Energy Management in Smart Buildings by Using M2M Communication

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***Abstract*— The energy consumed by appliances is increasing year by year for the purpose of providing desired occupant comfort in buildings. In this paper, a new Heating, ventilation, and air conditioning (HVAC) system is implemented in order to control and monitor the energy consumption of buildings by using fuzzy logic, machine to machine (M2M) communication, and Internet Technologies. The embedded design's charge is to save energy during peak hours, without affecting the comfort of the occupant and with self-control managing energy with Internet of Things (IoT) technology. Our first prototype was validated and applied to a realistic scenario with two air conditioners. The results show that the system developed is capable of automatically reducing energy consumption and maintaining steady comfort level required by the occupants in the building.**

Keywords—energy management system, fuzzy logic, iot, m2m, smart air conditioning, smart building.

I. Introduction

Nowadays, the consumption rate troubling the power plants comes from the building sector. This is why various technologies used in construction appear as a cure for rising load peaks. The main two reasons for using building automation system is to ensure the safety and energy efficiency for residents.

Therefore, the producer of electric power can face a critical problem which leads to equipment damage, loss of network performance, and, at the very worst, partial or full system shutdown [1].

Recently, practical solutions have focused on attaining energy management as well as efficient control of smart grid and smart building technologies for many reasons. First, energy consumption in buildings rises to interesting stage 32% of global total final energy consumption in the world. In fact, buildings represent around 40% in most IEA (International Energy Agency) countries [2] and 41% of the total electric consumption in Europe [3]. Buildings are also responsible for 36% of the EU CO2 emissions [2]. The solution lies in more focus on energy performance and load management in buildings to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the greenhouse gases emissions by 2020 and a 20% energy savings by 2020 [4].

Many researchers in the arena focus on managing energy that controls thermal appliances in smart buildings, such as heating and air conditioning systems, which need huge demand of energy compared with other appliances in such buildings. Those studies could be classified into two main categories when it comes to the methodology of how to save energy in a building.

The first category is based on one control system that handles all the processes of energy management. One of those researchers focuses on smart heating and air conditioning scheduling method without affecting the comfort of occupant [5]. Another one is interested in energy management to control air conditioners based on low-cost web-based IR remote control system [6]. In Ref. [7], the management of home energy system is realized with ZigBee standard and infrared control technology to reduce the standby power. In Ref. [8], the energy management system is realized by managing the start and stop of air conditioners via Bluetooth. Other researchers developed an optimum operation scheduling model of domestic electric appliances by relying on mixed integer linear programming [9]; In addition, a simulation based on HomeSim to simulate platform aimed at residential energy modeling that can explore smart appliances (cost-aware scheduling and peak power reduction) [10] and on the other side, a design based on consumption models in combination with timing schedule, power, temperature or ambient light measurements and prioritization [11].

The second category is based on Machine-to-Machine (M2M) technologies in order to have the optimal control functionality by collecting sensing data related to the devices. For example, Ching-Hu Lu et al. [12] proposed a new energy saving system by taking into account multiple comfort-constrained optimization in M2M based on home environment. Others like F. J. Belido-Outeirino et al. [13] used the latest M2M communication trends and standards defined by the oneM2M consortium in order to control devices in smart homes. Other researchers proposed a new approach of software agent intelligence based on M2M communications for smart city design [14]. Kazem Sohraby et al. [15] focused on the Smart Grid, namely for the transmission and distribution space sector in order to save energy by using M2M technology as well as the Internet of Things (IoT).

In the literature, most of the studies of energy management problem are realized by using a central unit that controls all appliances in smart buildings. However, this work is relatively complicated to use and the occupants may face some serious problems when applying the right setting for the right case. Other studies focus on energy management system based on efficient communication, like M2M. The numbers of devices based on this kind of communication have increased to 300% in the last five years [16]. It provides limited occupant intervention, self-controlled appliance, and scalability. Hence, we have proposed an architecture based on this kind of communication which includes a simple web interface based on Java Script and HTML to monitor and control all the system. It employs a fuzzy logic controller using IoT technology without sacrificing comfort level.

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The paper is organized as follow: Section II contains the proposed solution for smart building. The implementation and the validation of our prototype are presented in Section III. The discussion results and the conclusion are in Sections IV and V respectively providing final remarks and the future work.

II. THE PROPOSED SOLUTION

A. Architecture Design

Our design deploys a simple and efficient energy management system by applying a novel approach consisting of three main parts; first, collecting data from sensors “Temperature (T) and Humidity (H)”, second, monitoring the entire system over the cloud, and third, controlling devices “Air conditioners (AC)” by manipulating the level of fan speed, temperature, and the mode/state “Heat, Cool or Dry”) as illustrated in Fig. 1. Those expectations are related to the energy management system in order to manage energy without affecting the comfort level of occupants. The system takes sensing data like temperature and humidity as inputs to configure and control air conditioners (AC) by using infra-red (IR) signal of AC. The design proposes auto-controlled system by using M2M communication over Zigbee Network (Three nodes used “two for M2M communication as an end device and one for gateway interface as a coordinator), as depicted in Fig. 2.

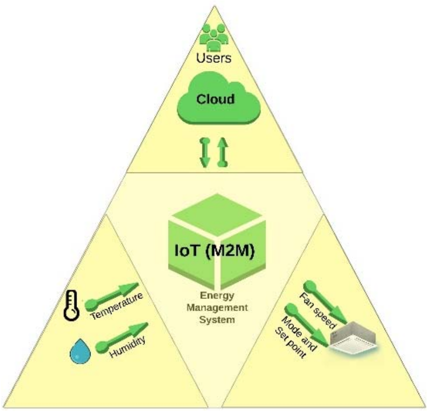


Fig. 1. The big picture of the energy management system proposed.

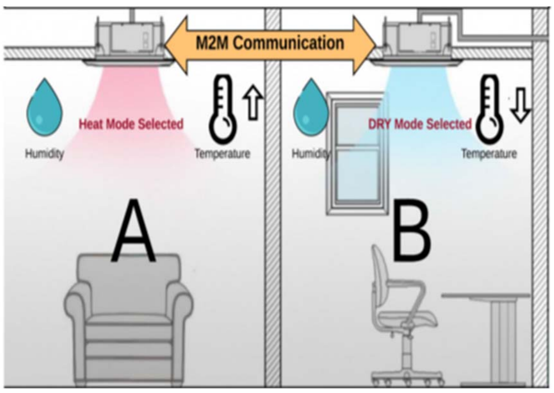


Fig. 2. M2M communication between two AC.

B. M2M communication

The system uses M2M communication over ZigBee module in order to handle data transfer function. It supports a wide communication range with lower power consumption and is capable of providing both Point-to-Point and Point-to-Multi-Point connections. The product has been widely used on M2M fields, such as intelligent transportation, smart grid, and in our case smart building. Sensing data related to the device is formatted according to the JavaScript object notation (JSON) standard. JSON is one of lightweight standard and can be parsed by JavaScript implementation.

C. Scheduling algorithm

The scheduling algorithm reflects our proposed solution in order to control and handle two ACs as shown in Fig. 3 through three steps:

1- Check the state of each AC (ON/OFF).

2- Check if the requested mode for both ACs are set on the same mode (Heating); otherwise, the system will be forward to standby mode.

3- The fuzzy logic controller (FLC) takes sensing data (Temperature (T) and Humidity (H)) of each room (A and B) as inputs in order to determine the efficient value of the fan speed level.

The priority will be given to the side that has the lowest temperature level in order to set the Heating mode on and the Drying mode for the other side. During this time, the controller will inverse the modes of each side if we have a different priority condition.

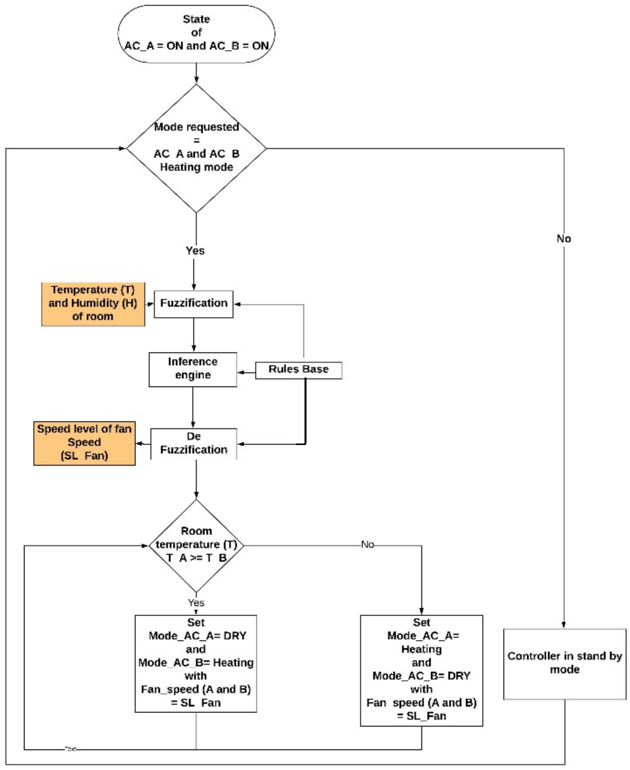


Fig. 3. Flowchart of the scheduling algorithm.

Rules of FLC are decomposed into eleven cases as described below (TABLE 1):

TABLE 1. Rules of fuzzy logic control.

Number of Rule	Temperature	Humidity	Fan Speed
1	Normal	Very Wet	Fast
2	Hot	Very Dry	Medium

3	Hot	Dry	Fast
4	Hot	Humid	Fast
5	Hot	Wet	Fast
6	Hot	Very Wet	Fast
7	Very Hot	Very Dry	Fast
8	Very Hot	Dry	Very Fast
9	Very Hot	Humid	Very Fast
10	Very Hot	Wet	Very Fast
11	Very Hot	Very Wet	Very Fast

De-fuzzification process uses the center of area method (COA). This methodology looks at the center of the area of the distribution of the composite fuzzy set B':

$$B' = B_1 \vee B_2 \vee \ldots \ldots . . \vee B_n$$

Where (**f**) fuzzy sets $B_1, B_2, \ldots \ldots, B_n$ as output variable. Assume y the output of inference from (**f**) fuzzy rules.

$$y_{COA} = \frac{\sum_{j=1}^{n} y_j \sigma_{f'}(y_j)}{\sum_{j=1}^{n} \sigma_{f'}(y_j)} \quad (1)$$

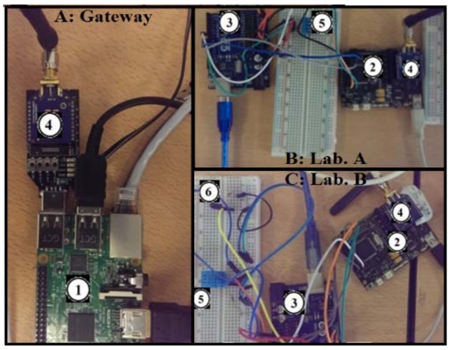
Where the output variable is quantified as $\{y_1, y_2, \ldots . . y_n\}$, n is the number of quantization levels, $\{y_j\}$ is the amount of control output at the $\{j^{th}\}$ quantization level, and $\sigma_{f'}(y_j)$ is the value of membership function of fuzzy set B' at $\{y_j\}$.

III. Implementation and Validation

A. *Implementation:*

The implementation phase is divided into two parts:

- Communication Level: The communication level includes enabling and managing Digi radio frequency (RF) for all XBee modules by using X-CTU application for ZigBee network. Our network which is based on mesh network topology is composed of:
  - One coordinator, used as a gateway.
  - Two routers, used for M2M communication.
- Embedded Level: The embedded phase focuses on our first prototype as well as all the experimental tests being applied to the real scenario by using those listed devices illustrated in (Fig. 4):
  - Raspberry Pi3: is used as a Gateway to collect all sensing data related to the device and forward it to the cloud.
  - Waspmote controller is used for ZigBee network: it sends and receives sensing data.
  - Arduino controller is used as a controller for AC and handles the FLC process by being given the efficient value of fan speed.



1-Gateway (Raspberry Pi3).
2-Waspmote with Xbee module (node).
3-Arduino.
4-Xbee Module.
5-Humidity sensor.
6-IR led sensor.

Fig. 4. Final prototype for IoT web application for managing energy of AC.

In order to optimize the implementation of our embedded system, we have decomposed all the tasks executed by those boards (controller) as following (Fig. 5):

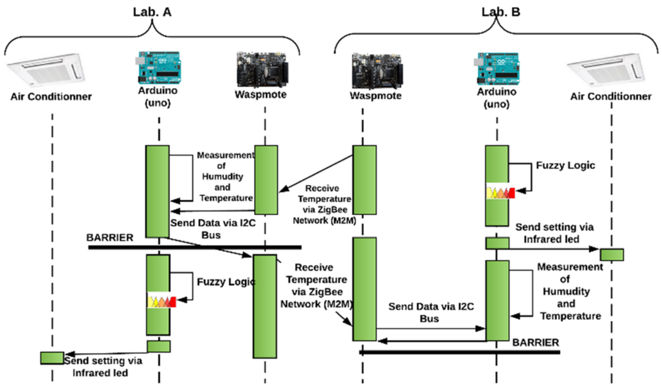


Fig. 5. Sequence diagram of M2M communication.

All the tasks are executed in parallel and synchronized by using two barriers for each side. Barriers guarantee that the process of fuzzy logic could start only when data is sent to Waspmote board via I2C bus.

We delve into the details of the validation phase for our system with different use cases (with and without M2M) in the following sections.

B. *Validation:*

In this section, we present the validation results of our proposed design applied to AC implemented in two laboratories (Lab. A and Lab B).

The user could easily set the maximum of average ambient temperature and the maximum of energy consumption over our web interface as below:

- Maximum of average ambient temperature ≤ 23° C.
- Power < 5000 W.

As the initial status, we apply HEAT mode on air conditioners A and B and then, as a second step, we take all measurements data during sixty minutes for both scenarios: with and without M2M communication.

Measurements test without M2M communication:

During the test we control the (AC) based on predefined test case for each LAB. The predefined test case is applied without any communication between controllers (Without M2M) as shown in Fig. 6 and Fig. 8.

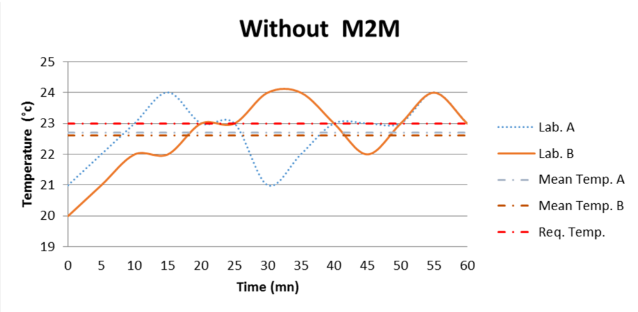


Fig. 6. Ambient Temperature of Lab. (A and B).

During the experimental test, the controller of AC switches to the Heating mode if the temperature of laboratory gets below the requested value by one degree (in our case 22°C) and switches to the DRY mode if the temperature of laboratory gets above the requested value by one degree (in our case 24°C) (Fig. 6).

On the other hand, we can clearly figure out that the system is unable to meet the requested preference (the maximum energy consumption exceed 5000 W) as shown in Fig. 8.

Measurements test with M2M communication:

During the experimental test, our controller is set to active mode. We take the same measurements as in the previous scenario (state of AC, power consumption, and ambient temperature) presented in Fig. 7 and Fig. 8 by taking into account that all the initial conditions are the same compared to the first scenario (without M2M communication).

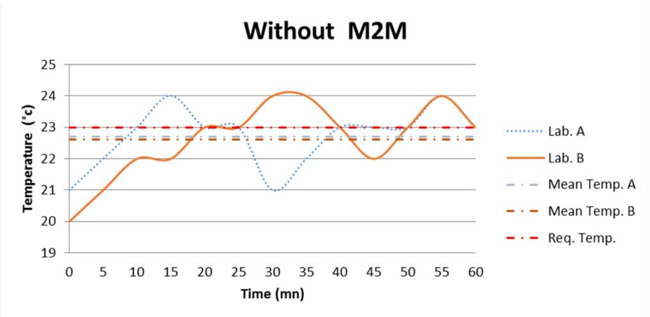


Fig. 7. Ambient Temperature of Lab. (A and B).

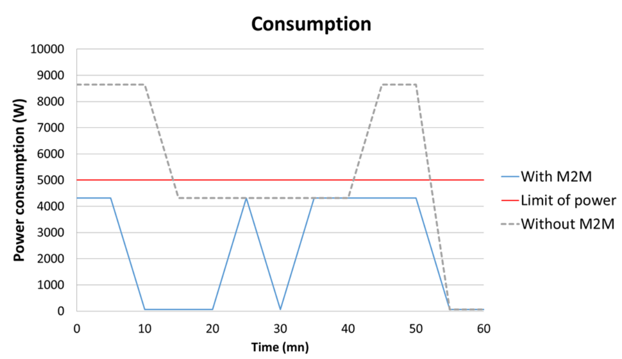


Fig. 8. Total power consumption of air conditioners with/without M2M.

IV. Discussion

A solution was proposed through using fuzzy logic controllers, M2M, and Internet of Things (IOT). The major contributions of this research lie in the HVAC systems control without affecting the comfort of the use as well as in the simplicity of control system application for occupants. Objectively, our results obtained from experimental test validate that our system saves energy as shown in (Fig. 8) somewhat without affecting the comfort of occupant. The inside temperatures in the two labs, as shown in Fig. 6 and Fig. 7, clearly illustrate that the scenario without M2M control system achieved at least 1°C closer to the desired temperature compared to the scenario with the proposed M2M control system. Thus, it can be maintained that the desired comfort level has been attained with an acceptable range for the inside temperature.

V. Conclusion and Perspective

Energy management using M2M communication in smart buildings during peak period, without affecting the comfort of occupants, are interpreted as a research problem. In this paper, an analysis of our architecture design from an auto-control point of view has been performed in order to save energy using IoT technology and a web application designed for managing energy of AC with M2M communication. Measurements test validate our first prototype embedded on two ACs by providing auto-control for managing energy in order to save energy. These results motivate the occupants to embed our prototype on their own smart building or home. The next step is to apply a big system comprising multiple aircons with various constraints accumulated within the system and verify its performance and ease of acceptance in real big system.

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