data are processed and analyzed to provide insights and make decisions. It may be a web portal or mobile application. The topmost 2 layers are applied at the remote end.

Figure 3a shows the five-layered generic IoT architecture of SEMS, whereas Figure 3b displays the block diagram of the presented SEMS. It comprised ECON, ESP 32 [61] as a microcontroller (MCU), DA and bidirectional communications, a middleware module for efficient EM and a client application module.

![Figure 3. (a) Five-layered generic IoT architecture of SEMS. (b) The block diagram of the presented SEMS.](image)

3.2. Hardware Components

Hardware components include: ECON, which inculcates current and temperature sensors; DA-SOC microcontroller; and relays.

The ACS712 [62] is a linear current sensor based on the Hall effect that has a sensitivity of 185 mV/A and can measure DC or AC currents up to 30 A. It is appropriate for precise current measurement in a range of applications because it has a low offset voltage of 20 mV.
and a low noise level of 20 mV rms. It is a simple to integrate with ESP32 MCU since it offers an analogue output that is able to access the ESP32s ADC inputs directly. The DS18B20 is a digital temperature sensor that is connected using the OneWire protocol. The ESP32 is a powerful Wi-Fi+BT MCU that can be used for a wide variety of applications. It is designed to be scalable and adaptive, making it suitable for DA and other IoT applications. Depending on the signal received from the cloud server, a relay is utilized to either switch on or off by opening or closing of the connections of any appliances. Table 2 provides the specification of ESP-32.

Table 2. Characteristics of ESP32 [61].

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<tr>
<th>Manufacturer</th>
<th>Type</th>
<th>Memory</th>
<th>CPU</th>
<th>Power</th>
<th>Input</th>
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<td>Espressif Systems</td>
<td>32-bit microcontroller</td>
<td>4 MB flash</td>
<td>160 MHz</td>
<td>3.3 V DC</td>
<td>48 pins</td>
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</table>

3.3. Software Components

Software components include a cloud-based IoT middleware module [64] and web application [65]. The middleware module acts as a bridge for software applications to implement communication between ECON and consumers. It acts as a connective tissue to provide the communication channel between digital devices and the middleware. DA-SoC constantly communicates the information of power consumption details to the middleware module via the MQTT protocol. It requires a very flexible and scalable data repository to store user-related details such as energy consumption, temperature, and device status. Based on temperature and per-device power usage, the collected data are filtered and categorized. Power usage trends are analyzed and predicted through these data in the form of a graph, charts and reports. This allows each consumer to see their pattern of power consumption. Consequently, the consumer/facility manager can turn the system on/off based on such information through a command. In addition, the tool will allow consumers/community managers to see the trend of energy usage as per their specific needs. These reports and graphs are provided to the client application via the HTTP protocol.

The interfaces of the front-end mobile users were created using a cross-platform Integrated Development Environment (IDE) [65]. The benefit of using such a platform is that it makes use of common languages for web creation. The cross-platform function is guaranteed for the application, which means one application can be used for the various digital networks and there is no requirement for re-implementation. The software uses two forms of verification for activation of the connection: a standard combination of username and passwords. Upon the verification of the user, an Application Programing Interface (API) key is assigned to validate the operations. The API key is changed for every session and this key can be altered at any time. So, when the user logged out of his session, the API key is changed. Additionally, it needs a special parameter called a secret key to perform assigning entitlement. An API key is a unique identifier that is used to validate a programmer, consumer, or project. The API key changes regularly (monthly or yearly) and is supposed to be a secret known only to the client and the server. A pattern is illustrated in Figure 4 to display the sequence of the flow of data: two ways from household digital appliances to the user networks.

A web application helps users to communicate with the portal and to monitor home appliances remotely using IoT protocol. Figure 5 displays the main application that includes all possible choices, such as adding a place (shown as Figure 5a), tracking building appliances (Figure 5b), sensors information (Figure 5c), statistics on room temperature, current, voltage and power (Figure 5d) and obtaining RT controls (Figure 5e).
Figure 4. Sequence diagram: two-way sequence of the flow of data from digital appliances to the user networks (modified from [30]).

Figure 5. Web Application Interface, (a) adding a place, (b) tracking building appliances, (c) sensors information, (d) statistics on room temperature, current, voltage and power, (e) obtaining RT controls.
3.4. Flow Chart of Presented SEMS

The algorithm is a set of steps followed to read the data from various sensors, control the load based on the commands received and showing the data at consumer API.

- It starts with the initialization, which initiates the communication between sensors and MCU. It also sets an energy consumption interval of 1 millisecond.
- The second process is the energy calculation, which reads the current, voltage and temperature data from the sensors, calculates the cumulative power (kW) and communicates it to the DA-SoC, which is an ESP32 MCU utilizing a MQTT protocol. The middleware module acts as a bridge for software applications to implement communication between ECON and consumers. The first two steps are carried out every 30 s.
- It stores and provides the RT data to the consumer via an API which is integrated with the middleware module via HTTP protocol. ESP32 capacitates the bidirectional communication with ECON and the middleware module. It also aids in the execution of EC directives/commands from ECN layer that is processed at the cloud layer.
- Moreover, it also provides various reports/analytics such as sensor values, consumption statistics and device status.

Figure 6 illustrates the flow chart of presented SEMS, composed of five layers: DA-SoC, middleware module and consumer application.
4. Results and Discussion

HVAC contributes a significant portion of electricity consumption in buildings and the residential sector, so in an effort to reduce energy consumption and promote sustainability, our focus is on HVAC load, as it was found to be accountable for 60% of overall energy consumption in the buildings. The electricity consumption of each building has been calculated using a conventional approach. To this end, the electricity consumption of each electric appliance in 04 buildings was listed and it was found that AC contributes almost 60% of the electricity consumption in each building, as shown in Figure 7.

![Figure 7](image-url)

**Figure 7.** Total electricity consumption of each building.

We offer an EC approach while focusing on the temperature difference in a 24 h period, especially in countries such as Pakistan. To this end, we present a set of eight time slots (TSs) that have been designed to optimize energy consumption in four buildings. The eight TSs have been designed to consider the ambient temperature conditions and operational dynamics of the buildings. Each TS is designed to optimize the energy consumption of AC systems. Details of each TS are provided below and shown in Figure 8 and Table 3.

**Night Aware Intelligence (TS1)**  
Nights are cooler than days, it adjust thermostat to optimize energy consumption by considering ambient and room temperature

**Start of Business Automation (TS3)**  
It synchronizes and enables power-up of the air conditioners at start of business that saves at least 5% of energy consumption

**Peak Ambient Temperature Compensation (TS5)**  
It disable the thermostat lock to compensate sudden spike in ambient temperature to save energy and maintain thermal comfort

**Close of Business Automation (TS7)**  
It executes synchronized power down of unnecessary air conditioners at close of business and saves at least 5% of energy consumption

**Morning Soft Start (TS2)**  
It soft start the cooling in the morning when outside temperature is generally moderate to save energy

**Thermal Comfort Dynamic Lock (TS4)**  
It locks the allowable thermostat settings with human thermal comfort zone to ensure comfort while maximizing energy savings

**Close of Business Coasting (TS6)**  
It lets the coasting air conditioning towards close of business hours to facilitate ventilation while saving energy

**Evening Slow Down (TS8)**  
It tappers-off the energy consumption in off-evening as the outside temperature cool-off by optimizing the thermostat settings

![Figure 8](image-url)

**Figure 8.** Details of each time slot.
Table 3. Time duration of each time slot.

<table>
<thead>
<tr>
<th>Time Slots</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night Aware Intelligence (TS1)</td>
<td>0:00</td>
<td>4:00</td>
</tr>
<tr>
<td>Morning Soft Start (TS2)</td>
<td>5:00</td>
<td>7:00</td>
</tr>
<tr>
<td>Start of Business Automation (TS3)</td>
<td>8:00</td>
<td>9:00</td>
</tr>
<tr>
<td>Thermal Comfort Dynamic Lock (TS4)</td>
<td>8:00</td>
<td>18:00</td>
</tr>
<tr>
<td>Peak Ambient Temperature Compensation (TS5)</td>
<td>12:00</td>
<td>15:00</td>
</tr>
<tr>
<td>Close of Business Costing (TS6)</td>
<td>17:00</td>
<td>18:00</td>
</tr>
<tr>
<td>Close of Business Automation (TS7)</td>
<td>18:00</td>
<td>19:00</td>
</tr>
<tr>
<td>Evening Slow Down (TS8)</td>
<td>19:00</td>
<td>23:00</td>
</tr>
</tbody>
</table>

Night Aware Intelligence (TS1): It is designed to optimize energy consumption during the night when the outside temperature is cooler. It adjusts the thermostat settings to maintain thermal comfort while minimizing energy consumption.

Morning Soft Start (TS2): It is designed to gradually start cooling in the morning when outside temperatures are generally moderate. This helps to save energy while maintaining thermal comfort.

Start of Business Automation (TS3): It synchronizes and enables the power-up of AC systems at the start of business hours. This saves at least 5% energy consumption.

Thermal Comfort Dynamic Lock (TS4): It locks the allowable thermostat settings with a human thermal comfort zone to ensure comfort while maximizing energy savings.

Peak Ambient Temperature Compensation (TS5): It disables the thermostat lock feature during the hottest time of the day (12:00 to 15:00) to compensate for sudden spikes in ambient temperature to maintain thermal comfort.

Close of Business Costing (TS6): It allows for the coasting of AC systems towards the close of business hours to facilitate ventilation while saving energy.

Close of Business Automation (TS7): It executes shut down of unnecessary AC systems at the close of business hours and saves at least 5% energy consumption.

Evening Slow Down (TS8): It tapers off the energy consumption during the evening as the outside temperature cools off. This is achieved by optimizing the thermostat settings.

The case study was developed on multiple HVAC units in four different office buildings. Each AC unit has ECON, which collects details about power usage and the environmental situation regularly and then transmits this information to the middleware module. A time and sensors-based algorithm, as shown in Figure 9, is presented based on eight TSs. It is executed at the IoT layer and processed at the ECN layer.

For the validation of the proposed system, it is essential to acquire the data of electricity consumption before and after the proposed system installation. The aim of this investigation is to collect electrical energy utilization under ordinary (conventional) conditions and to equate these details with the final findings of a case (EMS) in which the proposed system is being utilized. For this purpose, the electricity bill issued by LESCO (Lahore Electric Supply Company) is used to calculate monthly, daily and hourly-based electricity consumption. In this scenario, consumers are carrying out everyday activities without taking care of their energy usage and without the support of the presented system.

The electricity consumption of each TS is recorded after the installation of the presented system, and a comparison has been made for both cases, i.e., under normal conditions (conventional) and after implementation of the EMS. The results of the comparison and EC percentage of each TS are shown in Figures 10 and 11, respectively.
Night Aware Intelligence

Start If
00:00
If
T_
max
< T
min
x
End;

Morning Soft Start

Start If
05:00
If
T_
max
< T
min
x
End;

Start of Business Automation

Yes

FAC HC

Yes

Thermal Comfort Dynamic Lock

Yes

Peak Ambient Temperature Compensation

Yes

Close of Business Costing

Yes

Close of Business Automation

Yes

Evening Slow Down

Yes

Enable

Coasting with facilitating Ventilation

Turn Off Acs Gradually

Start If
19:00
If
T_
max
< T
min
x
End;

End

Figure 9. Time and Sensor-based algorithm based on 8 time slots.

Figure 10. Electricity consumption comparison of each time slot. (a) Electricity consumption comparison of Night Aware Intelligence (TS1), (b) Electricity consumption comparison of Morning Soft Start (TS2), (c) Electricity consumption comparison of Start of Business Automation (TS3), (d) Electricity consumption comparison of Thermal Comfort Dynamic Lock (TS4), (e) Electricity consumption comparison of Peak Ambient Temperature Compensation (TS5), (f) Electricity consumption comparison of Close of Business Costing (TS6), (g) Electricity consumption comparison of Close of Business Automation (TS7), (h) Electricity consumption comparison of Evening Slow Down (TS8).
It has been observed that percentage of energy conservation is maximum during the Close of Business Automation, i.e., TS7 due to shut down of all unnecessary AC units and its minimum during the Peak Ambient Temperature Compensation, i.e., TS5 due to sudden spike in ambient temperature and disabling of thermostat lock to maintain thermal comfort. Percentage of energy conservation during Evening Slow Down (TS8), Night Aware Intelligence (TS1), Close of Business Costing (TS6) and Morning Soft Start (TS2) is 41%, 37%, 35% and 26%, respectively whereas during Start of Business Automation (TS3) and Thermal Comfort Dynamic Lock (TS4) percentage of energy conservation is 14% and 11%, respectively.

Data analytics provided by the IoT middleware module allow us to derive deeper information out of data obtained from the SEMS to give a realistic view of energy usage. In this case study, the collected dataset is reviewed to explain the trends of power consumption in different TSs and to aid in the identification of EC techniques that can assist users in minimizing their energy consumption.

The dataset of electricity consumption of four buildings is collected and analyzed. The total electricity units consumed are compared with before and after installation of the presented system, which clearly shows that power consumption in different buildings is reduced significantly, as stated in Table 4.

Table 4. Comparison of units saving before and after the installation of the proposed system.

<table>
<thead>
<tr>
<th>Building</th>
<th>KWH Reading</th>
<th>Units Saved</th>
<th>% Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>EMS</td>
<td></td>
</tr>
<tr>
<td>Building 1</td>
<td>41,120</td>
<td>20,800</td>
<td>20,320</td>
</tr>
<tr>
<td>Building 2</td>
<td>21,084</td>
<td>15,840</td>
<td>5244</td>
</tr>
<tr>
<td>Building 3</td>
<td>32,480</td>
<td>25,600</td>
<td>6880</td>
</tr>
<tr>
<td>Building 4</td>
<td>14,360</td>
<td>12,260</td>
<td>2100</td>
</tr>
</tbody>
</table>

The implementation of these strategies resulted in significant energy savings, which can have a positive impact on the environment by reducing greenhouse gas emissions and can also result in cost savings for the building owners. There are several benefits of the presented SEMS, as follows.

Real-time Monitoring: The SEMS enables RT monitoring of electrical appliances through its multilayered architecture. By integrating sensors, actuators and communication protocols, the system continuously collects and analyzes energy consumption data from
Figure 12. Summary of the numerous benefits of SEMS.

Longer Equipment Life: The SEMS helps prolong the lifespan of HVAC system by implementing load control strategies. By preventing excessive load demand and optimizing the operation of appliances, the system reduces the strain on equipment, minimizing wear and tear. This leads to improved equipment reliability, lower maintenance costs and a longer lifespan. Figure 12 summarizes the numerous benefits of SEMS.

Better Control: The SEMS provides effective control over electrical appliances by incorporating the ECON and middleware module. These components enable intelligent scheduling and load control strategies based on the received commands. By optimizing the operation of various HVAC appliances, the system ensures efficient utilization of energy resources, minimizes peak load demand, and maintains a balance between energy conservation and user comfort.

Cost Savings: Through the system’s optimization algorithms and load control strategies, the SEMS helps achieve significant cost savings in energy consumption. By identifying and managing energy-consuming devices efficiently, the SEMS can reduce electricity bills by avoiding unnecessary energy usage during peak tariff hours. The intelligent scheduling of appliances will also allow users to take advantage of off-peak electricity rates, maximizing cost savings.

Environmental Benefits: By optimizing energy consumption and load control, the SEMS contributes to environmental sustainability. Consequently, the system will reduce the overall energy demand, leading to decrease in greenhouse gas emissions and environmental impact. The intelligent management of appliances ensures that energy resources are utilized in an efficient and sustainable manner, promoting a greener and more eco-friendly approach to energy consumption.

Improved Comfort: The SEMS enhances user comfort by intelligently managing and controlling appliances. By considering ambient temperature conditions and operational dynamics of buildings, the system can contribute to the provision of a comfortable living environment.

Longer Equipment Life: The SEMS helps prolong the lifespan of HVAC system by implementing load control strategies. By preventing excessive load demand and optimizing the operation of appliances, the system reduces the strain on equipment, minimizing wear and tear. This leads to improved equipment reliability, lower maintenance costs and a longer lifespan. Figure 12 summarizes the numerous benefits of SEMS.
5. Conclusions

This research highlights the significance of implementing advanced technologies such as cloud computing and IoT in the domain of DSM for SG. The integration of cloud computing and IoT enables the development of a SEMS that effectively optimizes EE in buildings. The SEMS enables effective DSM strategies by utilizing RT data from various IoT devices as well as cloud-based analytics and control techniques, which further enables effective energy consumption patterns analysis and the implementation of energy-saving techniques. In this study, we developed the SEMS that integrates ECON and IoT middleware module to manage energy consumption in four buildings. By integrating sensors, actuators and communication protocols, the presented system continuously collects and analyzes energy consumption data from the HVAC units. It provides valuable insights into energy consumption patterns and enables users to track and manage devices remotely through a user-friendly mobile application. Notably, we focused on collecting energy consumption data from AC units through various TS that are designed to regulate the energy consumption of AC systems based on ambient temperature conditions and operational dynamics of buildings. The presented approach offers several advantages over traditional controllers by providing RT monitoring, incorporating effective load control strategies, demonstrating practical application in multiple locations and a user-friendly interface and enabling RT energy savings. The presented system was tested and implemented, and the results demonstrated its effectiveness in terms of electrical energy savings ranging from 15% to 49. This system can be applied to various sectors to reduce energy consumption, increase EE, and lower energy costs. By optimizing the energy consumption of AC systems while maintaining thermal comfort for building occupants, we can contribute towards promoting sustainability and reducing our carbon footprint. The presented SEMS can be extended to other appliances in the building and can help reduce energy costs and promote sustainability.

However, there are still opportunities for improvement of SEMS, including standardizing communication protocols, revising safety regulations, enabling plug and play functionality, managing big data, recalculating billing metrics and enhancing TEG infrastructure, particularly in underdeveloped nations. It is important to acknowledge these limitations, as they provide insight into the challenges associated with implementing and utilizing the SEMS. Future SEMS can leverage IoT-based smart energy meters, deep learning, machine learning, and advanced techniques for better power quality, efficient distribution and optimal system configurations. Addressing these limitations through ongoing research, technological advancements, and user engagement strategies will contribute to the continued improvement and effectiveness of the SEMS in real-world scenarios.

Despite these limitations, the presented research showcases the effectiveness of the SEMS in achieving EE goals and highlights its potential for wider implementation. The results obtained contribute to the body of knowledge in the field of DSM for SG and provide a foundation for further advancements in smart EM and sustainability efforts.

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