Building Energy Management System Based on Microcontrollers

Fazal Noor(✉), Atiqur Rahman, Yazed Alsaawy, and Mohammed Husain

Islamic University of Madinah, Madinah, Kingdom of Saudi Arabia
mfnoor@gmail.com, fmatiq@yahoo.com, yalsaawy2@gmail.com, mohd.husain90@gmail.com

Abstract. In this research, a platform is proposed based on optimization algorithms for Energy Management System for buildings. Building energy consumption can be minimized based on Artificial Intelligence and user requirements of power supplied therefore allowing comfort to consumer with efficient operation and functioning of the building. A prototype using SMART devices with a microcontroller is implemented and tested. It is observed with proper management of the operation of devices efficiency increases and therefore consumer costs reduced. A master controller communicating with multiple apartment controllers is proposed with massage passing interface.

Keywords: Energy management system · SMART devices · Optimization algorithms

1 Introduction

In today's energy management system, there is the need for consumer participation in demanding comfort and partial management of which appliances should be powered on or off [1]. Commissioning of buildings has many benefits such reducing power wastage, operating of equipment HVAC efficiently, and many others [2]. The Organization for Economic Cooperation and Development (OECD) consisting of 34 countries have shown in their report the building sector accounts for 25 to 40% consumption of energy [5]. In [6], it was predicted that the amount of power required for lighting would be 80% higher in year 2030. It also mentions efficient lighting would reduce the amount of CO2 emissions. It has been shown building energy management systems are required for the increasing demand for energy [8, 9]. Performance studies on energy management systems have shown by proper control of HVAC in buildings lowers the costs to the owners [3, 4, 7, 10, 11]. Artificial intelligence using neural networks have been studied to even further reduce energy consumption in the Smart buildings [12].

The owner of the building and the tenants may agree on abiding by their agreed upon rules and have fixed and flexible scheduling of their own for how long or when the appliance may be used during which time of the day. The basic idea is to have a microcontroller system using either wired ethernet connections or wireless access points at the apartment level. There is another microcontroller system at the building level called the Master Premises energy management system and which is connected to

© ICST Institute for Computer Sciences, Social Informatics and Telecommunications Engineering 2019
Published by Springer Nature Switzerland AG 2019. All Rights Reserved
M. H. Miraz et al. (Eds.): iCETiC 2019, LNICST 285, pp. 305–313, 2019.
https://doi.org/10.1007/978-3-030-23943-5_24

a substation layer. Internet of Things (IoT) is a useful platform to achieve this control. It is observed the IoT devices continue to increase in numbers and therefore efficient energy management for IoT in Smart Cities is highly desired. Another important thing in energy management software is the security aspect and the applications must have high level of authentication and security built into them.

There are many vendors producing Smart devices and are available in the market now a days. One of the main problems among the vendors is the compatibility issue and users or developers need open source building automation platforms. Two open source platforms discussed in this paper are the OpenEMS and BEMOSS.

2 OpenEMS and BEMOSS Open Source Platforms

An electrical power management system (EPMS) is defined as an electronic system that provides detailed information about the transmission of power in an electrical power generation system or power substation. PMS record and provide data about power systems and power-related events. That information is used to manage power generation efficiencies, batteries and capacitor banks, gas or steam turbine relays and other systems in power generation stations and power substations. EPMS can visually display real-time or historical data. The system ties together the essential data that formerly had to be checked on numerous readouts and gauges by equipment operators. Supervisory control and data acquisition systems (SCADA) systems often use EPMS, especially those used in power plants.

Besides power generation stations, EPMS can be found in manufacturing plants, on large ships' generators and in similar high power demand locations. Some EPMS are their own systems, while others integrate with supervisory control and data acquisition (SCADA) and yet others are hybrid systems.

EPMS that include generator protection and control (GPC) relays and those that are integrated with SCADA can automate many power-related relays. This control helps increase power efficiency, especially in times of high draw. Some products claim they can help reduce peak power draw by 50%. Applied to the power grid, this reduction could theoretically alleviate concerns of a power crisis resulting from peak demand.

Better power management is helpful in terms of smoothing power demands. Smoothing out peak and low demand is often very beneficial and lower in cost as the problem in energy systems is often not that overall average power is too high but that peak draw times exceed momentary power production. In North America, this is true of the power grid as well as many power generation stations large and small.

2.1 OpenEMS

OpenEMS was developed by FENECON GmbH, a German company specializing in manufacturing and project development of energy storage systems [13]. It is a modular platform for energy management applications and is widely used in private, commercial, and industrial applications. OpenEMS is useful in applications which control, monitor, and integrate energy storage systems, complementary devices, and renewable energy sources. OpenEMS has Internet of Things (IoT) stack which consists of the following 3 main components. OpenEMS Edge controls the devices and executes on the site.

OpenEMS UI is the generic user interface component, and OpenEMS Backend executes on a server (e.g. cloud) and connects the decentralized Edge systems [14]. It also provides aggregation, monitoring, and control through the internet.

The main features of the OpenEMS are wide range of supported protocols and devices (meters, battery inverters; modern web based real-time interface, extendable with the use of modern programming languages and its modular architecture.

2.2 BEMOSS

BEMS stands for building energy management system, which monitors and controls building's power requirements [14]. It can control, fire alarm system, lighting, security, ventilation, air conditioning, and heating in residential or commercial buildings. BEMS is similar in some ways to OpenEMS as it also has a centralized control center from which to control other systems.

BEMOSS stands building energy management open source software built upon VOLTTRON which is a distributed agent platform developed by Pacific Northwest National Laboratory (PNNL) [15]. BEMOSS is a middleware having a seamless interface to variety of devices manufactured by various companies and also has the interface to the application layer where the software developers can develop modules which can be integrated with a variety of functionalities. It has the following features, open source, plug & play, interoperability, scalability and ease of deployment, local and remote monitoring, security, and support.

3 Experiment Results

3.1 Hardware Setup

The testbed is shown in Fig. 3 which is setup in our university lab and consists of hardware having SMART devices such as plugs, inverters, lights, and controllers. These devices are compatible with the BEMOSS system installed on our main PC. As currently there is no integration of BEMOSS with Arduiono microcontroller. In our lab, the Arduino using a webserver communicates wirelessly with the PC and transfers data read from the sensors. The main controller consists of an Arduino microcontroller. The Arduino microcontroller is open source and easily available in the market. The Fig. 1 below shows a Smart home environment. The Smart residential building environment can be thought of multiple stacks of Smart home environments.

The main distinction in this research is the customer demand of power and device management. For example, a customer may demand the home heating, air conditioning, and ventilation (HVAC) be at comfortable levels or at the level of their desire. Multiple apartment controllers communicate with master building controller for power demand. The communication occurs between master and apt controller via message passing interface. The Master controller is connected to grid station and receives information such as time when power cost is minimum and load is peaking. This information is conveyed to apt controller notifying the occupant when is the best time to use appliance such as washing machine or clothes dryer, or best time to iron clothes. Also, the user may demand which appliances to be powered on for their comfort such as A/C or heating.

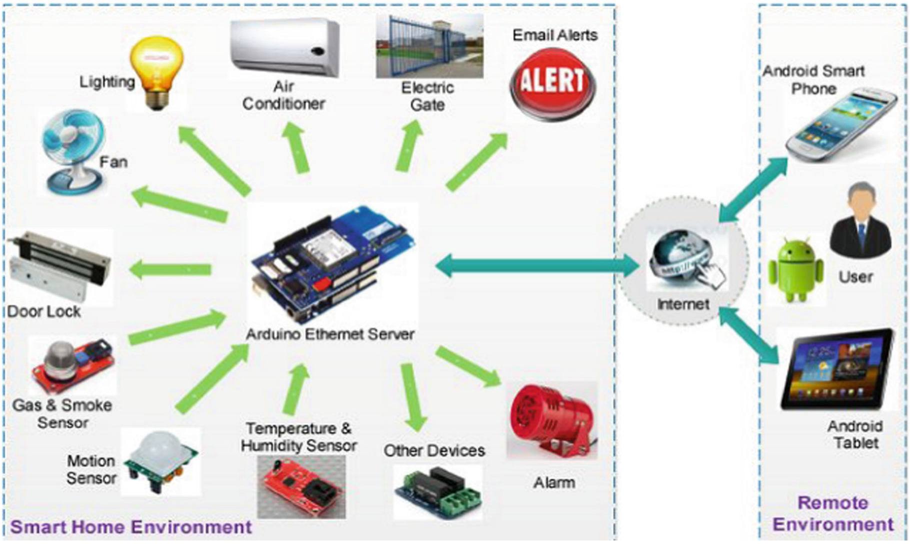

Fig. 1. A SMART home environment with master arduino ethernet server and remote environment based on android systems [16].

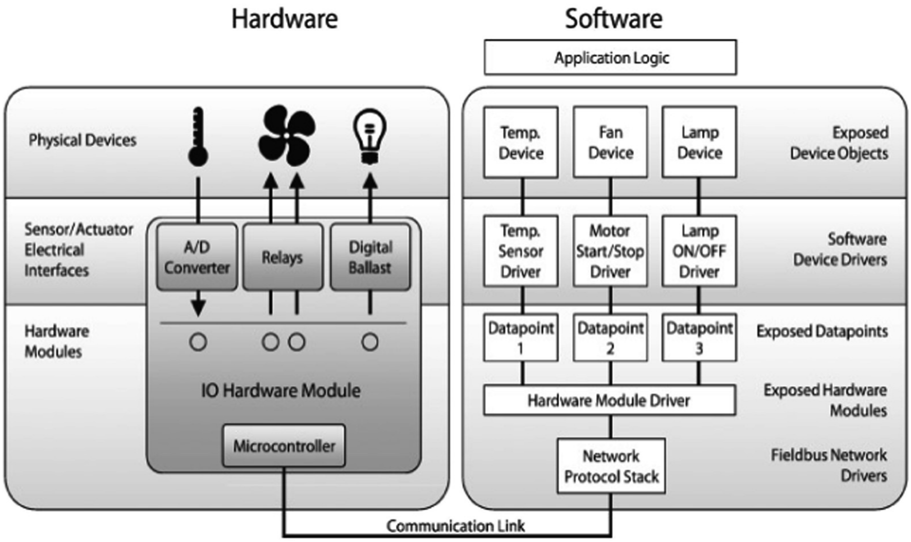

Fig. 2. An overview of hardware and software for a smart building with master controller and communication with multiple apartment controllers [16].

As it is seen in Fig. 2 a microcontroller is useful in controlling devices via a communication link. For residential buildings air conditioning, heating, and ventilation are the items most desired by customers to control. Therefore, sensors installed would be constantly monitoring the environment and communicating with the Building Energy management systems. The communication channels may be wired or wireless. In our experiments, wireless modules were used with an Arduino microcontroller. Arduino is an open source microcontroller and comes with IDE software for programming. The sensors monitor outside temperature, occupancy of apartment whether it is occupied or not, also sensors to monitor inside temperature of apt, and whether lights are on or off. As more sensors are installed to monitor the environment and control the devices the more precisely power efficiency is achieved. A common scenario is when in winter time a sudden cold front occurs and the tenants of a building increase the heat at the same time. In this situation, the power company will have to provide more power and a peak in power output will occur and therefore a rise in cost to the owner and tenants of the building. Too much rise in peak power are the usual cause of blackouts. Table 1 below shows how information from sensors will help provide power efficiency. Neural networks can be incorporated to read in sensor data and classify power usage depending on the device, hour of the day, temperature, daylight, etc. Using Artificial intelligence in studying the behavior of tenants, climate change, receiving data from sensors, etc. may also lead to systems with overall cost savings to tenants and building owners. The major savings comes when the sensors notify the master controller whether the apt is occupied or not occupied. If not occupied then there is no need to increase the temperature and hence less heating therefore will be a decrease in power consumption. Also, in this case of no occupancy there will be no need for lights therefore further reduction in power consumption. The heating of building may also be controlled by opening or closing of blinds of windows, closing of open doors by automatic controlling of motors. The lighting system of a building is also controlled by an Arduino micro-controller based system. Table 2 below shows typical appliances which are controlled by the building owner, and those controlled by the tenant. The hours of operation those controlled by the tenant are flexible compared those controlled by the owner of building. The Master controller may communicate with the apartment controllers and notify it of the best price offered by the utility company at which hours of the day the power is cheapest. Consumer having this information then will be able to program their devices or use them at the hours which are cheapest cost to them.

The monitoring and control of devices utilizing the BEMOSS platform and integrating it with multiple Arduino microcontrollers is studied for reliability of operation. The energy saving = energy cost (without algorithm) – energy cost (with algorithm) where the algorithm is used to properly manage the devices based on energy cost savings, and based on user demand priority settings. The algorithm is based on optimization algorithms such as the Genetic algorithm. The bottom line is to minimize power usage under the constrained of user demand, comfort, priority of appliance operation, hour of the day, and minimum cost times. Table 2 shows the typical types of power loads, KiloWatss (KW), and number of hours the appliance is typically on. Different tenants may differ slightly in their hours of usage.

The function to minimize is

$$f(\mathbf{x}) = E_c(\boldsymbol{x}) + E_h(\boldsymbol{x}) + E_f(\boldsymbol{x}) + E_L(\boldsymbol{x}) + E_p(\boldsymbol{x}) + E_o(\boldsymbol{x}) \quad (1)$$

where E_c is the energy consumption for A/C, E_h is the energy consumption for heating E_{f} is the energy consumption of the fans, E_{L} is the energy consumption of lighting, E_{p} is the energy consumption of pumps, and E_{o} is the energy consumption that includes other appliances such as washing machine, clothes dryers, and iron. The genetic algorithm consists of the following phases, 1. Initial population, 2. Fitness function, 3. Selection, 4. Crossover, and 5. Mutation. The prediction of energy consumption is a difficult problem and varies with outside temp, user demands, occupancy, sunlight, etc. The daily power consumption continuously varies ups and down as shown in Fig. 4. However, when climate changes it becomes more predictable the demand will increase such as cold front kicking in. Another scenario is when there is no tenant and apt is unoccupied then power consumption is more predictable to be less.

Furthermore, to minimize power is to incorporate SMART devices communicating and recommending the tenant on time of day to operate an appliance when the cost of utilities providing power is minimum. For example, if the user is informed of best time to operate washing machine or clothes dryers, or the best time to iron clothes. The building owner is informed automatically to turn off lights in areas of building where not required. Figure 5 shows the energy savings on average of a typical apartment. Series1 is without using any algorithm and series2 graph is the result of using algorithm. It is seen minor savings can add up when considering large residential buildings. Energy savings of 10% to 30% were obtained in lab simulated environment.

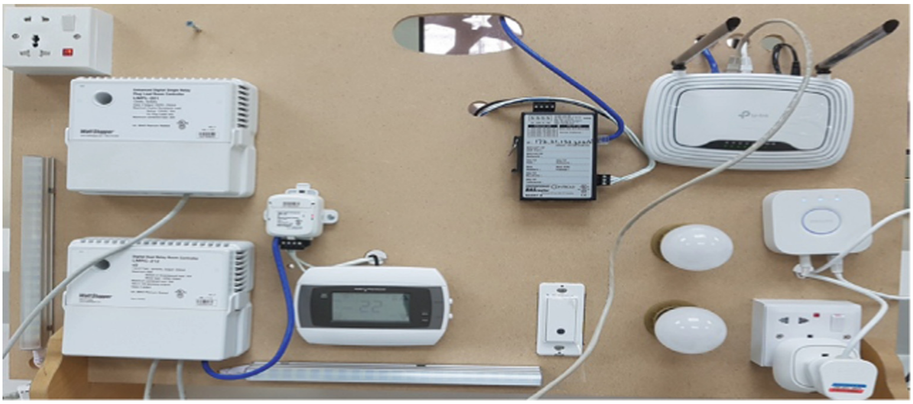

Fig. 3. A testbed of SMART devices used in experiments with BEMOSS and Arduino micro controlled sensors in our university lab.

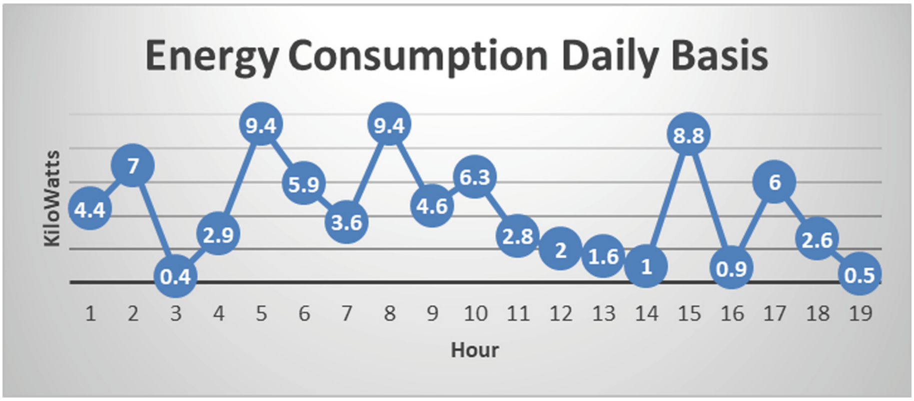

Fig. 4. Power consumption on average daily basis with fluctuates randomly in a residential building.

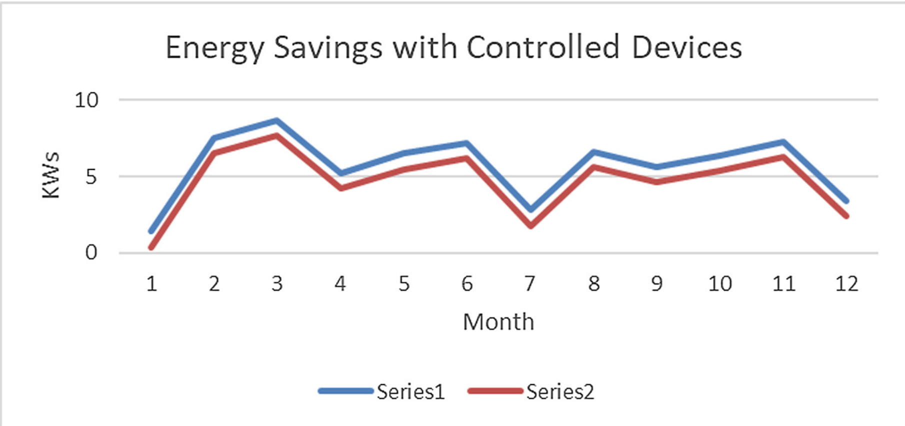

Fig. 5. Power consumption on average on a simulated monthly basis, series1 is without using any algorithm and series2 is with using algorithm.

Table 1. Power efficiency based on temp and occupancy sensors.

Apt	Lights	Heating	Occupied	Outside temp before 12 °C	Outside temp now 5 °C	Power
				Heat before	Heat demand	
1	25	20	Yes	22	27	Increased
2	40	30	Not	24	24	No change
3	75	10	Yes	23	28	Increased

Table 2. Appliances load

	Water boiler	Heating	AC	Washing machine	Clothes dryer	Clothing iron
Power	4 KW	5 KW	2.5KW	2.0 KW	3 KW	2KW
Typical hours of operation	12 h	15 h	15 h	½ h	1 h	½ h
Controllable by	Building owner	Building owner	Building owner	Tenant	Tenant	Tenant
Operating time	Fixed	Fixed	Fixed	Flexible	Flexible	Flexible

4 Conclusion

With the year over year increasing demand for energy in residential or commercial buildings. It is seen that power efficiency is necessary when user demands a certain level of comfort, for example due to a sudden cold front kicking in. It is necessary for owners of buildings to communicate with the tenants and inform them of energy reduction and its benefits to both in cost savings. Also, installation of SMART devices will help in energy savings and usage of certain types of Led lighting. Timers and power strips are also helpful in energy reduction and therefore recommended. It is seen open source microcontrollers can be used with sensors for sensing the environment and providing valuable information to the energy management system and integrating to robust BEMOSS platform and therefore providing a more versatile power efficient system. In the future, large number of sensors will be utilized with microcontrollers to simulate a realistic environment and a performance study will be made with integration to the BEMOSS system. A robust communication and security are also necessary in such large sensor systems.

Acknowledgement. This work is funded by the Deanship of Scientific Research, Islamic University of Madinah (Tamayyuz Project #20/40 titled: “An Intelligent Software Platform for Energy Efficiency and Peak Load Reduction for Buildings”).

References

1. Windapo, A.O.: Managing energy demand in buildings through appropriate equipment specification and use. In: Energy Efficient Buildings, Eng Hwa Yap. IntechOpen, 18 Jan 2017. https://doi.org/10.5772/66363. https://www.intechopen.com/books/energy-efficient-buildings/managing-energy-demand-in-buildings-through-appropriate-equipment-specification-and-use. Accessed 2 Feb 2019
2. Claridge, D.E., Liu, M., Turner, W.D.: Commissioning of existing buildings - state of the technology and its implementation. In: Proceedings of the International Short Symposium on HVAC Commissioning, Kyoto, Japan (2003)
3. Levermore, G.J.: Building Energy Management Systems; Application to Low-Energy HVAC and Natural Ventilation Control, 2nd edn. E&FN Spon, Taylor & Francis Group, London (2000)

4. UK DTI. The Energy Challenge: Energy Review. http://www.dti.gov.uk/energy/review/page31995.html. Accessed 2 Feb 2019
5. OECD. Environmentally sustainable buildings: Challenges and Policies. http://www.oecd.org/env/consumption-innovation/2715115.pdf. Accessed 3 Feb 2019
6. IEA. Light's labours lost, OECD/International Energy Agency, Paris, France (2006)
7. IEA. Technical Synthesis Report: A Summary of Annexes 16 & 17 Building Energy Management Systems. Energy Conservation in Buildings and Community Systems (1997). http://www.ecbcs.org/annexes/annex17.htm. Accessed 2 Nov 2010
8. MOD. Building Energy Management Systems. Ministry of Defence: Defence Estates Design and Maintenance Guide, vol. 22 (2001)
9. Levine, M., et al.: Residential and commercial buildings. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (eds.) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York (2007)
10. Birtles, A.B., John, R.W.: Study of the performance of an energy management system. BSERT, London (1984). http://bse.sagepub.com/content/5/4/155.abstract. Accessed 3 Feb 2019
11. Roth, K., Llana, P., Detlef, W., Brodrick, J.: Automated whole building diagnostics. ASHRAE J. **47**(5) (2019). http://www.ashrae.org/publications/page/424. Accessed 3 Feb 2019
12. Álvarez, J.A., Rabuñal, J.R., García-Vidaurrázaga, D., Alvarellos, A., Pazos, A.: Modeling of energy efficiency for residential buildings using artificial neuronal networks. Adv. Civ. Eng. **2018,** 10 pages (2018). Article ID 7612623
13. OpenEMS. https://openems.github.io/openems.io//openems/latest/introduction.html. Accessed 3 May 2019
14. BEMOSS platform. http://www.bemoss.org/. Accessed 3 May 2019
15. https://www.researchgate.net/publication/260127438_Ubiquitous_Smart_Home_System_Using_Android_Application/figures?lo=1. Accessed 3 Mar 2019
16. https://www.google.com/search?q=hardware+software+%2B+communication+link+%2B+fan+%2B+temp+%2B+control&tbm=isch&source=hp&safe=strict&sa=X&ved%20=2ahUKEwjalMON4dzhAhVLzIUKHSFgDcYQ7Al6BAgJEA0&biw=1121&bih=530#imgrc=%20EJ9mdUU5aWBbsM. Accessed 3 Mar 2019