INTELLIGENT ENERGY MANAGEMENT SYSTEM FOR RESIDENTIAL BUILDINGS BASED ON ZIGBEE TECHNOLOGY

SANGEETA MODI[1], RITU NAIYA[2] & SHAIK SHABANA[3]

[1,2,3]Electrical and Electronics Department, PES Institute of Technology, Bangalore, India
E-mail: smodi@pes.edu

Abstract - Energy consumption in residential buildings account for 20 to 40 per cent of total energy consumed in a country and therefore represents a significant and potential source of energy savings. An Intelligent Energy Management System can contribute to major reductions of energy use in hundreds of millions of buildings. This paper gives an overview of sensor technology and wireless networks in the development of an intelligent energy management system for residential buildings (IEMSRB). This technology has ample potential to change the way we live and work. In this paper ZigBee is used as a communication medium in building intelligent energy management system. From the prototype setup, it is shown that ZigBee is a suitable technology to be adopted as the communication infrastructure in energy management system for residential buildings .The performance analysis discussed in this paper verifies the effectiveness of using ZigBee in energy management system. The novelty of the present scheme is its ability to save the energy and improve the performance as it learns and gains more experience in real-time operations. Results also demonstrate that the proposed scheme can achieve the minimum electricity cost for residential customers. The proposed system can be installed and maintained in residential environments with ease.

Keywords - *Energy Management System; ZigBee; Sensor and Actuator Networks, Intelligent Energy Management System for Residential Buildings.*

I. INTRODUCTION

Energy was once a commodity which most enterprises did not have that much control of in the past. In this day and age, energy control is now a top priority. It is important for all of us to have the responsibility and make sure that we have a good energy system. The energy system includes energy of water, electricity, gas, air, and steam. The energy system cannot only affect our corporation or industry, but also affect the environment around our corporation or industry. An intelligent energy management system can contribute to major reductions of energy use in hundreds of millions of buildings. Energy savings and user happiness are two major design considerations for intelligent home system.Intelligent homes in a building must fulfill four basic requirements. First, they must facilitate a safe, convenient, and healthy lifestyle. Secondly, they must be environmentally sustainable. Thirdly, they must promote comfort. And finally, an intelligent home must provide an efficient workspace to its occupants. The most effective way to reduce energy is to turn devices off. The second most effective way is to turn them down. An automated control system can do both for consumer based on factors such as occupancy, available daylight and time of day. Removing the wires from the controls provides additional benefits, including greater flexibility in where controls can be placed, and significant savings in installation by avoiding the expense and disruption of wiring.This paper describes the development of an intelligent energy management system for residential buildings using the concept of a sensor technology and wireless network. In this paper ZigBee is used as a communication medium in energy management systems. By using this energy management system, it is possible to see and control the energy system of various devices. Wireless sensor technology is fast replacing wired technology in almost all the fields, because it is less costly and also because it is more efficient as compared to wired networks [1]. Sensors measure multiple physical properties and include electronic sensors, biosensors, and chemical sensors. These sensors can thus be regarded as “the interface between the physical world and the world of electrical devices, such as computers” [2].

In this paper ZigBee is used as a communication medium in energy management system which can be implemented in building, household, research laboratory and so on. The rest of the paper is organized as follows: Section II describes the sensor and actuator networks. In Section III, the ZigBee network is discussed. Section IV discusses the proposed intelligent system for the residential building. Section V describes the implementation details and performance analysis, followed by a conclusion in Section VI.

II. WIRELESS SENSOR AND ACTUATOR NETWORKS

The whole point of a wireless network is to send reliable data between nodes in the network. Wireless sensor and actuator networks (WSANs) are networks of nodes that sense and potentially also control their environment. They communicate the information through wireless links “enabling interaction between people or computers and the surrounding environment". The data gathered by the different nodes is sent to a sink which either uses the data locally, through for example actuators, or which "is connected to other networks (e.g. the Internet) through a gateway. Sensor nodes are the simplest devices in the network. A sensor node typically consists of five main parts: one or more sensors gather data from the environment. The central unit in the form of a microprocessor manages the tasks. A transceiver communicates with the environment and a memory is used to store temporary data or data generated during processing. Fig 1 shows architecture of a sensor node. To assure a sufficiently long network lifetime, energy efficiency in all parts of the network is crucial. Due to this need, data processing tasks are often spread over the network, *i.e.* nodes co-operate in transmitting data to the sinks. Fig 2 shows the most important fields of application. If compared the performance with wired Local Area Network (LAN), it is generally accepted that wired LAN network offers higher speed than wireless LAN network.

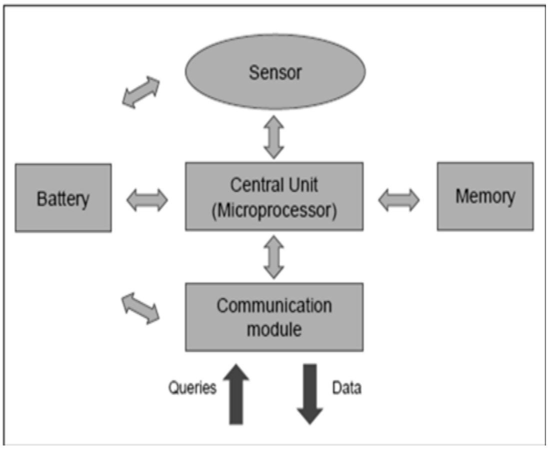

Fig 1 : Architecture of a sensor node

Fig 2 : Application of wireless sensor networks

The distinct in transmission speed is even more obvious when optical cable is being used in wired LAN network which transmission rate can easily reach up to 1Gbps or more. Although wireless communication system is less reliable, prone to interference and lower transmission rate at 54 Mbps, it is still being used by some power companies due to the advantages that offered only by wireless communication network [9,10]. LAN technologies connect different smart devices at customers' sites. These technologies can be classified into three main groups: wireless IEEE standards 802.x, wired Ethernet, as well as in-building power line communications Wireless IEEE standards include Wi-Fi (IEEE 802.11), WiMAX5 (IEEE 802.16), ZigBee (IEEE 802.15.4) and Bluetooth (IEEE 802.15.1). Based on [7], Table 1 shows a short description of strengths and weaknesses of these standards.

Table 1 : Comparison of IEEE Standards

IEEE Standard	Strengths	Weaknesses
ZigBee (IEEE 802.15.4)	• Low power requirements • Low implementation cost • Good scalability	• Limited range • Relatively low data rates • Possibly more secure than other standards
Wi-Fi (IEEE 802.11)	• Easy deployment and falling costs	• Only useful within the customer site • Additional security layers required
Bluetooth (IEEE 802.15.1)	• Permits higher data rates than ZigBee	• Limited maximum number of devices in a network • Security vulnerabilities

ZigBee is used to provide an efficient wireless communication standard for Home Area Networking

III. ZIGBEE NETWORKS

A. Introduction and Characteristics

Energy conservation, control, and safety are some of the prospects of ZigBee. Word ZigBee was originated from word Zigzag indicating cross-shaped network cables and Bee to indicate economical communication method. The name refers to the waggle dance of honey bees after their return to the beehive. The ZigBee network automatically figures out how to route the data from one node to another with the maximum chance of success. ZigBee networks have the following requirements and features: low power consumption, low cost, low packet throughput, lots of network nodes, low request on quality of service, security control, and high reliability [3]. ZigBee can be used in various applications such as HVAC controls, Lighting Controls, and Utility Networks. ZigBee consumes low electricity supply and can be configured to large scale sensor networks by integrating with sensor (Activity, light, temperature and humidity, etc) and transmitter/receiver devices. This type of structure is defined as foundation technology for sensing, monitoring and controlling. ZigBee has recognized as next generation short-distance wireless communication standard based on strong advantages including lowest costs, lowest energy consumption which can be last 2 years with 2 AA type batteries, scalability of up to 65,000 nodes, simple network configuration and reliability from immediate recovery function from data transmission errors. Especially, ZigBee supports multi-hop function to ensure highest transmission success rates.

B. ZigBee Topologies

ZigBee supports star, peer-to-peer i.e. mesh, and tree topologies [4]. In star topology, there are several nodes and a central coordinator [5]. Coordinator is the main part of star topology, as communication between nodes takes place through the coordinator. Nodes can communicate directly in peer-to-peer topology; Nodes can communicate directly in peer-to-peer topology, without the need of coordinator. In tree topology, network consists of a central coordinator node along with routers and other nodes [6].

IV. PROPOSED INTELLIGENT ENERGY MANAGEMENT SYSTEM FOR RESIDENTIAL BUILDINGS

Fig 3 shows the architecture of the proposed Intelligent Energy Management System for Residential Buildings (IEMSRB).Each home of the building has one living room, one bed room, one kitchen, one rest room and each section is equipped with necessary load as shown in Fig 3, one power outlet, and one ZigBee hub. The dimming light and the power outlet include a power measurement function to measure the power consumption. They report the information periodically to the ZigBee hub through ZigBee communication. Because home appliances are connected to the power outlet, their power usage can be acquired by the power measurement function of the power outlet. The ZigBee hub in the room gathers the power information reports of the light and the power outlet, and then it transfers the information to the home server. The home server analyzes the power information of all home appliances in each room. It displays the real-time active power consumption of each home appliance and the accumulated power consumption of each home appliance. A user can figure out which home appliance is unnecessarily turned on through the real-time active power consumption and how much power each home appliance consumes in this month through the accumulated power consumption. A user can also analyze the power usage of each room through the ZigBee hub. A user can access the home server and turn off unnecessarily turned on home appliances. The power outlet periodically monitors the power consumption of the connected home appliance. As soon as the monitored power consumption of the home appliance is below the threshold for the determined period, the power outlet automatically cuts off the AC power to reduce the standby power of a home appliance.

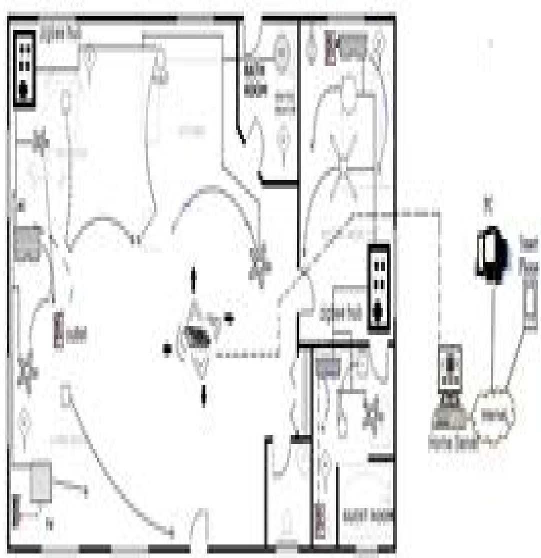

Fig 3 : Architecture of the proposed intelligent energy management

V. IMPLEMENTATION DETAILS AND PERFORMANCE ANALYSIS

To show the achievability of the proposed architecture an experimental based case study has been done on the system which is developed to demonstrate that smart, simple sensor devices can be used to manage, control and save energy in smart home in a smart building. We have developed a smart node that has sensing, processing and networking abilities. It is equipped with a microcontroller (8952) as shown in Fig 6 and a narrow-band radio frequency (RF) device that can support physical-layer functionalities of IEEE 802.15.4. Various optional sensor and actuator modules can be equipped with this smart node with the help of a connector and directly controlled by the microcontroller in our smart node. Temperature sensor is included in the smart node. An experimental based case study has been done on the system which is developed to demonstrate that smart, simple sensor devices can be used to monitor activities of daily living and life style of person living in smart home in a smart building. The system has been tested by connecting the soldering iron to the temperature sensor as shown in Fig 4 and Fig 5.

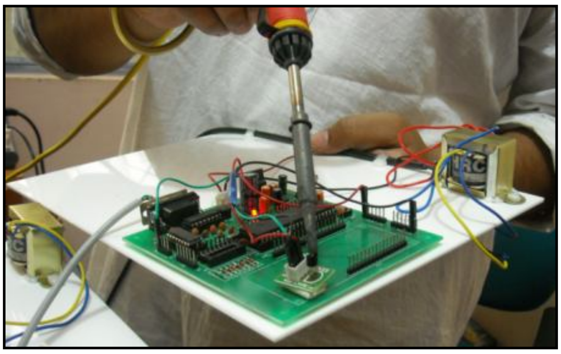

Fig 4 : System Testing with Soldering Iron

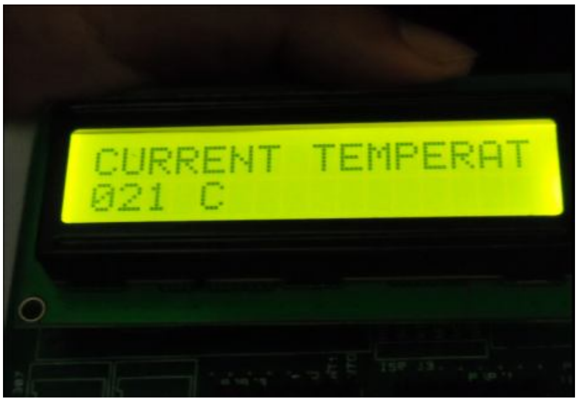

Fig. 5 : Temperature Measuring Unit

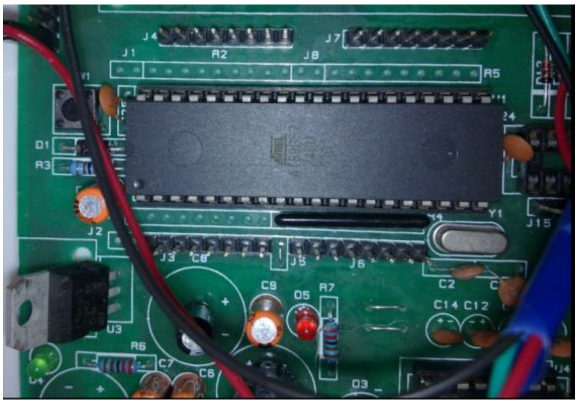

FIG 6 : MICROCONTROLLER WITH VOLTAGE REGULATOR

The following observations were made

Table 2 : Temperature Sensor Data

Sr. No.	Temperature monitored (°C)	Buzzer sounded
1.	16	No
2.	20	No
3.	23	No
4.	28	No
5.	31	No
6.	33	No
7.	40	Yes
8.	120	Yes
9.	35	No
10.	55	Yes

Each time the buzzer was sounded the power supply to the heating element was cut off thereby saving on energy. This has a wide application in areas where water or other fluids need to be heated or maintained at a constant temperature. In the second conduct of experiment to show the saving in energy consumption using ZigBee based temperature sensor, we have included an air conditioner (AC) and two tube lights in the system. ZigBee based temperature sensor network senses the ambient temperature of the room. The desired critical temperature required in the room is 27°C and the air conditioner should not exceed desired level, however lower temperatures can be allowed. Wattage of a 1 ton air conditioner (AC) is 3500 watts. Table 3 to Table 10 show the data collected during various seasons and Electricity bill on monthly basis for the said duration

On a winter morning if the average ambient temperature in the morning (6:00 am to 6:00 pm) is 25°C and the average ambient temperature at the night is (6:00 pm to 6:00 am) is 22°C then there is no necessity of the usage of air conditioner both in the day and night, then the sensor network sounds an alarm.

Table 3 : Winter Data

Time Duration	No of Air Conditioners working	No of lights on	kW Consumption of loads in an hour	kWh consumption for the duration specified
6:00 am – 6:00 pm	0	2	0.08	0.96
6:00 pm – 6:00 am	0	2	0.08	0.96
Daily energy consumption				1.92

Monthly energy consumption = 1.92*30 = 57.6 kWh

Table4 : Electricity Bill during winter

Description	Units Consumed	Rate (Rs / unit)	Total Charges (Rs)
Tariff Charges	57.6	2.90	167.04
Electricity Duty	57.6	0.09	5.184
Total Monthly Bill			172.224

On an autumn morning, if the average ambient temperature in the morning (6:00 am to 6:00 pm) is 29°C and the average ambient temperature at the night is (6:00 pm to 6:00 am) is 27°C then there is no necessity of the usage of air conditioner in the night, however AC is required in the morning duration, then the sensor network sounds an alarm

Table 5 : Autumn Data

Time Duration	No of Air Conditioners working	No of lights on	kW Consumption of loads in an hour	kWh consumption for the duration specified
6:00 am – 6:00 pm	1	2	3.58	42.96
6:00 pm – 6:00 am	0	2	0.08	0.96
Daily energy consumption				43.92

Monthly energy consumption = 43.92*30 =1317.6 kWh

Table 6 : Electricity bill during autumn

Description	Units Consumed	Rate (Rs / unit)	Total Charges (Rs)
Tariff Charges	1317.6	2.90	3821.04
Electricity Duty	1317.6	0.09	118.584
Total Monthly Bill			3939.624

On a summer morning, if the average ambient temperature in the morning (6:00 am to 6:00 pm) is 32°C and the average ambient temperature at the night is (6:00 pm to 6:00 am) is 28°C then if only AC is sufficient to maintain the desired level at both day and night time then the energy consumption is as follows:

Table 7 : Summer Data

Time Duration	No of Air Conditioners working	No of lights on	kW Consumption of loads in an hour	kWh consumption for the duration specified
6:00 am – 6:00 pm	1	2	3.58	42.96
6:00 pm – 6:00 am	1	2	3.58	42.96
Daily energy consumption				85.92

Monthly energy consumption = 85 .92*30=2577.6 kWh

Table 8 : Electricity Bill during summer

Description	Units Consumed	Rate (Rs / unit)	Total Charges (Rs)
Tariff Charges	2577.6	2.90	7475.04
Electricity Duty	2577.6	0.09	231.98
Total Monthly Bill			7707.024

In the absence of ZigBee based temperature control: If the average ambient temperature in the morning (6:00 am to 6:00 pm) is 32°C and the average ambient temperature at the night is (6:00 pm to 6:00 am) is 28°C and the ZigBee based sensor network will not control the temperature and both the ac's and light loads will be in operation. However it is not necessary that the temperature is always more than the desired level. This case is taken to explain the total kWh consumption when there is no control of temperature.

Table 9 : Data in the absence of ZigBee based sensor

Time Duration	No of Air Conditioners working	No of lights on	kW Consumption of loads in an hour	kWh consumption for the duration specified
6:00 am – 6:00 pm	2	2	7.08	84.96
6:00 pm – 6:00 am	2	2	7.08	84.96
Daily energy consumption				169.92

Monthly energy consumption=169.92*30 = 5097.6 kWh

Table 10 : Electricity bill in the absence of ZigBee based sensor

Description	Units Consumed	Rate (Rs / unit)	Total Charges (Rs)
Tariff Charges	5097.6	2.90	14783.04
Electricity	5097.6	0.09	458.784

Duty			
Total Monthly Bill			15241.824

Fig 7 gives graphical representation of the energy consumption in a room with and without the ZigBee based sensor in all the 3 seasons in a year. If February, March, April and May are assumed to be summer seasons June, July, August, September are autumn and October, November, December, and January are assumed to be winter seasons in tropical regions then the graphical description to explain energy saving is shown below. Graphical data that is plotted is tabulated below in Table 11.

Table 11 : Load Data on Monthly Basis

Months	Seasons	Monthly kWh consumption using ZigBee based temperature sensor	Monthly kWh consumption in absence of ZigBee based temperature sensor
January	Winter	57.6	5097.6
February	Summer	2577.6	5097.6
March	Summer	2577.6	5097.6
April	Summer	2577.6	5097.6
May	Summer	2577.6	5097.6
June	Autumn	1317.6	5097.6
July	Autumn	1317.6	5097.6
August	Autumn	1317.6	5097.6
September	Autumn	57.6	5097.6
October	Winter	57.6	5097.6
November	Winter	57.6	5097.6
December	Winter	57.6	5097.6

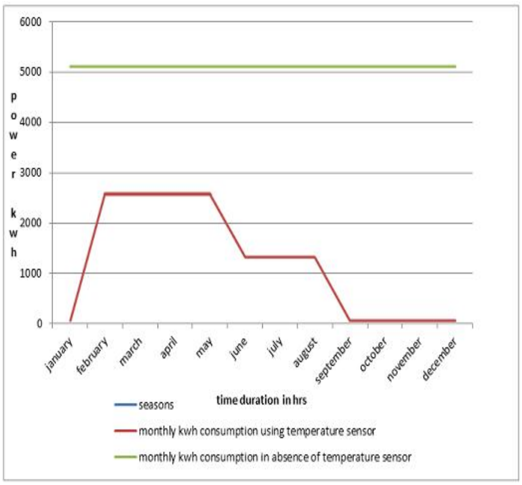

Fig. 7 : Monthly kWh consumption with and without ZigBee based sensor

VI. CONCLUSION

The system has been tested by connecting the ZigBee based temperature sensor to the following appliances - soldering iron, air conditioner and tube lights. Table 3 to Table 10 show the data collected during various seasons and Electricity bill on monthly basis for the said duration .Fig 7 shows the monthly kWh consumption of energy with and without ZigBee based sensors. This captured data can help us to identify load pattern and energy saving in smart homes of an intelligent building. The proposed system can be installed and maintained in residential environments with ease.A ZigBee based Intelligent Energy Management System for residential building system can provide significant cost savings in a building environment, great level of flexibility and control for the building administrators and great comfort for the occupants.

REFERENCES

[1] Baronti P, Pillai P, Chook V, Chessa S, Gotta A, Hu Y. Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards. Computer Communications 2007; 30: 1655–1695.

[2] Wilson, J. (2008), Sensor Technology Handbook, Newnes/Elsevier, Oxford.

[3] Gorday P, Hester L, Callaway E. Home Networking with IEEE 802.15.4: A Developing Standard for Low-Rate Wireless Personal Area Networks. IEEE Communications Magazine 2002; 70-78.

[4] Getting Started with ZigBee and IEEE 802.15.4. Daintree Networks 2008.

[5] ZigBee\ZigBee.htm: Wikipedia

[6] P. Kinney, ZigBee Technology: Wireless Control that Simply Works, White Paper dated 2 October 2003.

[7] Electric Power Research Institute (EPRI, 2006), IntelliGrid^{SM} Consumer Portal Telecommunications Assessment and Specification, Technical Report, Palo Alto, CA.

[8] ZigBee: The Choice for Energy Management and Efficiency – ZigBee White Paper - June 2007

[9] The magazine of the continental automated buildings association spring 2008 volume 5, number 1

[10] X. D. Zhang, Y. Gao, G. Y. Zhang, and G. Bi, “CDMA2000 cellular network based SCADA system,” in Proc. IEEE International Conference on Power System Technology (PowerCon 2002), vol. 2, pp. 1301-1306, 2002.

◈◈◈