IoT-ENABLED GREEN CAMPUS ENERGY MANAGEMENT SYSTEM

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ABSTRACT

Increasing cost and demand for energy is imposing us to find smart ways to save energy. To satisfy the energy requirement and at the same time to cut down the cost, consumption of energy must be monitored and controlled. Energy consumption can be well managed with the capabilities of the Internet of Things (IoT). This paper presents an architecture towards IoT-enabled Green campus Energy Management System. In the proposed system, the data acquisition module collects energy consumption information from each device and transmits it to the cloud platform for further processing and analysis. Since lighting and air conditioning appliances contribute to most of the electricity consumption in the campus environment, they have been taken as a prototype to validate the proposed architecture.

Keywords

Green campus, Internet of Things, Energy Management, data acquisition, cloud

1. INTRODUCTION

Electricity is generated from steam turbines, geothermal energy, biomass, coal, nuclear energy, natural gas, and solar energy. Using renewable resources helps us to achieve our goal of shifting towards green. But energy from fossil fuel such as coal alone contributes to 75% of the total energy produced worldwide. The burning of fossil fuel is the major contributor for greenhouse gas emission which results in greenhouse effect. Even though alternate sources of energy are available, it is not possible to replace fossil fuel in terms of its large production. Our aim is to reduce the consumption of electricity still meeting the energy demand. If the unwanted usage of electricity is avoided, it will help in reducing the energy consumption and hence the cost. It can be achieved by careful monitoring of the consumption pattern. A place where education and environmental responsibility go hand in hand is called green campus. The Green Campus inventiveness is to extend learning beyond the classroom by developing responsibility and commitment in youth towards the environment. It is designed in such a manner to prevent pollution, conserve energy by generating energy from non-renewable resources and helps in improving occupants' health. Among these features of the green campus, reduction in energy consumption is a crucial one because the demand, as well as the cost of energy, is increasing tremendously. So it is necessary to monitor and control energy consumption. The IoT-enabled Green campus provides energy efficient way to reduce the greenhouse effect in the existing application or to eliminate the same using IoT itself[1].

Any device can be connected to the Internet and to other connected devices with the help of the Internet of Things. Thus it is possible to acquire data from any device that needs to be controlled or monitored and upload it to the cloud for further analysis. IoT technology can be imparted to make the campus smartly green. The real-time data from IoT can aid the consumer to get clear

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insights into energy consumption behaviour. Thus the consumer can optimize their energy consumption and reduce their electricity bills. Using IoT also has an advantage of providing remote access control of devices where the consumer gets access to the ON/OFF usage pattern of electrical appliances via the internet. Thus IoT can be adapted for implementing energy management solution in the best possible way.

In [2], apparatus for Smart Energy Management System and ways and means for controlling energy consumption are proposed. The data are collected from the smart meter and compared with the threshold value to automatically control the power consumption of devices installed in a customer's area by analysing consumption patterns. But infrastructure for data storage and processing are not addressed here. Jinsoo et al. in [3] monitored energy consumption in the wireless networks using the ZigBee protocol. The data collected from the sensor nodes are aggregated at the cluster head which leads to data loss when the cluster head fails. A drawback of this system is that the network is not scalable because, bridging between ZigBee and transport layer TCP/IP stack has not been established. In[4], a hierarchical architecture for smart home service is employed where a controller system interfaced with device sensors sends the aggregated energy reporting of all devices to the consumer. A comparative analysis of Message Queuing Telemetry Transport Protocol (MQTT) and Hypertext Transfer Protocol (HTTP) is performed to determine the most efficient protocol. But it lacks the incorporation of analytical techniques such as big data which aids in analysing huge volume of data collected from the network. An architecture utilizing power line communication for Home Energy Management Systems (HEMS) was addressed in [5]. This system can monitor and provide real-time information on energy consumption along with device status. This design is based on the HTTP protocol and does not support light-weight communication protocol like MQTT which is essential to scale up the system. Authors in [6], utilized MQTT as the communication protocol for Energy Management System. This System is empowered with analytics and Business Intelligence through dashboard visualization and reporting. Energy management provisions are also implemented here for regional as well as national level utility providers.

The proposed paper presents an architecture for IoT enabled green campus Energy Management Systems. The data is collected from the data acquisition System On Chip (SoC) which processes the data and serially transmits it to the Wi-fi module. The power consumption of an individual device as well as the total power consumed are calculated and the electricity bill is computed. This computed data is uploaded to the Firebase cloud platform where the power consumption pattern is analyzed and displayed to the user through a mobile application. If the electricity usage exceeded certain threshold, it is intimated to the consumer through the SMS. The controlling of the device based on usage is also implemented to reduce energy consumption. A prototype is developed to mimic the campus environment and simulation is also carried out to cross-validate the result using node-red platform.

2. PROPOSED SYSTEM ARCHITECTURE

The current passing through the individual devices is captured using split-core current transformer clipped to the live or neutral wire. Since 230 V AC current cannot be directly interfaced to the Arduino, it should be converted to Arduino’s acceptable range of 0-5 volts using the burden resistor and voltage divider circuit. It is then finally connected to the controller analog input pin. The number of analog input pins in the System On Chip (SOC) controller decides the number of appliances that can be interfaced to the single controller board. From the captured current reading, the power consumed is calculated for each and every device and serially transmitted to the Wi-Fi module. In order to have synchronous communication between the controller and the Wi-Fi module, the transmission format is framed as the following: an indication of the start of the transmission, followed by the calculated power value from each device separated by an identifier and finally, the delimiter. In the Wi-Fi module, the total power consumed and the bill amount of each device and total bill amount is computed. These data are then classified based on the appliances and individually posted to the Firebase cloud in JavaScript Object Notation (JSON) format. JSON is a lightweight intermediate data format and is language independent. In the cloud, data are stored in an organized manner which can be used for power consumption analysis by interfacing the cloud platform with the dashboard. For better user experience a mobile application is developed to monitor consumption as well as the electricity bill. The topic is monitored regularly and if the bill amount exceeds a certain higher limit, SMS alert is triggered to indicate to the user about the energy consumption level. This helps the user to have a clear idea about consumption pattern thereby unwanted usage of electricity can be avoided to the possible extent. Fig.1 shows the proposed architecture for monitoring energy consumption.

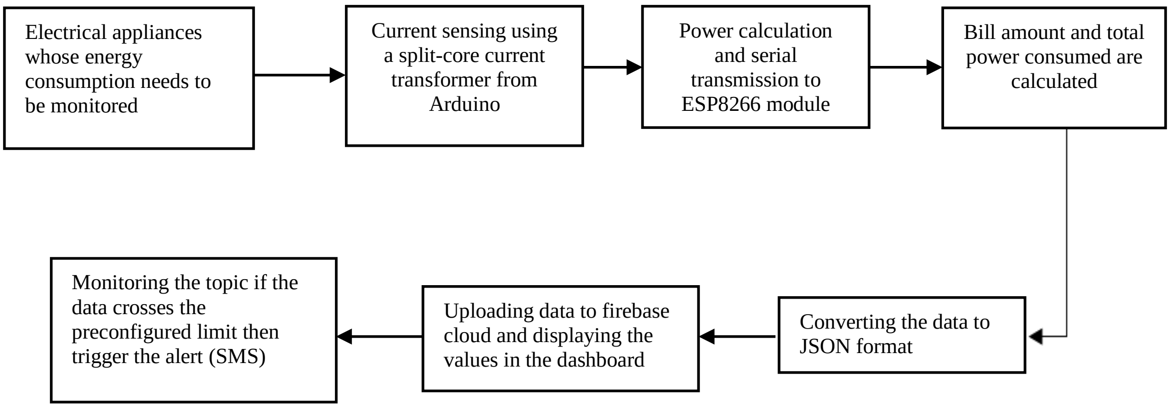


Fig. 1.Proposed Architecture for monitoring energy consumption

The consumption analysis alone does not contribute much towards the reduction in energy consumption. We are wasting electricity instinctively. Actuation techniques such as motion based as well as time-based controlling of devices help in this context in real-time applications. These automation techniques turn off the appliances when not in use without any human intervention.

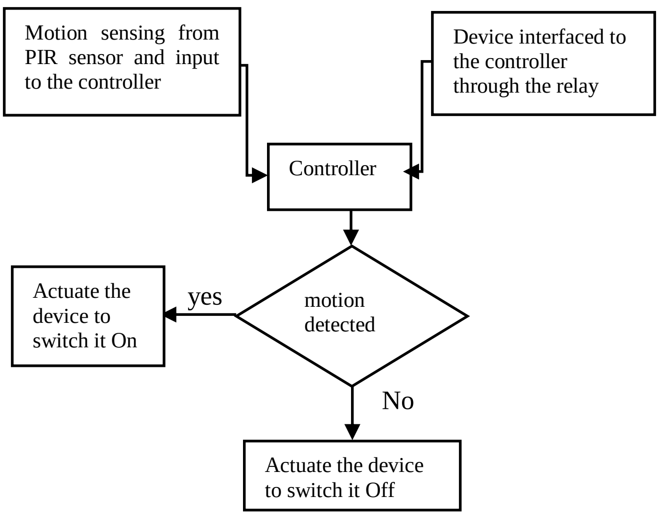


Fig. 2.The architecture for the motion based controlling of appliances

Fig.2 shows the architecture for the motion based controlling of the device. The human motion is detected using a motion sensor and given as input to the controller. The range of detection and the duration of sensing can be preconfigured in the motion sensor itself based on the requirement. The electrical device which needs to be controlled is interfaced with the controller through a relay. If motion is sensed, the device is turned on else it is turned off. Thereby the devices are controlled based on the motion and the energy consumption is reduced significantly.

Time-based controlling of the device is necessary for places like the laboratory where the appliances are not used after the working hours.Fig.3 shows the architecture for time-based controlling of devices. The appliances are interfaced with the controller input through the relay. The controller is then configured with the web service to publish it to the internet. This web service, in turn, is hooked up with the alerter platform, If This Then That (IFTTT). The configuration is such that if the time reaches preconfigured time then the web service is triggered and the device is turned off. The preconfigured time may be the non-usage time thereby contributing to the reduction of the energy consumption.

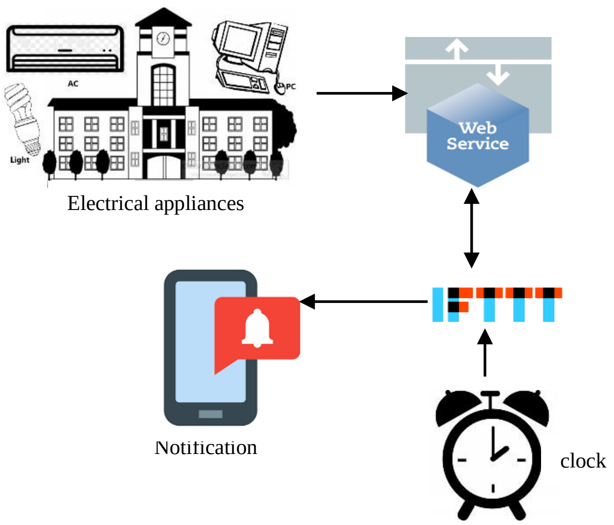


Fig. 3.Time-based controlling of devices

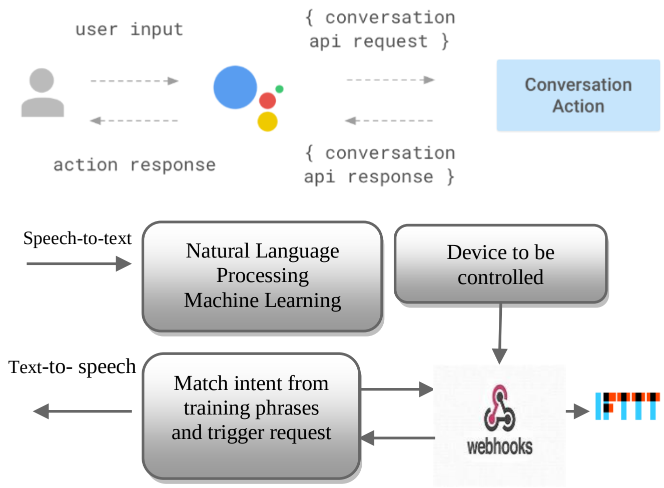


Fig. 4.Voice-based controlling of devices

For ease of access, the device can be controlled through voice commands. IFTTT actuator platform is used to achieve this goal. In the proposed technique Google Assistant is used to interpret the voice command and webhook web service is used as an interface between the device and IFTTT. Fig.4 shows the controlling of devices through voice. In Google Assistant, the input speech is converted to text which is then interpreted using Natural Language Processing and Machine Learning algorithm. The device endpoint is configured in webhooks web service. The intent from Google Assistant triggers the end-point configured in the web service. Thus the device is actuated via voice.

Temperature-based controlling of the device helps to avoid unnecessary use of electricity. During chill climate, running of the device like air conditioner is irrelevant and the device can be set of be turned off automatically.

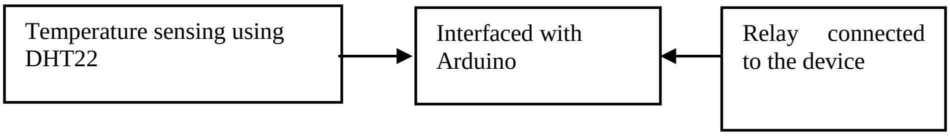


Fig.5. Temperature based controlling of device

Fig.5 shows the temperature based controlling of device. The temperature sensor senses the environment and computes the temperature of the surrounding. It is interfaced with Arduino and the input is read continuously. In the same way, the device which is to be controlled is also interfaced with Arduino through a relay. If the temperature is above pre-configured temperature then the device is turned on by switching the relay.

3. HARDWARE ARCHITECTURE

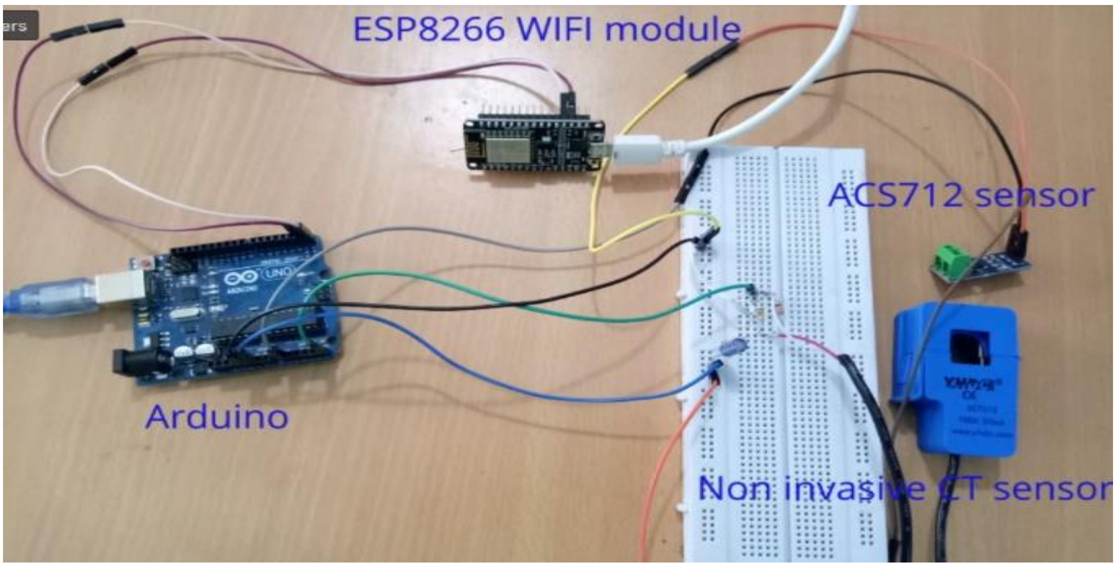


Fig. 6. Hardware setup

Fig.6 shows the hardware implementation for power consumption monitoring. The system comprises of the following building blocks:

3.1. Current Transformer sensor

Alternating current (AC) can be measured using Current transformer (CTs) sensors. It is based on the working principle of the transformer where the alternating current flowing through the primary winding produces a magnetic field, which in turn induces the current in the secondary winding. The primary winding here is the live or the neutral wire supplying to the appliance. The sensor can be clipped onto it. The secondary winding, made up of many turns of fine wire is placed within the sensor case. Thus, it is analogous to the transformer. The current through the secondary winding is commensurate with those of the current passing through the primary winding. This way the current supplied to the appliance can be sensed by the CT sensor.

3.2. Arduino platform

Arduino is an open-source hardware development board. It can read both analog and digital inputs from the sensor. The required functionality can be performed by instructing the microcontroller on the board with the set of instructions. It is inexpensive and platform-independent. The software used to program and communicate with an Arduino board is Arduino IDE. The sketches (Arduino programs) are written in Arduino IDE editor using a simple programming language which mimics the Processing language. Through IDE the program is transformed into C language and then compiled to produce binary code which the microcontroller can able to interpret and execute. Thus the Arduino IDE can compile and upload the program to the board connected to a computer using the USB cable.

3.3. ESP8266-Wifi module

ESP8266 is a Wi-Fi facilitated low-cost wireless transceiver used for IoT developments. It has System On Chip (SOC) with incorporated TCP/IP protocol that can permit the controller to connect to the Wi-fi network. It has onboard computational and memory potentialities that allow it to be integrated with the sensors through its General Purpose Input Output pins with minimum developmental efforts and minimum boot time.

3.4.Motion Sensor

The passive Infrared motion sensor can sense the levels of infrared radiation to identify whether a human being is within the sensor’s range. They are passive in the sense that they consume less power, are compact and cost-effective. Motion-based controlling of electrical appliances contributes more towards the reduction of power consumption.

3.5.Relay Board

The At-mega System On Chip (SOC) controller cannot control the high voltage appliances directly since its operating voltage is 5V. It has a 120-240V switch whose contacts are attached to an electromagnet. The electromagnet becomes charged when the relay receives a HIGH signal and in turn switches the contacts open or closed. The Arduino is used to control the 5V relay. Thus when certain event occurs the relay can be turned on by programming the Arduino.

4. SOFTWARE ARCHITECTURE

The software architecture consists of the following software components:

4.1.Node-red

Node-red is a simulation tool that acts like an event-processing engine. It is a server-side programming platform and it is based on the JavaScript node.js. It is used to implement real-time applications that run across independent systems. It provides Graphical User Interface(GUI) that allow users to drag-and-drop functional blocks that symbolize components such as devices, software platforms and web services that are to be connected.

4.2.Firebase

Firebase is a part of emerging trend known as Backend as a service(BaaS). Using this platform makes the development of android apps easier. Firebase provides ways for application developers to link their applications to backend cloud storage through the use of APIs and SDKs. It combines Database, Analytics, Authentication, Storage, Crash Reports, Hosting, Advertisement etc.. It integrates all basic services needed for the development of an android app.

4.3.IFTTT

If This, Then That (IFTTT) is an automation platform. It allows users to create applets that are triggered when specific conditions are met. This service also has the direct integration with third-party devices and data, other software platforms and IoT hardware. The "this" portion of an applet act as triggers. The "that" portion of an applet is the action that outputs from the input of the trigger.

4.4.Android Studio

It is designed specifically for android application development. It provides platform to develop android application for all android devices. Android Studio offers even more functionalities that enhance the productivity when building Android apps. It has Built-in support for Google Cloud Platform, enabling integration with Firebase Cloud Messaging.

5. RESULTS AND DISCUSSIONS

The prototype implementation is done for two electrical appliances: an air conditioner and a light bulb that mimic the campus environment. The results are then cross-validated with the simulation results.

5.1.Hardware Implementation

Fig. 7.sensors attached to an air conditioner and bulb

Fig.7 shows the sensors attached to different electrical appliances whose consumption pattern needs to be analysed. The inputs from two sensors are given to the Arduino and the serial communication port of the Arduino is connected to the Wi-Fi module.

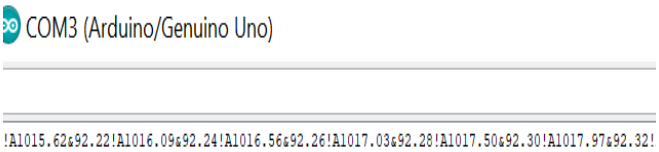


Fig. 8.serial transmission from Arduino

Fig. 8 shows the Arduino output transmitted to the ESP8266 Wi-Fi module through a serial communication protocol. As stated in the proposed methodology, the transmission format is framed as the following: the start of the transmission is indicated by an alphabet ‘A’, followed by the calculated power value from each device separated by an identifier ‘&’ and finally, ‘!’ the delimiter.

ESP8266 on receiving data from Arduino processes the data and posts it to the cloud platform. Fig. 9 shows the calculated power consumption and bill amount of individual device as well as the total power consumption and electricity bill amount from the ESP8266 serial monitor.

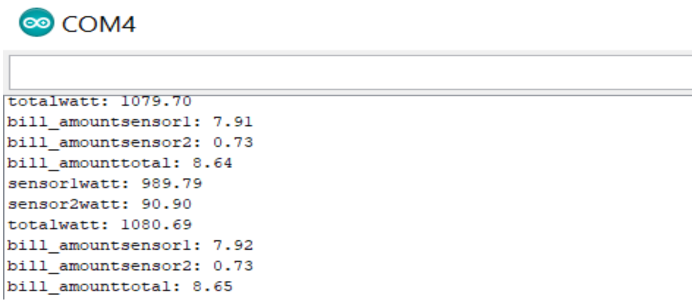


Fig. 9.Power in Watts and bill amount in Rupees displayed in ESP8266

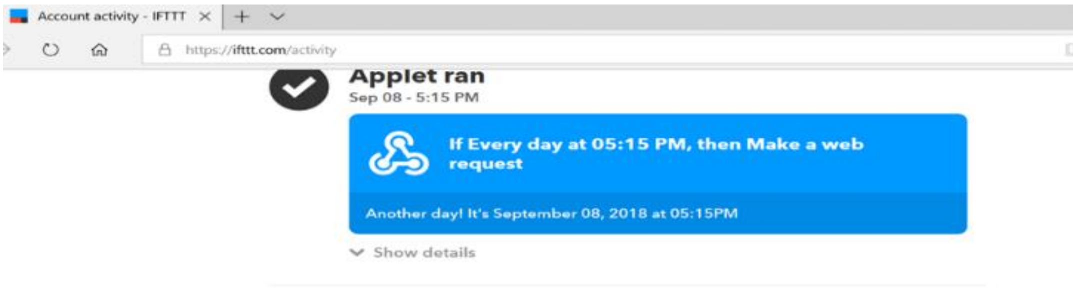


Fig. 10.Device actuation based on time

Fig. 10 shows the data uploaded to cloud platform which is in JavaScript Object Notation (JSON) format. It is in the form of key-value pair. JSON is a lightweight intermediate data format and is language independent.

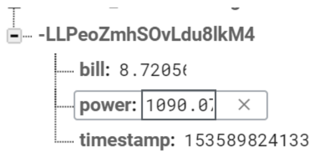


Fig. 11.Data uploaded in JSON format

Energy consumption can be reduced by means of controlling the appliances on the basis of time. The device is interfaced with an Arduino through a relay which is configured to the web service. An alerter platform is used to link the time and the web service. The desired time to automatically switch off the device is configured and the web service is triggered at that particular time. The web service, in turn, actuates the device.

Fig.11 shows the applet ran in IFTTT platform every day at the preconfigured time in order to control the device on a timely basis.

Temperature based controlling of the device make use of the climatic condition and avoids unnecessary usage of electricity.

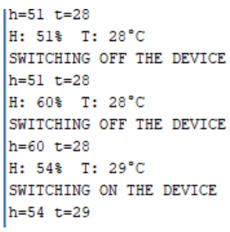


Fig.12.Serial monitor output for temperature based controlling device

Fig.12 shows the screenshot of the device automatically switching on when temperature crosses 28°C .

5.2. Software Simulation

Simulation is used to test whether the implementation is working as expected under normal conditions. Thus the correctness of the proposed methodology can be cross-validated with the help of simulation. The node-red simulation platform is used because of its flow-based programming nature. It wires together APIs, hardware devices and online services to develop an end-to-end application.

Fig. 13 shows the schema of the flow implemented in the node-red platform. Arduino input is replaced with an input node that injects data at regular time intervals. Power consumption calculation is done by means of functional nodes where the functionalities are written in JavaScript programming language. The calculated power consumption and bill amount are then pushed to the cloud and are visualized in the dashboard for user interfacing.

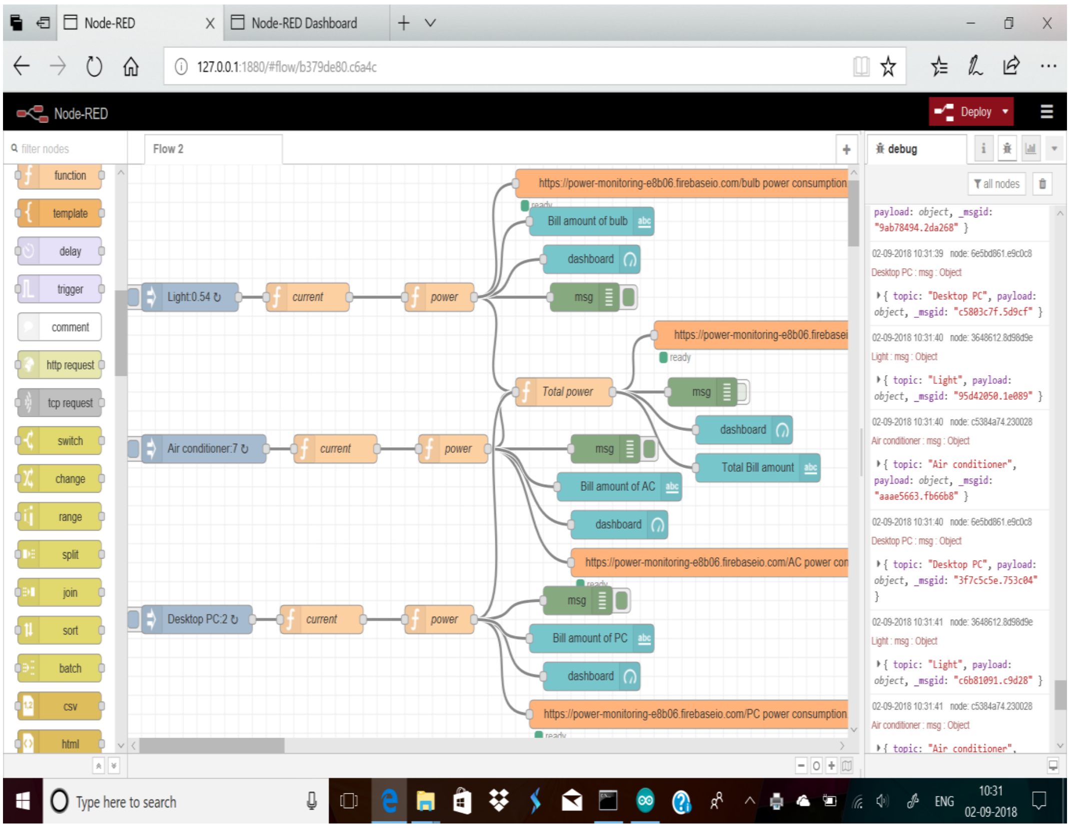


Fig. 13. Schema of simulation in node-red

Fig. 14 shows the power consumption details and the bill amount that each device contributes as well as the total power consumption and total bill amount.

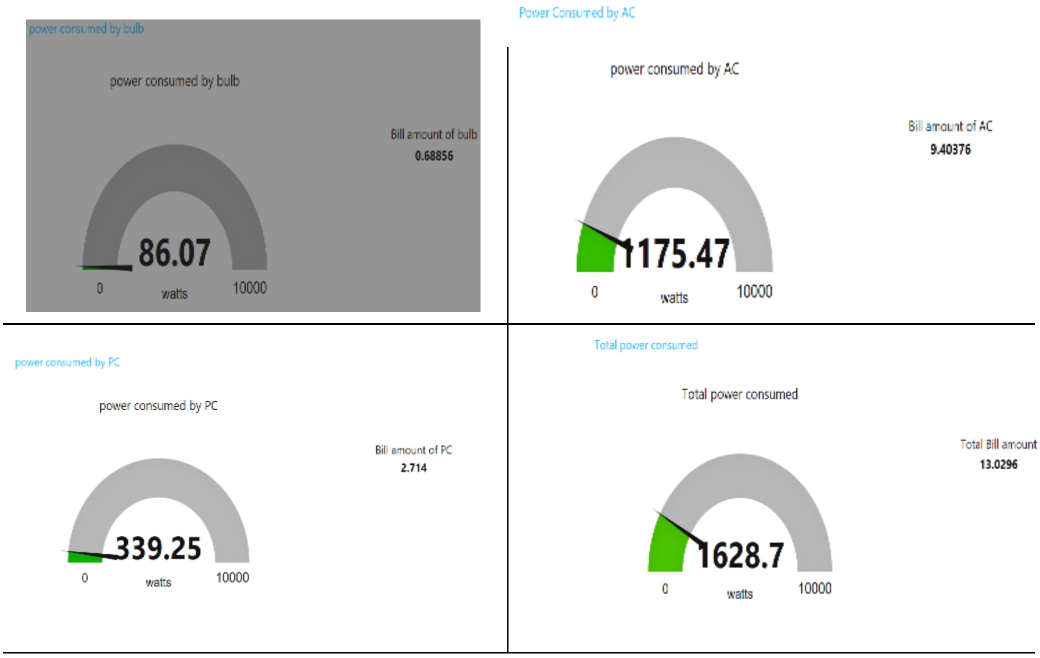


Fig. 14.Dashboard visualization

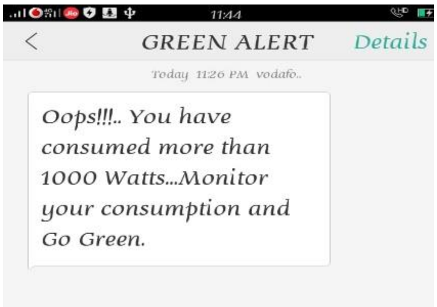


Fig. 15.Alert through SMS

Fig. 15 shows the SMS alert when the electricity bill exceeds a certain amount in order to notify the user about the electricity consumption.

Fig.16 shows the screenshots of the developed mobile Application for the Energy Management System. It contains individual activity for an Air conditioner, light bulb and total power consumption. Chart displaying power consumption and corresponding bill amount is designed using Highcharts which is a charting library written in pure JavaScript. The recent value of power consumption, bill amount and time stamp is queried from firebase platform and displayed in the text box for visualization purpose.

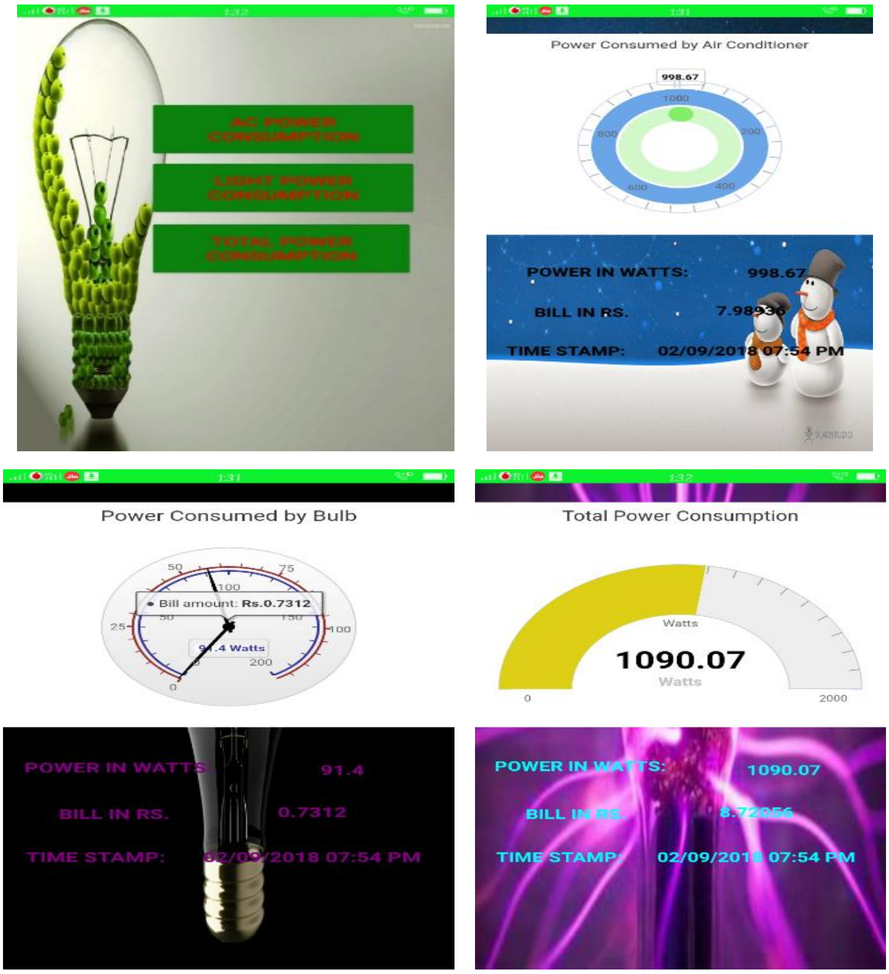
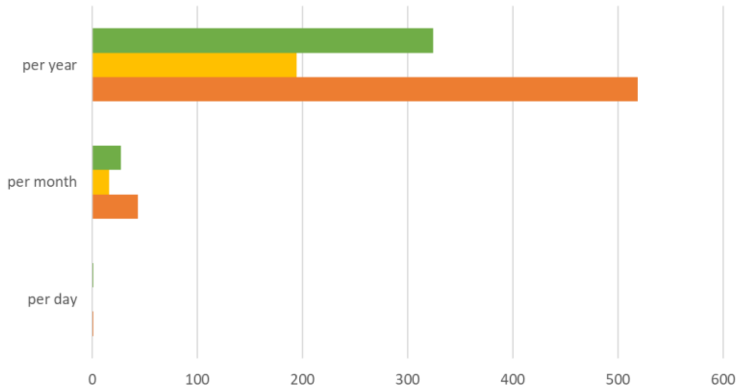


Fig.16.Mobile Application Screenshots

Power consumption can be reduced drastically by means of avoiding the unnecessary use of electricity. Time-based controlling of devices is chosen as a showcase to substantiate this claim. The computation is done to calculate power consumption, electricity bill and co_2 emission on per day, per month and per year basis. This can be visualized by means of plotting the charts. Fig 17 shows the power consumption analysis when time-based controlling mechanism is employed. This graph compares the amount of energy saved when controlling of appliances is entertained and the ideal case when the device is not turned off.

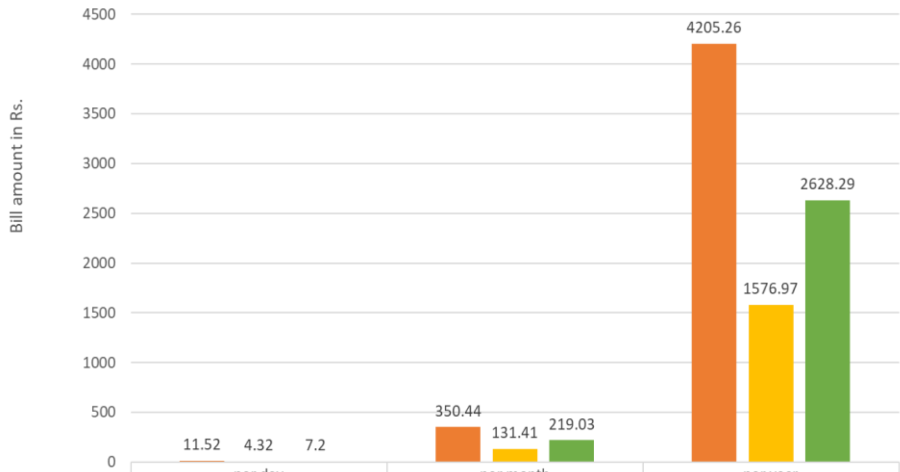


	per day	per month	per year
Power Saved in KWh	0.9	27	324
Power Consumed with Energy Saving in KWh	0.54	16.2	194.4
Power Consumed without Energy Saving in KWh	1.44	43.2	518.4

power consumed in kwh

Fig.17. Power consumption due to time-based controlling of devices

In the same way electricity bill analysis is shown in Fig.18 for per day, per month and per year.



	per day	per month	per year
Bill amount without Energy Saving in Rs.	11.52	350.44	4205.26
Bill amount with Energy Saving in Rs.	4.32	131.41	1576.97
Money Saved in Rs.	7.2	219.03	2628.29

Fig.18.Electricity bill reduction due to time-based controlling of devices

According to Carbon Neutral Charitable Fund, per kWh of electricity generates 0.94 kg (or 2.07 lbs) of CO_2 emissions to the atmosphere. This has been taken into account for computing CO_2

emission reduction when controlling of device is exercised. Fig.19 shows the carbon-dioxide emission due to burning of coal for producing electricity.

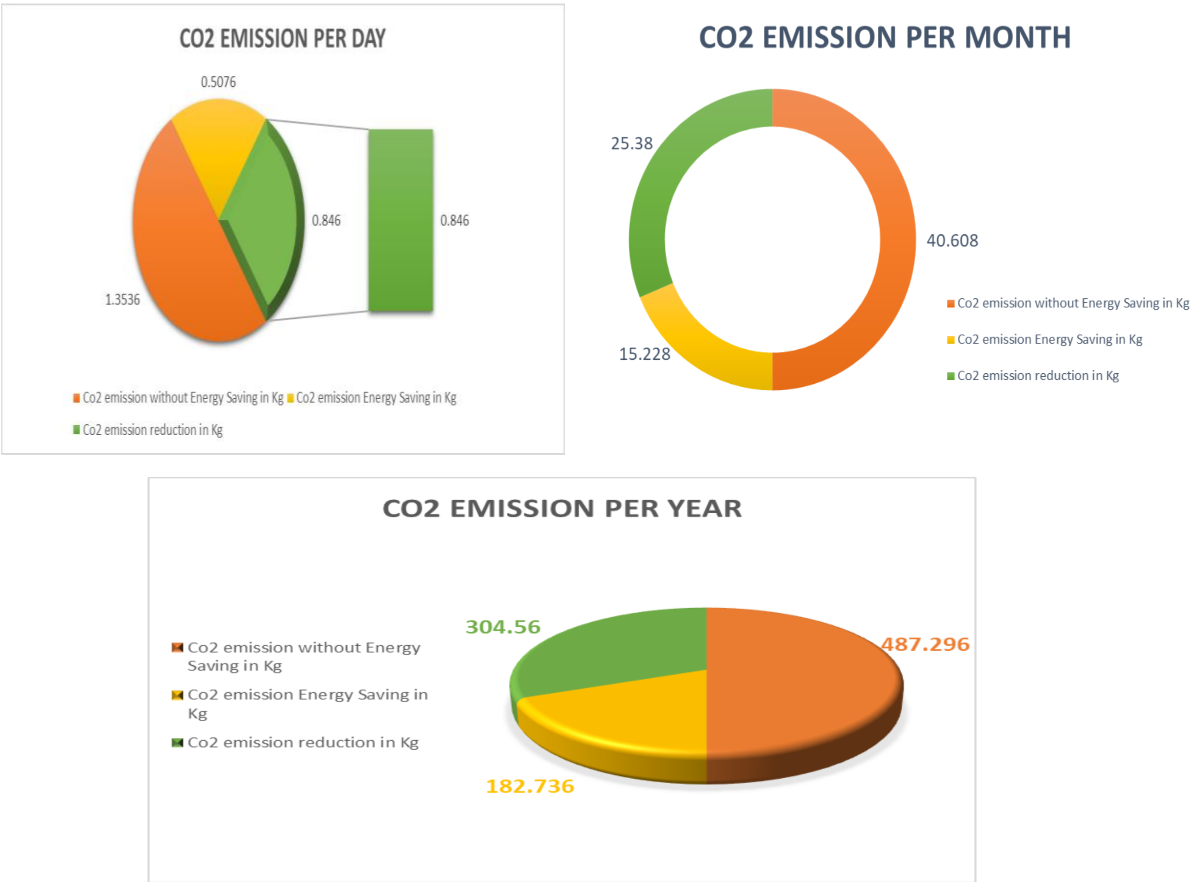


Fig.19. CO_2 emission analysis

6. CONCLUSIONS

This paper proposed the architecture for IoT-enabled green campus. The techniques for controlling the devices based on the motion, the temperature, the time and the voice are also implemented to monitor and save energy. The study is also made for implementing these techniques in real-time environment. It requires: Modification in the existing electrical wiring in the building, Uninterrupted Internet Connectivity and it is somehow costly but not as much expensive as other ready-made IoT products available in the market. Finally, time based controlling of appliances has been taken as a showcase. It is witnessed that controlling mechanism leads to carbon-dioxide emission reduction which in turn mitigate green house effect. Thus taking a step toward green.

Thus, it is concluded that IoT plays a major role in energy management and contribute much for green initiatives. My future work is to explore various energy efficient techniques to reduce energy consumption in the campus environment thereby making it green by utilizing IoT.

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