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Design, Development And Deployment Of Multi-Sensor Node Based Wireless Sensor Network For Campus Monitoring

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Abstract

This paper presents the design and deployment of wireless sensor network for campus monitoring. With the help of Passive Infrared (PIR) sensor, temperature sensor, humidity sensor and thermisters ,an effective utilization of energy resources has been implemented in rooms of Sharda University, Greater Noida, India. The security of campus against intruders moving in laboratories, class rooms, staffrooms or washrooms etc. after working hours and fire alarm are also provided by this system. The low power microcontroller is used for analysis of output of sensors and providing proper control using ZigBee protocol to achieve low power and low cost. Approximately 45% power has been saved due to implementation of this wireless sensor module in classrooms and faculty cabins. The cost is approximately $60 per node and each node can control a maximum eight sensors.

Index Terms— Campus Monitoring, Wireless Sensor Network, ZigBee Protocol, Occupancy Detection, Intelligent Control of appliances

I. INTRODUCTION

Campus monitoring is one of the applications of Wireless Sensor Network (WSN). Monitoring of temperature and humidity, security and short circuits, correlation based control and energy control are the main challenges in deployment of WSN for campus monitoring. The general objective of such systems is to fulfil the occupants' requirement for comfort while reducing energy consumption during building operations. According to the survey of energy efficiency in buildings in April 2009, energy-unaware behaviour consumes twice of the energy required [1]. Various researchers have focused on developing WSN for monitoring occupancy and environmental condition to provide intelligent control on appliances.

The area of building energy and comfort management has been receiving considerable attention and several models have been developed to monitor and control energy in buildings. Recent efforts have been to optimize the detection techniques, so as to improve the accuracy of estimating the occupancy. Tuan Anh Nguyen [2] has given a meaningful survey on energy intelligent buildings based on user activity. He has proposed future perspective on user activity that in contrast to other smart home applications, such as medical monitoring and security system, the domain of energy conservation can tolerate a small loss in accuracy in favour of cost and ease of use. Therefore, an energy intelligent building might not require cameras or wearable tags that may be considered intrusive to the user. Instead, WSN are today considered the most promising and flexible technologies for creating low-cost and easy-to-deploy sensor networks in scenarios like those considered by energy intelligent buildings. Rong-Shue Hsiao [3] has proposed a robust WSN for building lighting framework. PIR and microphone are used for occupancy detection. But it is only lighting control. Yuvraj et. al have proposed a WSN for detecting the occupancy to control heating, ventilation and air-conditioning(HVAC) [4]. This system fails if the door of cabin was closed and main occupant is sitting still on chair or door remains open while room is unoccupied because occupancy detected by reed switch depends on closing or opening of the door. Approximately 19% power savings has been estimated by this approach. Further, they have shown only occupancy detection without considering the role of environmental conditions. Padmanabh et al. have described the use of microphone and PIR sensors to drive efficient scheduling of conference rooms [5]. Various researchers are focusing on making buildings more energy efficient by including specific areas such as HVAC [6][7], managing IT energy consumption [8][9] and lighting [10] within buildings. HVAC loads include mechanical equipments for combined heating, ventilation and air conditioning which consumes significant amount of energy. This consumption becomes more significant if buildings are not designed using energy efficiency factors such as dynamic windows shadings, centralized ventilation and cooling/heating thermal requirements.

Several models have been developed to monitor and control electrical energy in buildings using occupancy detection as a driving factor. Recent efforts have been to optimize the occupancy detection techniques, so as to improve the accuracy of estimating the occupancy. Elder Naghiyen et. al have reviewed occupancy measurement techniques [11]. In this review PIR sensor, Carbon Dioxide sensor and Device-free Localization have been compared and have shown that PIR based occupancy detection is cheap, low in energy consumption, easy to deploy and operates in real-time. Delaney et al. have used PIR based wireless occupancy sensors to measure wasted energy in lighting even when there are no occupants [12]. These efforts however neither use occupancy information to drive actual systems nor evaluate accuracy of their detection sensor. Other methods for detecting occupancy include sonar based methods [13] or camera based systems [14] suffers from cost, deployment and privacy issues. Carbon dioxide- based occupancy detection has also been proposed but the main limitation is delay in the response of system to detect event of incoming people [15]. Barbato et. al have focused on algorithms supporting user profiles based on PIR sensed data [16]. This effort is in context of home only and is not suitable for large campus.

This work, therefore, focused on the design and development wireless sensor network in laboratories, class rooms and staffrooms of Sharda University for monitoring occupancy as well as temperature, humidity and security to provide intelligent control on appliances. The purpose of this system was to fulfil the occupant's requirement for comfort as well as reduction in energy consumption during building operations. An estimation of reduction in energy consumption was made using occupancy detail, weather conditions, number of occupants per floor area, construction of sensed/controlled area such as number of windows, materials used for walls, floors and roofs.

A. Proposed Design

This paper focuses on the design and deployment of a sensor-actuator node to monitor occupancy of rooms in a wide campus. The node can monitor temperature, humidity and fire as well. The goal of the proposed design is to minimize the power requirement and cost of the monitoring circuit and to provide an accurate estimate of occupancy to control appliances of rooms of a campus.This node is used to develop of a reliable and low cost WSN for monitoring of occupancy in buildings of a campus. temperature, humidity and motion and controlling the switching ON and OFF of electrical appliances such as lights, air conditioners, fans, and exhaust etc. The designed circuit has been tested in rooms of Sharda University campus.

Key Design Features

- PIC microcontroller based nodes have been developed to detect occupancy, temperature, humidity and fire. Occupancy is detected by combination of PIR motion sensor and IR sensor. This combination is of lesser cost than ultrasonic and more accurate than pyro sensors [9] as well as simpler algorithms are used than previous work [4].

- Monitoring of parameters of campus and controlling electrical appliances to save electrical energy and manpower.
- This approach also controls theft in rooms of university after working hour.
- This approach provides alarm against fire or short circuit since accidents due to short circuit may cause severe loss in a university campus.
- Zigbee protocol provides reliable and low cost communication between nodes and base station.
- The node covers more area of monitoring than other proposed works [4], [17].The nodes are actuators also.
- The cost of developed node is approximately $60 which is less than commercially available nodes [18].

B. Organization of paper

The organization of this paper is as follows; the design concepts and functioning details of the experiment setup are provided in section II. Section III contains hardware details enforced with circuit description and prototype design. Section IV explains the working algorithm of network. Section V explains software development .The experimental results of the developed WSN along with its performance characteristics are provided in section VI. Finally section VII gives conclusions and outlines the future work.

II. EXPERIMENTAL SETUP

The block diagram of the proposed Wireless Sensor Network for Campus (Sense-Campus) is shown in fig.1.

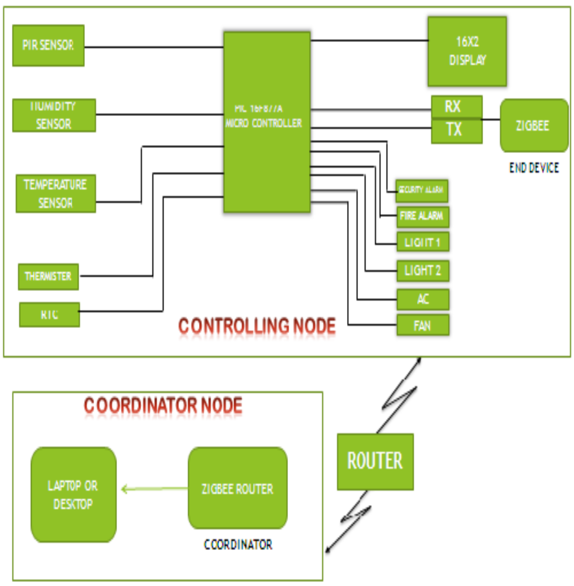

Fig 1: Block Diagram of Sense-Campus

Sense-Campus provided real time data collection and analysis for temperature, humidity and motion and controlling of electrical appliance e.g. lights, air conditioner, fans, exhaust etc. of the campus. The system alerted the security by giving alarm if motion is detected in faculty rooms, classrooms, laboratories and offices of administrative people beyond working hours. The circuit provided facilities to define variable working hours for different places and for different days. It could also provide fire alarm to protect buildings of a large campus from short circuits or from any fire accidents.

III. HARDWARE DEVELOPMENT

The hardware of the Sense-Campus consisted of mainly two parts:

A) Sensor-Actuator Node

B) Base Station

A. Sensor-Actuator Node

The node consisted of power supply unit, sensors, microcontroller and Zigbee module. Relays were connected with microcontroller to control appliances according to the conditions. The schematic of the node is detailed in fig.2. Subparts of schematic are detailed in figures 3 to 9. System was basically driven with precise power supply of 5V and 12V.

Four sensors were used to sense the parameters for complete solution of campus monitoring. Temperature sensor LM35DZ, humidity sensor HR202, PIR sensor and thermisters were connected to analog to digital converter (ADC) pins of microcontroller. PIR sensor is a pyroelectric device that detects motion by measuring changes in infrared level emitted by surrounding objects. It has a range of approximately 20 feet. The sensor toggles its output when a sudden change occurs, such as when there is motion.HR202 is a humidity-sensitive resistor that detects the humidity level of environment. It is made up of organic macromolecule materials. This sensor can be operated over humidity (20-95%RH) temperature (0-60°C).

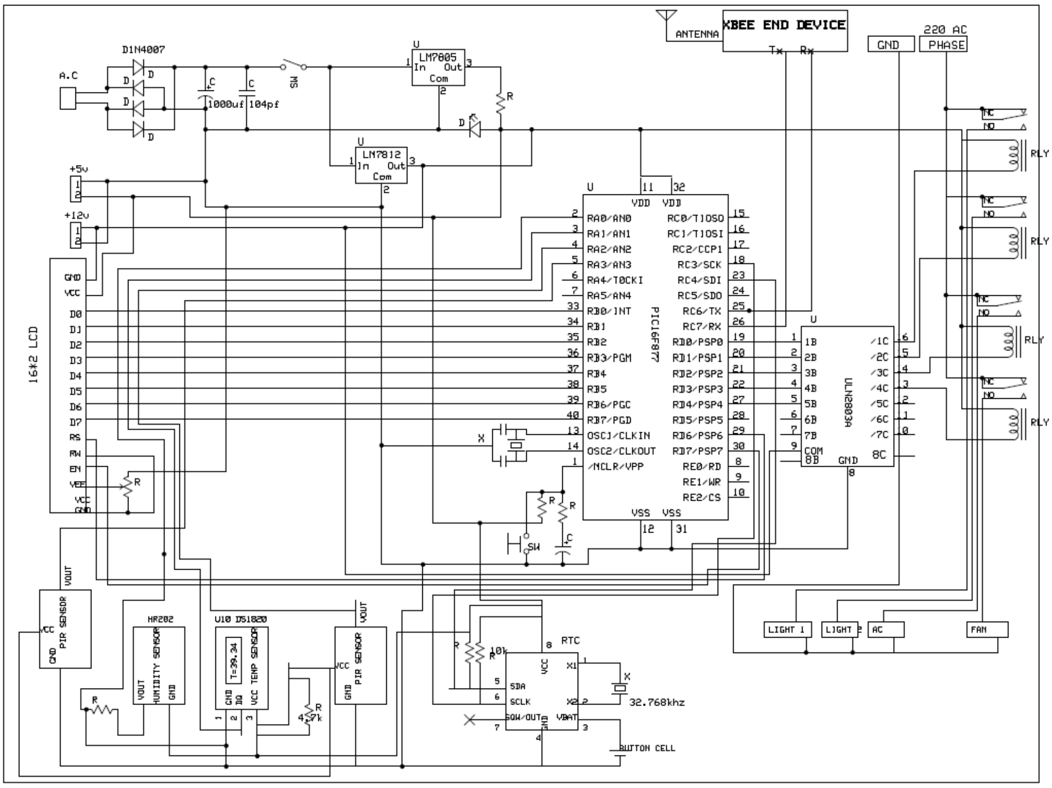

Fig.2. Schematic for nodes of Sense-Campus

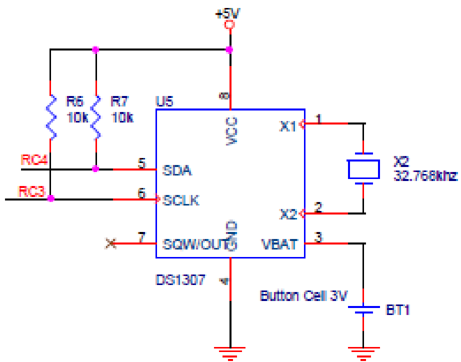

Fig.3. Circuit connections of RTC

To define working hours and working days, RTC (DS1397) was connected in each node through microcontroller in each node as shown in fig.3. PIC16F877A microcontroller was used to analyse the data received by sensors and controls appliances according to the conditions. Fig.4 shows the connection diagram of PIC microcontroller.

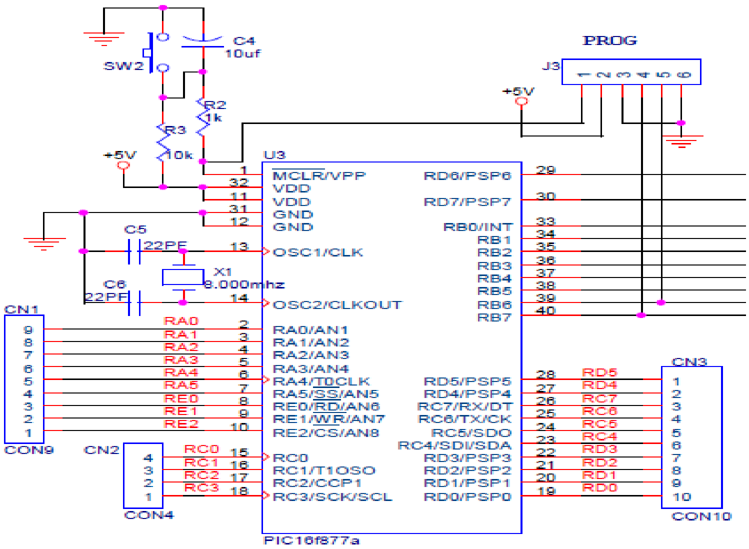

Fig.4. Connections of PIC microcontroller

The values of temperature, humidity and output of motion sensor were transmitted to base station. Fig.5 shows connectivity of Zigbee module to the microcontroller. The module size is small enough to be compatible with any radio frequency transmitter application. It allows reliable communication between sensor node and base station. It operates at 3.3V at 40 mA and has 250kbps maximum data rate. It is operable at 2.4GHz .

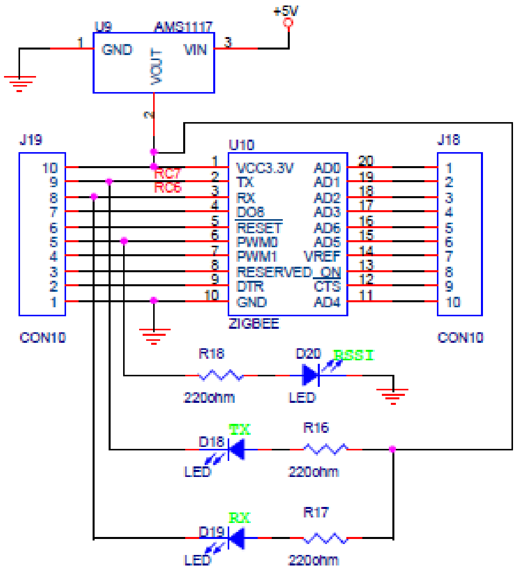

Fig.5. Connections of Zigbee Module

B. Base Station

Base Station was a computer connected with Zigbee module. Universal Serial Bus to serial port connector was used to interface Laptop and Zigbee module .At base station, Zigbee module was configured as co-ordinator.

IV. WORKING OF HARDWARE

PIR sensors sensed the movement inside its remote area. In our system, the remote areas were classrooms, laboratories, server rooms, workshops, cabins of faculty members and administrative rooms. Number of deployed PIRs varied on the size of remote areas. As soon as motion was detected, corresponding lights were ON. If motion was detected within defined working hour for that area, then outputs of temperature sensor, humidity sensor and thermisters were taken into consideration.

Room heaters, air conditioner, fans, exhaust fans were controlled according to the output of temperature and humidity sensors. Fig.6 shows the connections of appliances to be controlled. Threshold of temperature depended upon the seasons and weathers. For example, if temperature was more than 20^0C, fans were ON, if it was more than 27^0C, air conditioners were ON and if it was less than 7^0C, room heaters were ON. Similarly exhaust fans were controlled by humidity sensors. Thermisters were used for fire sensing. As soon as flame was detected, an alarm alerted the people of the remote areas. In laboratories, classrooms, workshops and faculty cabins, working hours were from 8:30A.M. to 4:00 P.M. except weekends and holidays. In rooms of administrative people, working hours had to define daily according to their schedule. If any motion is detected beyond the limit of working hour, a buzzer alerted security.

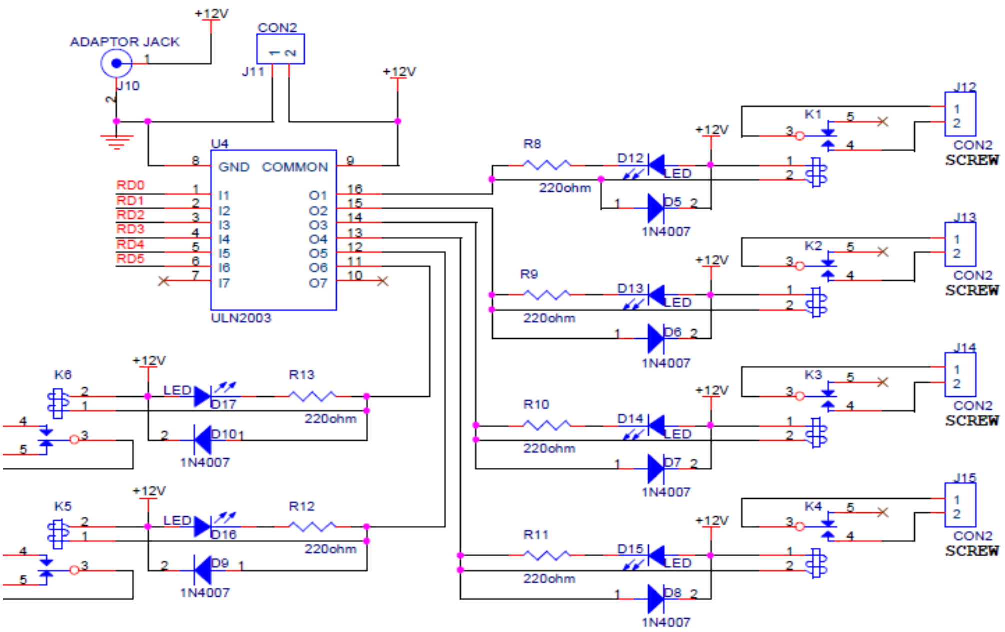

Fig.6. Appliances Control Circuit

PIR sensor cannot sense presence of the person if he is still for a long time. It mainly creates problem (false negative) when person is seating on chair and studying or working on laptop. For that purpose, IR sensors were also installed nearby seating position of the person. The position of IR and PIR are shown in fig.7.

Fig.7. Deployment of PIR and IR in a Cabin

If motion was not detected by PIR, microcontroller checked the output of IR sensor. If presence was detected by IR sensor, occupancy was considered. The delay of PIR had been set for two minutes. After each two minute, microcontroller checked occupancy by PIR and output of IR sensor if required. The distance between IR sensor and seating place like chair or benches was fixed. One example has been shown in fig.8. If no occupancy, node switched off all appliances. Algorithm has been shown in fig.9.

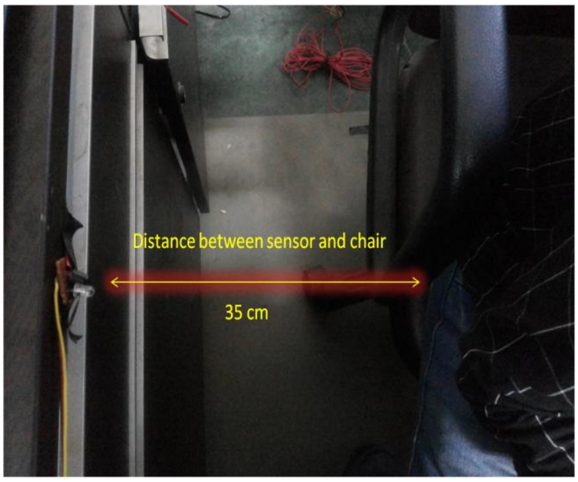

Fig.8. Distance between IR sensor and seating place

A. Deployment of nodes:

Deployment of nodes is very important to save energy and cost of the system for optimum utilization of circuit. One sensor node could control six to four staff cabins of 8x6 square feet. Each cabin had two tube lights, one fan and one room heater. Since cabins were open on top, two split Air Conditioners of cooling efficiency of 1.5 ton could cool six cabins. Since the microcontroller had eight ADC input pins, eight sensors were interfaced per node. Since temperature was almost same throughout the campus, there was no need to interface temperature sensor in each node. The nodes had been deployed on one floor of Department of Electronics and Communication. Two laboratories, six classrooms and thirty faculty cabins are on this floor. The sizes of laboratories are 18x16 square feet. Ten tube lights, 12 fans and two air conditioners are connected in each laboratory. 25 faculty cabins of 8x6 square feet, 5 cabins 10x12 square feet are on this floor. Numbers of appliances are same for each cabin. One room is of Head of Department (HoD) having one window air conditioner, one room heater and eight tube lights. The size of class room is 18x16 square feet of seating capacity of 60 students. Appliances are 12 tubes, 12 fans, two air conditioners and one room heater in each classroom. Fig.10 shows the deployment of nodes. Nodes have been configured in star topology. All sensor actuator nodes are connected to main supply to switch ON/OFF appliances according to terms and conditions explained in algorithm but few addition commands are given to base station to control appliances if required. Appliances could be controlled through base station (laptop) by pressing some input from keyboard of the base station such as Air Conditioner "ON", Air Conditioner "OFF", FAN "ON", FAN "OFF",ALL RELAYS "ON" and ALL RELAYS "OFF".Application of these commands are required if nodes were not working properly or unwanted occupancy had been detected in classrooms or laboratories.

STEP 1: Sense data from both PIR and IR sensors.

STEP 2: If motion is sensed go to STEP 3.
Else go to STEP 1.

STEP 3: Corresponding lights ON

STEP 4: If time is beyond limit go to STEP 5.
Else go to

a) Step i : Sense data from humidity sensor.

   Step ii: If more than threshold go to Step iii.
   Else go to Step i

   Step iii : Corresponding Exhaust ON

b) Step i : Sense data from Temperature sensor.

   Step ii: If beyond threshold go to Step iii.
   Else go to Step i

   Step iii : Corresponding Fan/A.C./Room Heater ON

STEP 5: Alarm ON.

Fig.9. Algorithm of programming of Sense-Campus

Sub meters were connected to measure the power consumption of each remote area. All data could be viewed and appliances could be controlled through base station also.

VI. EXPERIMENTAL RESULTS

The result analysis of Sense-Campus consists of two sections:

1. Development of low cost sensor node
2. Deployment of node to get proper result.

Schematic of circuit of sensor node has been developed to check occupancy of maximum area and temperature, humidity and fire conditions. Getting low power and low cost is the main objective .Snapshot of the circuit has been shown in fig.11.

The node could operate with eight sensors at a time. In faculty room of Sharda University, this node could monitor four cabins. The cost one node was $60.Power consumption of node was 1.8W using sleep mode configuration with internal wake-up using watchdog timer. The effective cost and power per cabin were $15 and 450 mW. The power consumption of circuit had been calculated using OrCAD and verified using multimeter.

Second type of results is data collected in different remote areas of applications after deployment of node.

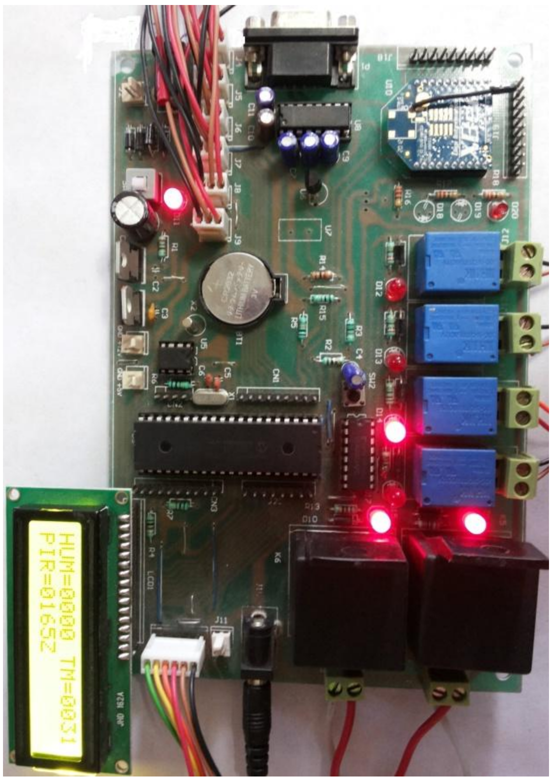

Fig.11. Snapshot of Sensor-Campus developed for Monitoring parameters

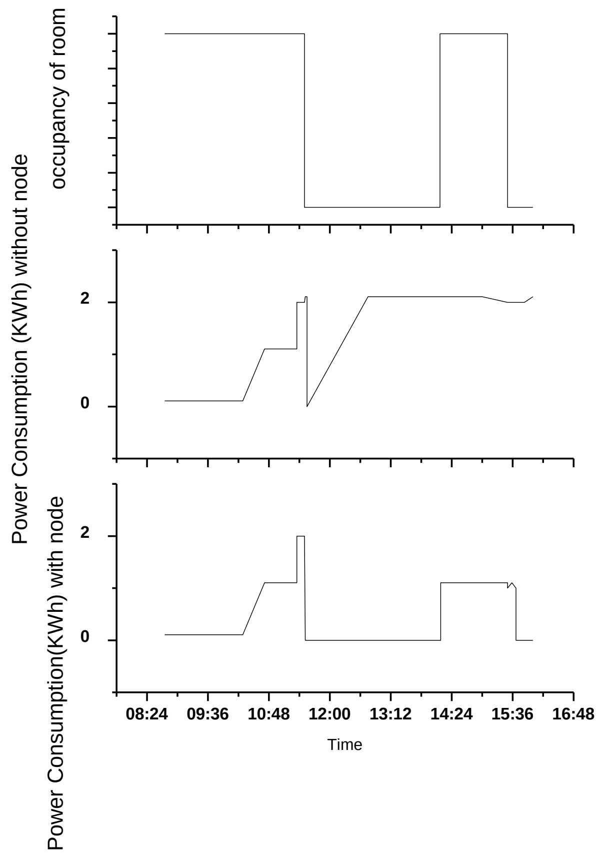

Fig.12 .Graph of power consumption in one cabin of faculty in one working day

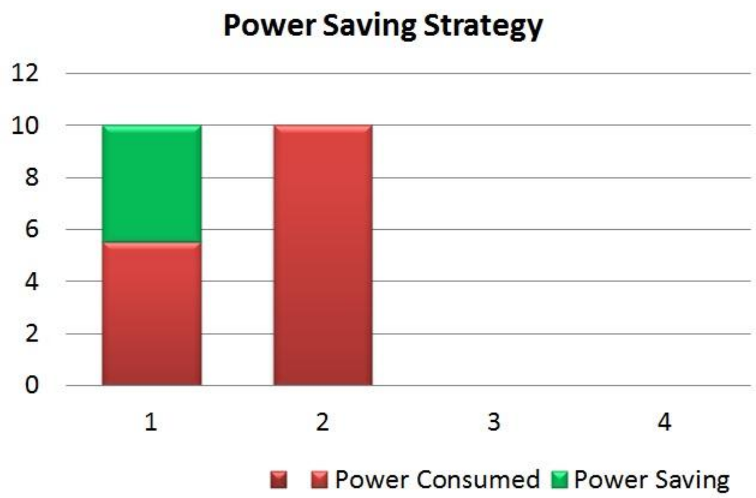

Fig.12 (c). Graph of power consumption in one working day

Our first observation was taken in cabins of faculties in month of June-July. Power consumption in one working day with application of the node is detailed in fig.12 .One working day means eight to nine hours. In one cabin light consumes .030 KWH, fan consumes .075KWH and air conditioner consumes 2KWH. Total consumed power is 2.105KWH per hour.

Without application of this circuit, the total consumed power for nine hours was 18.945KWH. After application of Sense-Campus, the total consumed power for nine hours was 10.525KWH. Electricity was saved for approximately 8.42KWH.

By this approach around 40% electric power can be saved without applying manpower per cabin as discussed in fig. 12 (b). The node has been deployed any place (laboratories, classrooms, staffrooms, workshops or office of Head of the Department). The deployment of nodes is shown in fig.13.

Fig.13. Deployment of nodes in Faculty cabins and laboratory

The observations have been taken for 60 days, first 30 days without Sense-Campus and next 30 days with Sense-Campus in the same area in three seasons: winter, summer and spring. Observations are shown in terms of cumulative values of power consumption for 30 days without node and power consumption for same period with node. After two months in each season, we could get data to conclude power savings

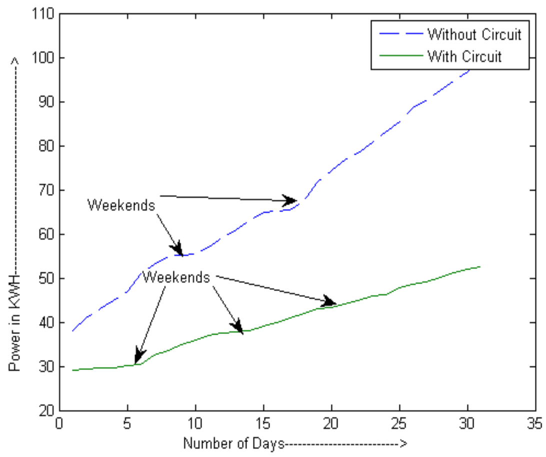

Fig.14. Graph of cumulative data of power consumed in May-June

In India, May and June are the hottest months. Most of the power consumption is due to air conditioners.Fig.14 is the graph based on data collected in during May and June in one of the laboratories. Maximum 30 students could attend the lab at a time. Two window air conditioners of 1.5 ton, 12 tube lights and 10 fans were working from 8:45A.M. to 4:10 P.M. Fig.15 is the graph of observed data in the same room for winter season. January and February are months of winter in India.

Fig.15. Graph of cumulative data of power consumed in Jan-Feb

Three room heaters of 2KWH and 12 tube lights were working in the laboratory for the same working hours.

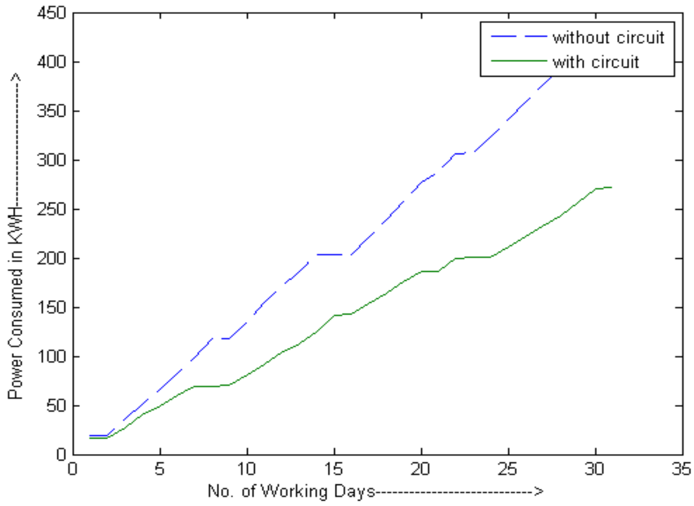

Fig.16. Graph of cumulative data of power consumed in March-April

Similarly data of power consumption was collected in the month of March-April. These months are spring season in India. Neither air conditioners nor room heaters are required for these months. Only 12 tube lights and 10 fans are working. Fig.16 shows the graph power consumption with and without nodes for spring.

From three graphs we could conclude that in summer about 20% power saving was calculated while in winter 30% power saving has been calculated. Similarly in spring about 10% power saving has been observed. Overall 20% power saving is observed within three seasons.

VII. CONCLUSION

The use of multi-sensor nodes in WSN has resulted in a low power low cost campus monitoring system. A reliable communication has been achieved between sensor nodes and base station using Zigbee protocol. False occupancy detection can be improved using combination of PIR and IR sensors. 20% power savings has been achieved by the system along with the savings of electrical energy and manpower. The system also provides security against theft after working hours and alarm against fire accidents.

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