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An IoT-Based Energy Conservation Smart Classroom System

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Abstract: With the increase of energy consumption worldwide in several domains such as industry, education, and transportation, several technologies played an influential role in energy conservation such as the Internet of Things (IoT). In this article, we describe the design and implementation of an IoT-based energy conservation smart classroom system that contributes to energy conservation in the education domain. The proposed system not only allows the user to access and control IoT devices (e.g., lights, projectors, and air conditions) in real-time, it also has the capability to aggregate the estimated energy consumption of an IoT device, the smart classroom, and the building based on the energy consumption and cost model that we propose. Moreover, the proposed model aggregates the estimated energy cost according to the Saudi Electricity Company (SEC) rates. Furthermore, the model aggregates in real-time the estimated energy conservation percentage and estimated money-saving percentage compared to data collected when the system wasn't used. The feasibility and benefits of our system have been validated on a real-world scenario which is a classroom in the college of computer science and engineering, Taibah University, Yanbu branch. The results of the experimental studies are promising in energy conservation and cost-saving when using our proposed system.

Keywords: Energy consumption; energy conservation; energy cost; Internet of Things (IoT); smart classroom

1 Introduction

One critical source that human beings need in life is energy. Electricity is a form of energy used in all buildings and should be paid for in accordance with the electricity usage. When you don't use electricity, it is important to switch off the devices that you are using such as lights. An indoor motion detecting device such as an occupancy sensor is great assistance here. According to Enerdata [1], energy consumption keeps rising annually worldwide. For example, the energy consumption was around 10,000 TWh in 1990, however, in 2020 the energy consumption increased to reach around 23,000 TWh (i.e., more than double). In Saudi Arabia, energy consumption is also rising. According to CEIC in [2], electricity consumption in Saudi Arabia is rising year by year based on reports provided by the ministry of environment, water, and agriculture. For example, the energy consumption was around 115 TWh in 2000. On the other hand, the energy consumption increased sharply to reach around 289 TWh (i.e., the growth percentage is around 251%). Heavy energy consumption is recorded in several domains such as industry, transportation, and education.

Given the accelerated energy consumption growth, proper smart solutions are needed for energy conservation. Managing energy is hard as it involves network distribution, power control in buildings and houses, etc. Several kinds of data should be shared at the present time. Therefore, a smart solution needs to use cutting-edge communication and data technologies, including IoT to observe and send information. This way, it is possible to implement complicated policies for managing energy in a smart environment [3]. A smart classroom system inspired by IoT involves digital equipment automation in accordance with Message Queue Telemetry Transport (MQTT), which is an IoT protocol. The system includes a user interface, a middleware, and a few wireless nodes. The last ones connect with the middleware through the existing or special-purpose network. This connection occurs in accordance with the MQTT protocol created for IoT. The protocol itself utilizes a publish-subscribe messaging pattern on the top of the Transmission Control Protocol (TCP/IP) protocol. Users can employ the system's middleware *via* the interface section. The system recognizes the user's command when they speak. In general, users can involve secret commands for better middleware interaction.

In this paper, we describe the design and the implementation of an IoT-based energy conservation smart classroom system. The system allows faculty members to access and control IoT devices in the smart classroom. Moreover, it allows building managers to view statistics related to estimated energy consumption and estimated energy costs, which will reduce energy consumption in smart classrooms and the entire building. Our main contributions are as follows:

- To the best of our knowledge, this work is the first that focuses on the issue of aggregating estimated energy consumption and estimated energy cost of IoT devices in real-time.
- We design an IoT-based energy conservation smart classroom system that helps in energy conservation. The system allows the user to access and control IoT devices (e.g., lights, projectors, and air conditions) and view statistics related to the estimated energy consumption and estimated energy cost in real-time (e.g., IoT device, classroom, and education building).
- We propose an energy consumption and cost model that aggregates estimated energy consumption and estimated energy cost in Saudi Riyals (SAR) (i.e., according to the Saudi Electricity Company (SEC) rates) for each IoT device, classroom, and education building in real-time. In addition, the model aggregates in real-time the calculated energy conservation percentage and estimated money-savings percentage compared to data collected when the system wasn't used.
- We validate our proposed IoT-based energy conservation smart classroom system using prototype implementation and experimentations using a real-world scenario which is a classroom in the college of computer science and engineering, Taibah University, Yanbu branch.

The remainder of the paper is organized as follows. Section 2 overviews the related work. Section 3 briefly presents the design of the IoT-based energy conservation smart classroom system architecture. Section 4 describe the details of our energy consumption and cost model. Section 5 reports the implementation of our IoT-based energy conservation smart classroom system and the results of experimental evaluations. Finally, we present the concluding remarks in Section 6.

2 Related Work

Several research works have recognized the significance of IoT technologies in energy conservation in several domains such as industry, transportation, health, smart cities, and education [4–7].

Some researchers focus on exploiting IoT technologies in energy conservation in the health domain. For example, Askari et al. [8] propose an Internet of Medical Things (IoMT)-based software-defined Wireless Body Area Network (SD-WBAN) communication system. In particular, the authors propose an energy-efficient two-tire algorithm for real-time Non-Orthogonal Multiple Access (NOMA) scheduling where Walsh Hadamard (WH) codes are employed to lower interference. Other researchers focus on exploiting IoT technologies in energy conservation at the smart cities' domain. For example, Metallidou et al. [9] present a novel management system for smart buildings. In particular, the management system consists of several sub-systems including: (i) ventilation system, (ii) heating system, (iii) air conditioning system, (iv) Domestic Hot Water (DHW) system, (v) system for electrification, and (vi) lighting system. All these systems use a Wireless Sensor and Actuator Network (WSAN) to provide a number of functionalities related to controlling IoT devices with respect to European legislation as for energy efficiency. Nahar et al. [10] present an energy-efficient system for smart rooms, namely, "EPSSR". In particular, authors propose to use an infrared sensor to detect whether the room is occupied or not and the room lighting will turn on or off accordingly. The infrared sensor is used as a counter and when the counter is equal to zero the lights are turned off.

Other researchers focus on exploiting IoT technologies in energy conservation at the education domain. For example, Gupta et al. [11] showcased a loT-based autonomous power control system for energy conservation in classrooms. In particular, authors propose the use of sensors to automatically sense the occupancy of the classrooms and turn the lights on and off accordingly. Moreover, the system has two control modes: (i) manual where the user can switch on or off devices; and (ii) auto depending on the sensors. Martirano [12] proposes a lighting system for energy conservation in classrooms. In particular, the author proposes to use sensors to automatically sense daylight and occupancy of the classrooms. In addition, the author proposes two different control approaches including switching and dimming, and two control modes manual and auto for light switching and dimming. Paudel et al. [13] present a context-aware architecture for energy conservation in a classroom environment. In particular, authors propose to use a Long Short-Term Memory (LSTM) to predict the classroom temperature and humidity based on classified activities of students to figure out when to turn on or off devices (i.e., lights, air conditioners, heaters, etc.), namely, a convolutional 3D network (C3D) model. Mohamad et al. [14] showcased an IoT-based energy smart saving classroom. In particular, the authors present a customized design for an IoT smart classroom for Universiti Tun Hussein Onn (UTHM) main campus. The smart classroom has a door lock system and an indoor and outdoor lighting control system. Furthermore, the system exploits a smartphone application with a Graphical User Interface (GUI) and WiFi connection to control IoT devices easily. Diddeniya et al. [15] present a novel architecture for an IoT-based energy-efficient smart classroom system. In particular, authors propose to use a couple of sensors including: (i) Microsoft Kinect sensor to sense the classroom occupancy, (ii) Light Dependent Resistor (LDR) sensor to sense the light intensity in the classroom to control the lighting, and (iii) Digital Humidity and Temperature (DHT22) sensor to control the air conditioning of the classroom.

Memos et al. [16] showcased a plan for a Revolutionary Interactive Smart Classroom (RISC). In particular, the implementation plan consists of three components including: (i) a cloud computing Learning Management System (LMS), (ii) data-transfer-application protocols, and (iii) connected components (e.g., tactile devices, virtual reality devices and other sensors). The planned smart classroom includes several services such as virtual classroom, augmented and cognitive sense, position, touch interaction, 3D design and modeling, and other services. Ani et al. [17] propose an IoT-based smart classroom architecture. In particular, authors propose an image processing approach to check the occupancy of the classroom and determine when to switch on or off electrical devices such as lights and fans. The classroom is divided into two frames and one camera is used to check occupancy. In other words, when a student is present in frame 1 the electrical devices should turn on and the same goes with frame 2. Pacheco et al. [18] present an osmotic IoT-based smart classroom architecture. In particular, authors propose a deep learning model for occupancy detection through cameras. The architecture consists of four layers including: (i) IoT layer that contains IoT devices and cameras, (ii) Edge layer that contains IoT hubs and mobile devices, (iii) Fog Layer that contains IoT and Vision servers, (iv) Cloud layer that contains Cloud data centers for computing the deep learning model. Banu et al. [19] propose an IoT-based Cloud integrated smart classroom system. In particular, the architecture of the proposed system consists of five layers including: IoT layer which consists of IoT devices such as camera, lights, sensors, air conditions, etc., (ii) Personal Digital Assistant (PDA) layer which consists of mobile phones, laptops, touchpads, etc., (iii) networking and storage which consists of a cloud server, routers, switches, etc., (iv) management layer which includes classrooms, and admin offices, etc., and (v) applications layer for teaching and management activities. Furthermore, the proposed system uses facial recognition for attendance. Chan et al. [20] and Sun et al. [21,22] present an IoT-based smart classroom system. In particular, the system consists of two sub-systems including, (i) Radio Frequency Identification (RFID) attendance system with an admin web page and a lecturer web page, and (ii) Wireless Sensor Network (WSN) energy-saving system to provide the ability to switch on or off lights, air conditions, etc.

Unlike previous works that focus on exploiting IoT technologies in energy conservation in the health or smart cities domains, our work focuses on exploiting IoT technologies in energy conservation in the education domain. In addition, previous works do not consider aggregating estimated energy consumption and estimated energy cost of IoT devices in real-time. In this work, we design an IoT-based energy conservation smart classroom system that allows the user to access and control IoT devices and view statistics related to the estimated energy consumption and estimated energy cost in real-time (e.g., IoT device, classroom, and education building). In particular, we propose an energy consumption and cost model that aggregates estimated energy consumption and estimated energy cost in Saudi Riyals (SAR) (i.e., according to SEC rates) for each IoT device, classroom, and education building in real-time. In addition, the model aggregates in real-time the estimated energy conservation percentage and estimated money-savings percentage compared to data collected when the system wasn't used. More details regarding our proposed system are elaborated in the following sections.

3 System Architecture

We propose an IoT-based energy conservation smart classroom architecture that not only allows the user to access and control IoT devices (e.g., lights, projectors, and air conditions) in real-time, it also has the capability to aggregate the estimated energy consumption and cost of an IoT device, the smart classroom, and the building. Fig. 1 depicts the architecture, which contains four different layers including: (i) the *Smart Education Buildings Layer*, (ii) the *Mobile Network Layer*, (iii) the *Smart Classroom Management Layer*, and (iv) the *Cloud Services Provider Layer*. *Smart Education Buildings Layer*. This layer consists of a number of smart education buildings B where each smart education building b consists of a group of smart classrooms C where each smart classroom consists of a set of IoT devices D where each IoT device d is managed, monitored and estimated energy consumption and cost are aggregated using the energy consumption and cost model in the *Smart Classroom Management Layer*. In addition, the smart education buildings layer consists of a group of faculty members F where each faculty member f has the capability to remotely turn on or off IoT devices in the smart classroom and access data statistics related to energy consumption and cost for the IoT device, or smart classroom (i.e., by week, month, or year). Furthermore, the smart education buildings layer consists of a group of building managers M where each building manager m has the capability to (i) remotely turn on or off IoT devices in the smart classroom, (ii) view the faculty member who turned on or off IoT devices, (iii) access data statistics related to energy consumption and cost for the IoT device, smart classroom, or smart building and (iv) add faculty members.

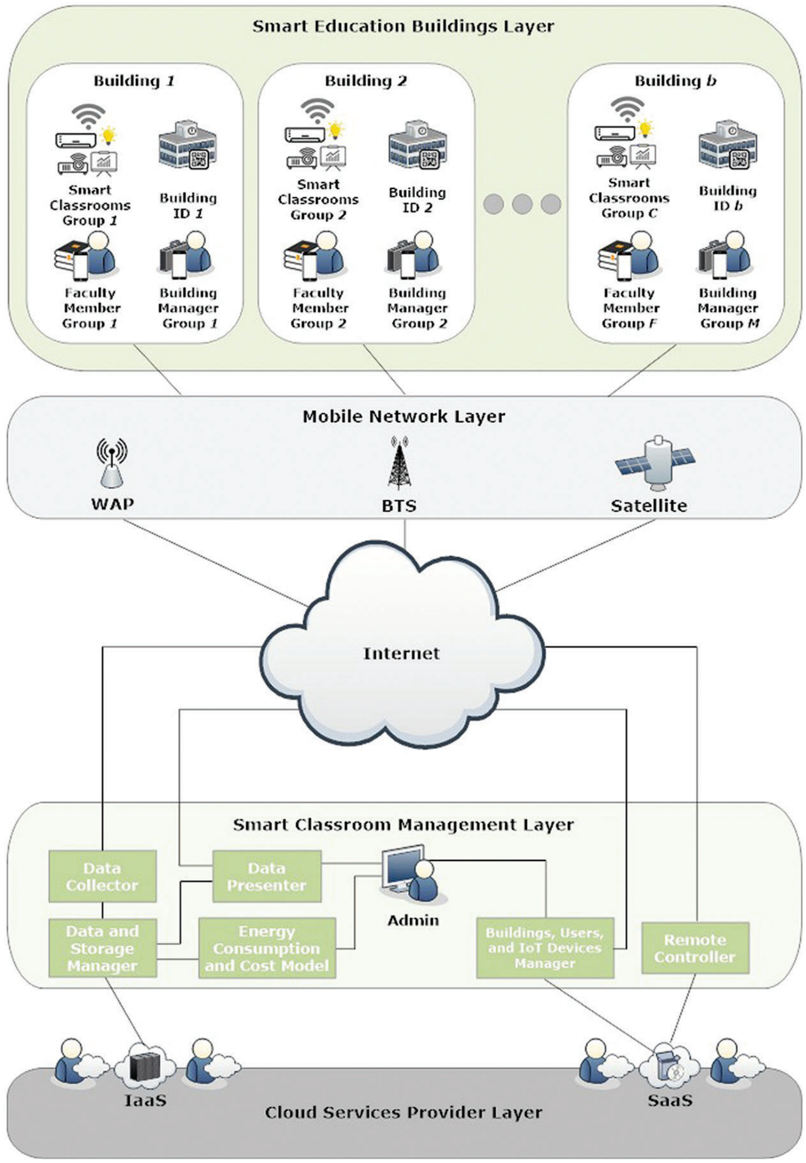


Figure 1: IoT-based energy conservation smart classroom architecture

Mobile Network Layer. This layer represents the communication medium that connects the *Smart Education Buildings Layer* with the *Smart Classroom Management Layer*. In particular, it consists of multiple Base Transceiver Stations (BTSs), satellites, and Wireless Access Points (WAPs) to enable communication. Interactions include: (1) IoT energy consumption and cost data, (ii) buildings, users and IoT devices management, (iii) users authentication, and (iv) remotely turning on or off IoT devices requests.

Smart Classroom Management Layer. This layer consists of seven different components including: (i) Remote Controller allows building managers *M* and faculty members *F* to remotely turn on or off IoT devices and send notifications to building managers and faculty members when an IoT device is turned on for more than 2 h which are enabled through a Software as a Service (SaaS) cloud service, (ii) Buildings, Users, and IoT Devices Manager facilitate the Admin with functionalities related to managing users accounts, adding the energy consumption rate for IoT devices, and adding buildings, (iii) Admin is responsible of adding the energy consumption rate for the d^{th} IoT device denoted n_d, energy cost rate E (i.e., according to SEC rates or Electricity Tariff), adding new smart education buildings b to the system and managing users and IoT devices (e.g., users and passwords, etc.), (iv) Data Collector which is responsible for IoT energy consumption data collection, (v) Data Management and Storage which is responsible for managing and monitoring IoT energy consumption and cost data and the access of their statistics including the IoT device, smart classroom, or smart building (i.e., by week, month, or year) where it is stored in the Cloud datacenter through an Infrastructure as a Service (IaaS) cloud service, (vi) Data Presenter which is responsible for presenting the IoT energy consumption and cost data statistics for building managers and faculty member, (vii) Energy Consumption and Cost Model which is responsible of aggregating the estimated energy consumption and cost of an IoT device, the smart classroom, and the building (i.e., which will be explained in detail in Section 4).

Cloud Services Provider Layer. There are several cloud providers in this layer who provide cloud data centers through IaaS cloud services for the storage of IoT energy consumption and cost data and a SaaS cloud service to remotely turn on and off IoT devices and send notifications to related users.

4 Energy Consumption and Cost Model

In our proposed IoT-based energy conservation smart classroom architecture, building managers and faculty members can turn on or off IoT devices remotely and request the estimated energy consumption and cost of an IoT device, smart classroom, or smart education building. The IoT devices energy status is actually a collection of the Remote Controller history records, represented by a tuple $R_h = (D, C, B, F, M, N_r, S_d, T_d)$, where D is the IoT device's ID, C is the smart classroom's ID, B is the smart education building's ID, F is the faculty member's ID, M is the building manager's ID, N_r is the energy consumption rate for an IoT device (i.e., normally found in technical specification sticker on devices usually called as device wattage), and S_d is the IoT device's energy status (i.e., whether the IoT device is turned on or off). Each IoT device's energy status is represented in numerical form, where 0 means that the IoT device is turned off and 1 means that the IoT device is turned on. T_d is the timestamps when the IoT device is turned off or on.

4.1 Energy Consumption and Cost Aggregation for an IoT Device

Whenever a building manager m or a faculty member f requests the estimated energy consumption of an IoT device, the *Energy Consumption, and Cost Model* aggregates the estimated energy consumption for a particular IoT device d, denoted $N(d, t_0, t)$, from the Remote Controller history records as in Eq. (1):

$$N(d,\ t_0,\ t) = \ \Delta_{\mathrm{Sd}}\ (d,\ t) * \ \mathrm{N_r(d)} \tag{1}$$

where $\Delta_S(d, t)$ denotes the actual operational hours of the IoT device d in a period of time which are aggregated from the IoT device's energy status S_d in the Remote Controller history records (R_h). $N_r(d)$ is the energy consumption rate for the IoT device d (i.e., also called Wattage of the IoT device). The result of this equation will be in kWh.

Whenever a building manager m or a faculty member f request the estimated energy cost of an IoT device, the *Energy Consumption and Cost Model* aggregates the estimated energy cost for a particular IoT device d, denoted $O(d, t_0, t)$, from the Remote Controller history records as in Eq. (2):

$$O(d,\ t_0,\ t)\ =\ N(d,\ t_0,\ t) * \varepsilon \tag{2}$$

where $N(d, t_0, t)$ is the estimated energy consumption for a particular IoT device d in a in a period of time and ε is the energy cost rate (i.e., according to SEC rates or Electricity Tariff). For example, if an IoT device's energy consumption rate (i.e., Wattage) is 1000 watts and the actual operational hours of the IoT device are 50 h., then the estimated energy consumption for the IoT device is 50 kWh (i.e., 50,000 Watts Hours). Based on estimated energy consumption for the IoT device, and we assume that the energy cost rate (i.e., according to SEC electricity tariff for governmental institutes) is 0.32 Saudi Riyals (SARs), then the estimated energy cost for the IoT device is 16 SAR.

4.2 Energy Consumption and Cost Aggregation for a Smart Classroom

Whenever a building manager m or a faculty member *f* request the estimated energy consumption of a smart classroom, the *Energy Consumption* and *Cost Model* aggregates the estimated energy consumption for a particular smart classroom *c*, denoted $N(c, d, t_0, t)$, from the Remote Controller history records as shown in Eq.(3).

$$N(c,\ d,\ t_0,\ t) = \sum_{d=1}^{|C(d)|} \Delta_{\mathrm{Sd}}\ (c, d,\ t) * N_{\mathrm{r}}(c, d) \tag{3}$$

where *C(d)* denotes the IoT devices in smart classroom *c* and |*C(d)*| represents the total number of IoT devices in smart classroom *c*. Δ_{Sd} *(c, d, t)* is the actual operational hours of the d^{th} IoT device in the c^{th} smart classroom in a period of time which are aggregated from the IoT device's energy status S_d in the Remote Controller history records (R_h). $N_r(c, d)$ is the energy consumption rate for the d^{th} IoT device in the c^{th} smart classroom (i.e., the result of this equation will also be in kWh).

Whenever a building manager *m* or a faculty member *f* request the estimated energy cost of a smart classroom, the *Energy Consumption* and *Cost Model* aggregates the estimated energy cost for a particular smart classroom *c*, denoted $O(c, d, t_0, t)$, from the Remote Controller history records as shown in Eq.(4).

$$O(c,\ d,\ t_0,\ t) = \left(\sum_{d=1}^{|C(d)|} N(c,\ d,\ t_0,\ t) \right) *\ \varepsilon \tag{4}$$

where *C(d)* denotes the IoT devices in smart classroom *c* and |*C(d)*| represents the total number of IoT devices in smart classroom *c*. $N(c, d, t_0, t)$ is the estimated energy consumption for the d^{th} IoT device in the c^{th} smart classroom. ε is the energy cost rate (i.e., according to SEC rates or Electricity Tariff).

4.3 Energy Consumption and Cost Aggregation for a Smart Education Building

Whenever a building manager m or a faculty member *f* request the estimated energy consumption of a smart education building, the *Energy Consumption and Cost Model* aggregates the estimated energy consumption for a particular smart education building *b*, denoted $N(b, c, d, t_0, t)$, from the Remote Controller history records as in Eq. (5):

$$N(b, c,\ d,\ t_0,\ t) = \left(\sum_{d=1}^{|B(d)|} \Delta_{\mathrm{Sd}} \left(b, c, d,\ t \right) * N_{\mathrm{r}}(b, c, d) \right) \tag{5}$$

where *B(d)* denotes the IoT devices in smart education building b and |*B(d)*| represents the total number of IoT devices in smart education building *b*. Δ_{Sd} *(b, c, d, t)* is the actual operational hours of the d^{th} IoT device in the c^{th} smart classroom at the b^{th} smart education building in a period of time which are aggregated form the IoT device's energy status S_d in the Remote Controller history records (R_h). $N_r(b, c, d)$ is the energy consumption rate for the d^{th} IoT device in the c^{th} smart classroom at the b^{th} smart education building (i.e., the result of this equation will also be in kWh).

Whenever a building manager *m* or a faculty member *f* request the estimated energy cost of a smart education building, the *Energy Consumption* and *Cost Model* aggregates the estimated energy cost for a particular smart education building b, denoted $O(b, c, d, t_0, t)$, from the Remote Controller history records as in Eq. (6):

$$O(b, c,\ d,\ t_0,\ t) = \left(\sum_{d=1}^{|B(d)|} N(b, c,\ d,\ t_0,\ t) \right) * \varepsilon \tag{6}$$

where *B(d)* denotes the IoT devices in smart education building *b* and |*B(d)*| represents the total number of IoT devices in smart education building *b*. $N(b, c, d, t_0, t)$ is the estimated energy consumption for the d^{th} IoT device in the c^{th} smart classroom at the b^{th} smart education building. ε is the energy cost rate (i.e., which is entered by the Admin).

4.4 Energy Conservation and Money-Saving Percentages Aggregation for an IoT Device

Whenever a building manager *m* or a faculty member f request the energy conservation percentage of an IoT device, the *Energy Consumption* and *Cost Model* aggregates the energy conservation percentage for a particular IoT device *d*, denoted $\alpha(d, t_0, t)$, from the Remote Controller history records as in Eq. (7):

$$\alpha(c, d, t_0, t) = \begin{cases} 1 - \left(\dfrac{\int_{t_0}^{t} N(c, d, t)dt}{\int_{t_0}^{t} N'(c, d, t)dt} \right) * 100 & \text{if } \int_{t_0}^{t} N'(c, d, t)dt > \int_{t_0}^{t} N(c, d, t)dt \\ 1 - \left(\dfrac{\int_{t_0}^{t} N'(c, d, t)dt}{\int_{t_0}^{t} N(c, d, t)dt} \right) * 100 & \text{if } \int_{t_0}^{t} N(c, d, t)dt > \int_{t_0}^{t} N'(c, d, t)dt \\ 0\% & \text{otherwise} \end{cases} \tag{7}$$

where the *N'(d, t)* is the estimated energy consumption for a particular IoT device *d* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only (i.e., without using the features of the system such as the remote controller and consumption notifications). *N(d, t)* is the estimated energy consumption for a particular IoT device *d* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control (i.e., while using the features of the system such as the remote controller and consumption notifications). In the first case of Eq. (7), the numerator represents the whole area under the curve where the estimated energy consumption is captured while using the features of the system (i.e., area *b* as shown in Fig. 2). The denominator represents the whole area under the curve where the estimated energy consumption is captured without using the features of the system (i.e., area *a* as we can see in Fig. 2). One minus the whole fraction represents the ratio between the two areas which represents the energy conservation percentage for the IoT Device *d* (i.e., $a - (a \cap b)$ see Fig. 2). In the second case of Eq. (7), the numerator represents the whole area under the curve where the estimated energy consumption is captured without using the features of the system and the denominator represents the whole area under the curve where the estimated energy consumption is captured while using the features of the system. One minus the whole fraction represents the ratio between the two areas which represents the energy wastage percentage for the IoT Device *d*. Finally, the third case of Eq. (7), means that the areas of both curves are equal and there is no energy conservation nor energy wastage, therefore the percentage is assigned to 0%.

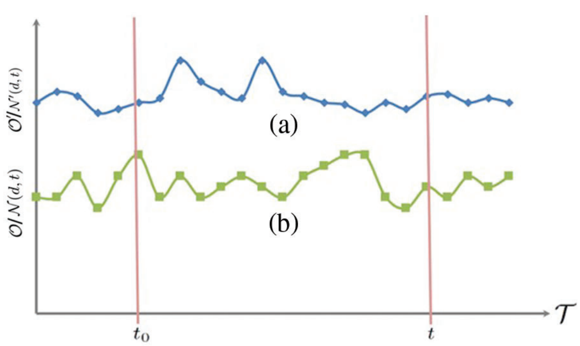


Figure 2: Energy conservation and money-saving percentages aggregation for an IoT device

Whenever a building manager m or a faculty member *f* request the money-saving percentage of an IoT device, the *Energy Consumption* and *Cost Model* aggregates the money-saving percentage for a particular IoT device *d*, denoted $\omega\ (d,\ t_0,\ t)$, from the Remote Controller history records as in Eq. (8):

$$\omega(c,d,t_0,t)=\begin{cases}1-\left(\dfrac{\int_{t_0}^{t}O(\mathrm{c,d,t})\mathrm{dt}}{\int_{t_0}^{t}O'(\mathrm{c,d,t})\mathrm{dt}}\right)*100 & \textit{if}\int_{t_0}^{t}\mathrm{O}'(\mathrm{c,d,t})\mathrm{dt}>\int_{t_0}^{t}O(\mathrm{c,d,t})\mathrm{dt}\\ 1-\left(\dfrac{\int_{t_0}^{t}O'(\mathrm{c,d,t})\mathrm{dt}}{\int_{t_0}^{t}O(\mathrm{c,d,t})\mathrm{dt}}\right)*100 & \textit{if}\int_{t_0}^{t}O(\mathrm{c,d,t})\mathrm{dt}>\int_{t_0}^{t}O'(\mathrm{c,d,t})\mathrm{dt}\\ 0\% & \textit{otherwise}\end{cases} \tag{8}$$

where the $O'(d,\ t)$ is the estimated energy cost for a particular IoT device *d* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only (i.e., without using the features of the system such as the remote controller and consumption notifications). $O(d,\ t)$ is the estimated energy cost for a particular IoT device *d* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control (i.e., while using the features of the system such as the remote controller and consumption notifications). In the first case of Eq. (8), the numerator represents the whole area under the curve where the estimated energy cost is aggregated while using the features of the system (i.e., area *b* as shown in Fig. 2). The denominator represents the whole area under the curve where the estimated energy cost is aggregated without using the features of the system (i.e., area a as we can see in Fig. 2). One minus the whole fraction represents the ratio between the two areas which represents the money-saving percentage for the IoT Device d (i.e., $a - (a \cap b)$ see Fig. 2). In the second case of (8), the numerator represents the whole area under the curve where the estimated energy cost is aggregated without using the features of the system and the denominator represents the whole area under the curve where the estimated energy cost is aggregated while using the features of the system. One minus the whole fraction represent the ratio between the two areas which represents the money wastage percentage for the IoT Device *d*. Last but not least, the third case of (8), means that the areas of both curves are equal and there is no money-saving nor money wastage, therefore the percentage is assigned to 0%.

4.5 Energy Conservation and Money-Saving Percentages Aggregation for a Smart Classroom

Similarly, whenever a building manager *m* or a faculty member f request the energy conservation percentage of a smart classroom, the Energy Consumption and Cost Model aggregates the energy conservation percentage for a particular smart classroom *c*, denoted $\alpha(c,\ d,\ t_0,\ t)$, from the Remote

Controller history records as in Eq. (9):

$$\alpha(c,d,t_0,t)=\begin{cases}1-\left(\dfrac{\int_{t_0}^{t}\mathrm{N(c,d,t)dt}}{\int_{t_0}^{t}N'(\mathrm{c,d,t})\mathrm{dt}}\right)*100 & \textit{if}\int_{t_0}^{t}N'(\mathrm{c,d,t})\mathrm{dt}>\int_{t_0}^{t}\mathrm{N(c,d,t)dt}\\ 1-\left(\dfrac{\int_{t_0}^{t}N'(\mathrm{c,d,t})\mathrm{dt}}{\int_{t_0}^{t}\mathrm{N(c,d,t)dt}}\right)*100 & \textit{if}\int_{t_0}^{t}\mathrm{N(c,d,t)dt}>\int_{t_0}^{t}N'(\mathrm{c,d,t})\mathrm{dt}\\ 0\% & \textit{otherwise}\end{cases} \tag{9}$$

where the $N'(c,\ d,\ t)$ is the estimated energy consumption for a particular smart classroom *c* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only. $N(c,\ d,\ t)$ is the estimated energy consumption for a particular smart classroom *c* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control. In the first case of Eq. (9), one minus the whole fraction represents the energy conservation percentage for the smart classroom *c*. In the second case of Eq. (9), one minus the whole fraction represents the energy wastage percentage for the smart classroom *c*. The third case of Eq. (9), means there is no energy conservation nor energy wastage in the smart classroom *c*.

Whenever a building manager *m* or a faculty member *f* request the money-saving percentage of a smart classroom, the *Energy Consumption* and *Cost Model* aggregates the money-saving percentage for a particular smart classroom c, denoted $\omega(c, d, t_0, t)$, from the Remote Controller history records as in Eq. (10):

$$\omega(c,d,t_0,t) = \begin{cases} 1 - \left(\dfrac{\int_{t_0}^{t} O(c,d,t)dt}{\int_{t_0}^{t} O'(c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} O'(c,d,t)dt > \int_{t_0}^{t} O(c,d,t)dt \\ 1 - \left(\dfrac{\int_{t_0}^{t} O'(c,d,t)dt}{\int_{t_0}^{t} O(c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} O(c,d,t)dt > \int_{t_0}^{t} O'(c,d,t)dt \\ 0\% & otherwise \end{cases} \tag{10}$$

where the $O'(c, d, t)$ is the estimated energy cost for *a* particular smart classroom *c* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only. $O(c, d, t)$ is the estimated energy cost for a particular smart classroom *c* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control. In the first case of Eq. (10), one minus the whole fraction represent the money-saving percentage for the smart classroom *c*. In the second case of Eq. (10), one minus the whole fraction represent the money wastage percentage for the smart classroom *c*. The third case of Eq. (10), means that there is no money-saving nor money wastage in the smart classroom *c*.

4.6 Energy Conservation and Money-Saving Percentages Aggregation for a Smart Education Building

Similarly, whenever a building manager *m* or a faculty member *f* request the energy conservation percentage of a smart education building, the *Energy Consumption* and *Cost Model* aggregates the energy conservation percentage for a particular smart education building *b*, denoted $\alpha(b, c, d, t_0, t)$, from the *Remote Controller* history records in Eq. (11).

$$\alpha(b,c,d,t_0,t) = \begin{cases} 1 - \left(\dfrac{\int_{t_0}^{t} N(b, c, d, t)dt}{\int_{t_0}^{t} N'(b,c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} N'(b, c,d,t)dt > \int_{t_0}^{t} N(b,c,d,t)dt \\ 1 - \left(\dfrac{\int_{t_0}^{t} N'(b,c,d,t)dt}{\int_{t_0}^{t} N(b,c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} N(b,c,d,t)dt > \int_{t_0}^{t} N'(b,c,d,t)dt \\ 0\% & otherwise \end{cases} \tag{11}$$

where the $N'(b, c, d, t)$ is the estimated energy consumption for a particular smart education building *b* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only. $N(b, c, d, t)$ is the estimated energy consumption for a particular smart education building classroom *b* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control. In the first case of Eq. (11), one minus the whole fraction represent the energy conservation percentage for the smart education building *b*. In the second case of Eq. (11), one minus the whole fraction represent the energy wastage percentage for the smart education building *b*. The third case of Eq. (11), means there is no energy conservation nor energy wastage in the smart education building *b*.

Whenever a building manager *m* or a faculty member *f* request the money-saving percentage of a smart education building, the Energy Consumption and Cost Model aggregates the money-saving percentage for a particular smart education building b, denoted $\omega(b, c, d, t_0, t)$, from the Remote Controller history records as in Eq.(12):

$$\omega(c,d,t_0,t) = \begin{cases} 1 - \left(\dfrac{\int_{t_0}^{t} O(b,c,d,t)dt}{\int_{t_0}^{t} O'(b,c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} O'(b,c,d,t)dt > \int_{t_0}^{t} O(b,c,d,t)dt \\ 1 - \left(\dfrac{\int_{t_0}^{t} O'(b,c,d,t)dt}{\int_{t_0}^{t} O(b,c,d,t)dt}\right) * 100 & if \int_{t_0}^{t} O(b,c,d,t)dt > \int_{t_0}^{t} O'(b,c,d,t)dt \\ 0\% & otherwise \end{cases} \quad (12)$$

where the *O′(b, c, d, t)* is the estimated energy cost for a particular smart education building *b* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring only. *O(b, c, d, t)* is the estimated energy cost for a particular smart education building *b* in a period of time where the IoT-based energy conservation smart classroom system is used for monitoring and control. In the first case of Eq. (12), one minus the whole fraction represents the money-saving percentage for the smart education building *b*. In the second case of Eq. (12), one minus the whole fraction represents the money wastage percentage for the smart education building *b*. The third case of Eq. (12), means that there is no money-saving nor money wastage in the smart education building *b*.

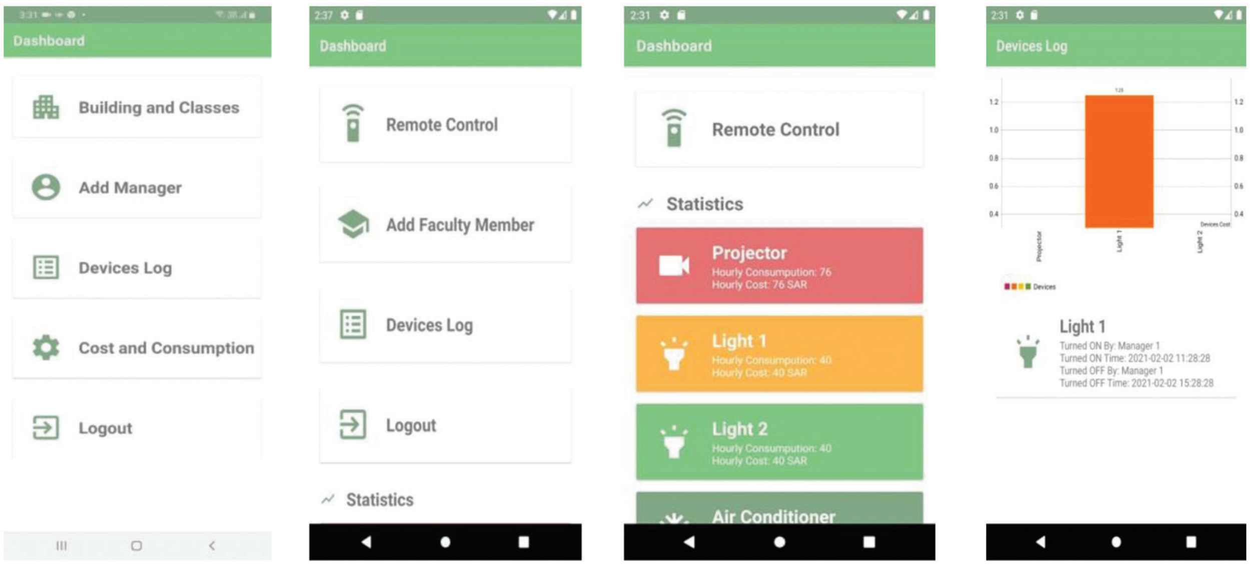
5 Implementation and Experimental Evaluation

The implementation of the IoT-based energy conservation smart classroom system is developed using Arduino UNO WiFi REV2 for monitoring and controlling IoT devices, Android Studio for the development of the Graphical User Interface (GUI), MySQL 8.0.27 for database, and PHP for the mobile application backend. The proposed system is validated on a real-world scenario which is a classroom in the college of computer science and engineering, Taibah University, Yanbu branch. The classroom consists of 4 units of 18,000 BTU air conditioners, 10 LED lights, and a wireless projector. The IoT devices' energy consumption rate is detailed in Tab. 1 (i.e., all of these energy consumption rates were entered by the admin after the devices were installed).

Table 1: IoT devices' energy consumption rate

IoT device	$N_r(d)$
18,000 BTU air conditioner	2.25 kWh
LED light	18 W
Wireless projector	475 W

For the implementation of the IoT-based energy conservation smart classroom system, we have implemented several GUIs for the faculty members, building managers, and the Admin. Fig. 3 showcases some of the GUIs. For example, Fig. 3a illustrates the admin's dashboard where she can add smart education buildings and smart classrooms, add building managers, add the energy consumption rate for the IoT device d (i.e., $N_r(d)$, also called Wattage of the IoT device) and the energy cost rate (i.e., E, according to SEC rates or Electricity Tariff), and check the IoT devices logs. Fig. 3b illustrates the building manager's dashboard where she can remotely turn on or off IoT devices in the smart classroom using the remote control, add faculty members, check the IoT devices logs, and access statistics related to the estimated energy consumption and cost of the IoT Device, the smart classroom, or the smart education building. Fig. 3c illustrates the faculty member's dashboard where she can remotely turn on or off IoT devices in the smart classroom using the remote control and access statistics related to the estimated energy consumption and cost of the IoT Device or the smart classroom. Fig. 3d illustrates the IoT devices log where the energy consumption and cost of each IoT device can be monitored in real-time, the recent status of the device (e.g., turned on or off), the user who controlled the IoT device and time stamp.



(a) Admin Dashboard (b) Building Manager Dashboard (c) Faculty Member Dashboard (d) Devices Log

Figure 3: IoT-based energy conservation smart classroom system GUIs

Fig. 4 shows the running and testing of the remote control. In our experimental evaluation, we focus on validating the energy consumption and cost model. To do that, we first use the IoT-based energy conservation smart classroom system for monitoring only and the IoT devices' energy status is collected and the actual operational hours of all the IoT devices in the smart classroom are calculated for a 15 weeks period. As an experimental setting, we refer to the data collected for this period of time as conventional model data. Based on the collected data, the estimated energy consumption and energy cost for the smart classroom are aggregated. We then use the IoT-based energy conservation smart classroom system for monitoring and control (i.e., while using the features of the system such as the remote controller and consumption notifications). The IoT devices' energy statuses are collected and the actual operational hours of all the IoT devices in the smart classroom are calculated for the same period of time (i.e., another 15 weeks period). We call the collected data for this period of time the energy consumption and cost model data as another experimental settings. Based on the collected data, the estimated energy consumption and energy cost for the smart classroom are also aggregated. The energy cost rate for the experiments is set to 0.32 Saudi Riyals (SARs) (i.e., according to the SEC Electricity Tariff for government institutions).

Fig. 5 depicts the energy consumption and conservation experimental results. Fig. 5a shows the energy consumption for two experimental settings: (i) conventional model (i.e., without using our proposed approach features) and (ii) Energy consumption and cost model (i.e., while using our proposed approach features). From Fig. 5a, we note that energy consumption results from the energy consumption and cost model are significantly lower than energy consumption results from the conventional model regardless of the oscillation of the energy consumption results. Fig. 5b shows the total energy consumption for the conventional model and the energy consumption and cost model. From Fig. 5b, we can observe that the amount of energy conservation is around 6179 kWh after using the energy consumption and cost model in the 14 weeks period. In other words, based on (9) the energy conservation percentage for the smart classroom is 43.7%.

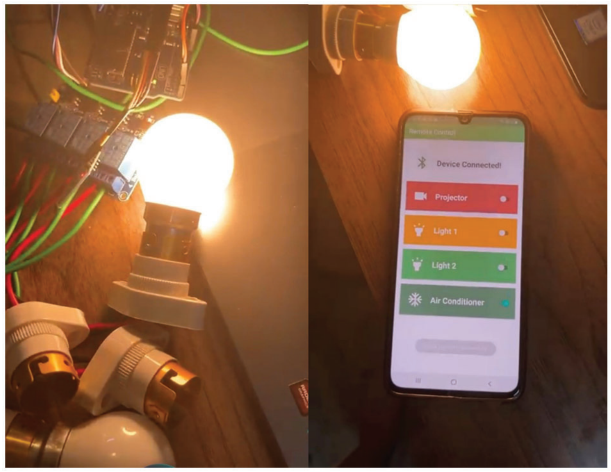
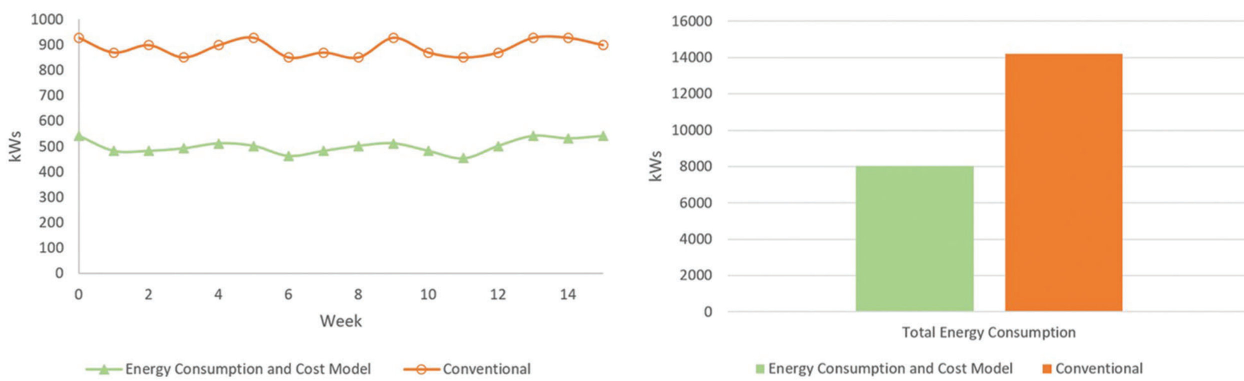


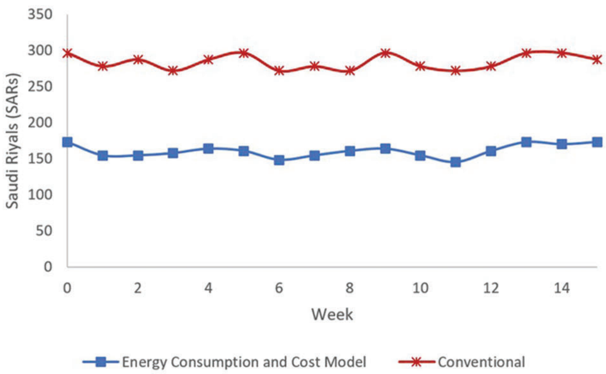
Figure 4: Remote control running and testing



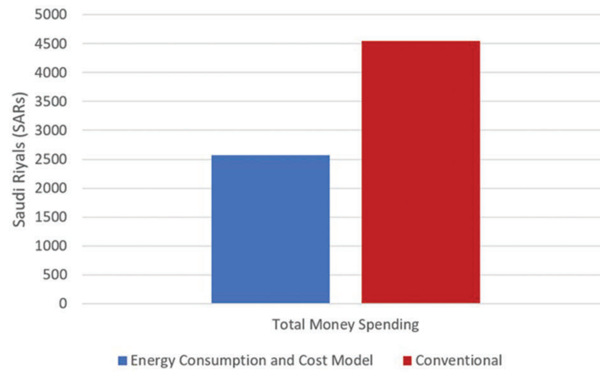
(a) Energy Consumption Analysis (b) Energy Conservation Analysis

Figure 5: Energy consumption and conservation experimental evaluation

Fig. 6 illustrates the energy cost and saving experimental evaluation. Fig. 6a shows the energy cost for two experimental settings: (i) conventional model (i.e., without using our proposed approach features) and (ii) Energy consumption and cost model (i.e., while using our proposed approach features). From Fig. 6a, we note that energy cost results from the conventional model are significantly higher than energy cost results from the energy consumption and cost model through the 15 weeks period. Fig. 6b shows the total money spending for the energy consumption and cost model and the conventional model. From Fig. 6b, we can observe that the amount of energy cost saving is approximately 1977 SAR (i.e., around 527$ USD) after using the energy consumption and cost model in the 14 weeks period. Specifically, the energy cost saving percentage for the smart classroom is 43.7% based on Eq. (10).



(a) Energy Cost Analysis



(b) Energy Cost Saving Analysis

Figure 6: Energy cost and saving experimental evaluation

6 Conclusion

Internet of Things (IoT) is one of the leading technologies in energy conservation that will help the world become greener and more energy-efficient. In this article, we describe the design and implementation of an IoT-based energy conservation smart classroom system that contributes to energy conservation in the education domain. The proposed system is based on a novel energy consumption and cost model that we propose. In particular, we design an IoT-based energy conservation smart classroom system that allows the user to access and control IoT devices and view statistics related to the estimated energy consumption and estimated energy cost in real-time (e.g., IoT device, classroom, and education building). In this study, we propose an energy consumption and cost model that aggregates estimated energy consumption and estimated energy cost in Saudi Riyals (SAR) (i.e., according to SEC rates) for each IoT device, classroom, and education building in real-time. In addition, the model aggregates in real-time the estimated energy conservation percentage and estimated money-savings percentage compared to data collected when the system wasn't used. The feasibility and benefits of our system have been validated in a real-world scenario which is a classroom in the college of computer science and engineering, Taibah University, Yanbu branch. The experimental results show that the proposed system can conserve energy and save money by 43.7% compared to the current energy. For our future work, we plan to enhance our proposed system by adding occupancy sensors to automatically turn IoT devices on or off. Expanding the system to cover the whole smart education building is another focus of our future research work.

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