A Real-Time Controlling Mechanism Using Fuzzy Logic for Efficient Comfort Supporting and Power Consumption in Smart Homes

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Abstract: Background/Objectives: Many researchers have been interested on the power-efficiency solutions in buildings because of the power consumption is a huge amount in our modern life through heterogeneous electronic devices. Methods/Statistical analysis: For making a more comfortable environment in an indoor environment of building such as smart homes, the electronic devices are required to changing environmental parameters, such as temperature, illumination and air quality. Moreover, the power consumption also needs to be efficient for avoiding wastage and unnecessary usage of power. The intelligent controlling mechanism enables minimal power consumption with a comfortable environment. Findings: In this paper, a real-time controlling mechanism is proposed, which is based on the fuzzy logic to control actuators for the comfortable environment using minimal power consumption. The fuzzy logic controlling is based the fuzzy inference which defines the fuzzy membership for the temperature, illumination, and air quality to support the controlling factors of air conditioner, boiler, fan and light. For applying the proposed controlling mechanism, we present the virtual environment that emulates the sensing environment with presented environment parameters which provides air quality data, illumination data and temperature data. The actuators also are implemented to emulate the air conditioner, boiler, fan and light for evaluating the proposed mechanism in the virtual environment. Improvements/Applications: Through the evaluation, the results show the controlling mechanism updates the parameters to keep the comfortable environment using optimized power consumption.

Keywords: Control Mechanism, Comfort, Fuzzy, Power, Virtual Environment, Smart home

I. INTRODUCTION

For the residential building environments such as smart homes, efficiently managing the power consumption is very important to save the cost. However, the power consumption is increased rapidly and become more and expensive to use various electronic devices for the comfort of the living environment. The building power consumption can be saved 20%-30% through the optimization controlling without changing the hardware and configurations in the power supply system [1]. Therefore, in any building, the control system is required for providing user comfort as well as power consumption minimization. In an intelligent and power efficient building environment, the environment control system is required to provide a comfortable environment and save the cost.

The major challenge is minimizing the power consumption using the optimization solution to optimize the controlling factor of the electronic devices. In the indoor environment of buildings, most of the power is consumed by Heating, Ventilation and Air Conditioning (HVAC), lighting [2]. The values of temperature, illumination and air quality are the environmental factors to affect the comfort index. To change those parameters in the environment, the power is required to operate electronic devices such as fan, boiler, light, and air-con.

The power management in buildings has been interested by many researchers in a various research area. The building power system considers many elements in the building environment, such as comfort index, electronic devices, power supply, and environment parameters [3]. Improving the efficient power consumption of the HVAC system is the most considered research topic since it uses the most power cost in buildings [4]. For increasing the efficiency of HVAC power consumption, heterogeneous solutions are proposed, such as natural ventilation-based method [5], ice storage based operating cost reducing [6], and integrated controlling system [7]. However, in order to get a more comfortable environment, sensors and actuators are required to work together through the complex real-time controlling logic. Therefore, an intelligent controlling system is required to make a controlling decision based on environmental parameters.

In this paper, we provide a comfortable environment which considered temperature, illumination, and air quality in buildings. Those three basic factors determine the occupants' quality of lives in a building environment [8]. For calculating the comfort index, a formula has been presented to be used in Particle Swarm Optimization (PSO) [9]. In PSO, each optimal result is a particle to approach the global optimal result through the multidimensional search. Therefore, the comfort index can be defined in multiple ways based on the specific customer needs. The PSO is an algorithm for the optimization problems that was introduced as a novel evolutionally optimization approach in 1995 [10-11]. The PSO is used for many optimization applications to support powerful optimization solutions which are reached by updating generations iteratively to find the optimal factor [12].

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The fitness function is the most important element in the optimization approach which is used for defining the optimal situation. The Mamdani fuzzy inference was proposed as the first attempt to control a steam engine and boiler combination by a set of linguistic control rules obtained from experienced human operators [13]. Defuzzification refers to the way a crisp value is extracted from a fuzzy set as a representative value. In general, there are five methods for defuzzification of a fuzzy set. The Center of Gravity (COG) is applied for defuzzification function for the Mamdani fuzzy inference.

In this paper, we present the environment controlling system using the Mamdani fuzzy inference for controlling the actuator to supporting comfort environment through the optimized power supply. The proposed system is applied to a virtual environment that supports data of temperature, illumination and air quality to simulate an indoor environment of building s. Through the environment data, the fitness function of optimization is used for optimizing the comfort index using air quality data, illumination data, and temperature data. The initial velocities of optimizer are assigned to be a position with randomly, and a comfort index formula is used for the fitness function. The weight is randomly generated value between 0 and 2, the c1 and c2 both are 2 and the criteria is the iteration loop as 30 times. Once the optimal values are generated by the optimizer, then the fuzzy logic generates the controlling factors for the actuators to change the parameters of virtual environment.

The rest of the paper is organized as follows. Section 2 introduces the proposed method for the controlling process. Section 3 introduces the implementation result of the proposed system and describes the evaluation results. Finally, Section 4 concludes the paper.

II. MATERIALS AND METHODS

The proposed controlling mechanism includes the optimizer to get the optimal controlling factors and using the factors to control the actuators based on the fuzzy logic.

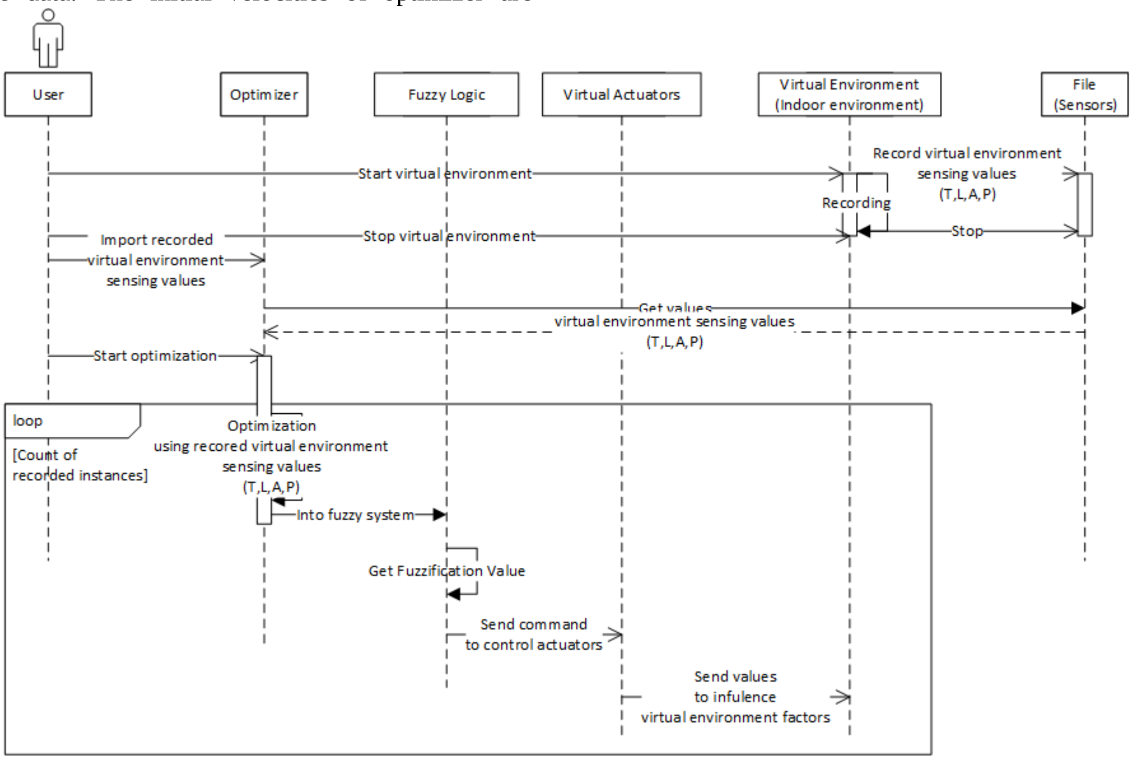

Figure 1. Sequence diagram of proposed process

Figure 1 shows the sequence diagram for the proposed process. The first part of the process illustrates running the virtual environment to generate data for the required parameters. The user starts the virtual environment to generate virtual data for temperature, illumination and air quality. The power data is generated using those virtual environment data. In this process, the values are saved to a file for using in the optimization process. Once data are saved, the user needs to stop the virtual environment. The second part of the process illustrates optimization and controlling functions. The user starts the optimization function to optimize the parameters for the virtual environment. Once the values of parameters are generated by the optimizer, then the fuzzy logic generates the control factors using the virtual environment parameters. The control factors are used for controlling the actuators to change the environment.

Once the user starts the process of the system, the system generates a "vir.csv" file with columns which includes temperature, illumination, air quality and power consumption. Then the recoding process shall be started. The process generates 2 subprocesses, one for saving environment values and another one for generating the values. Once the data is prepared for training the optimizer, the user can start the process. The instance of the recorded virtual environment is optimized using comfort formula and get the optimal values through the optimizer. The optimal values are used by fuzzy logic for getting the control values. From the fuzzy logic, the emulators of boiler, air conditioner, light and fan are controlled to updating temperature, illumination and air quality in the virtual environment.

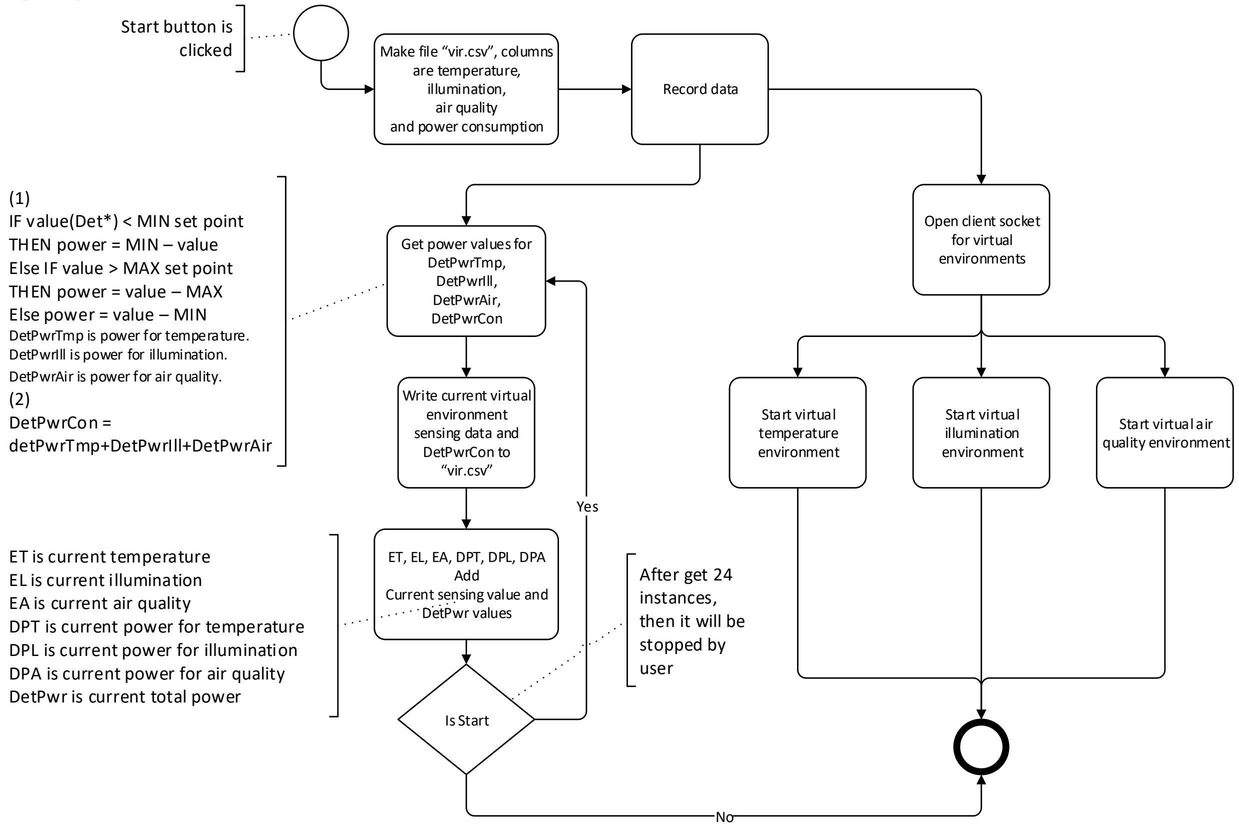

Figure 2. Flowchart of virtual environment initialization

Figure 2 illustrates the detail process steps of virtual environment initialization using a flowchart. Once the user starts the process of the system, the system generates a "vir.csv" file with columns that include temperature, illumination, air quality and power consumption. Once the recoding process is stared, the process generates 2 subprocesses, one is used for saving environment values and another one is used for generating the values. For example, the user can generate 24 instances for a day and stop the process.

Once the data are prepared for training optimization, the user can start the process as shown as Figure 3. The controlling mechanism includes 2 parts, one is used for the optimization based on the PSO, and another one is used for the fuzzy logic based on the Mandani fuzzy inference. The instance of the recorded virtual environment is optimized using comfort formula and get the global best by the optimizer. The global best is used by the fuzzy logic for getting the control value. From the fuzzy logic, we can control value for boiler, air conditioner, light and fan using temperature, illumination and air quality. When getting the fuzzification value, the system can level value for controlling an actuator. And the level values are sent to actuators. The actuators also send influence value to virtual environment for changing values of the environment.

In this process, the real-time optimization for getting optimal comfort index is presented. The PSO function gets a real-time environment values from sensors and calculates the values for getting the optimized value. Using the optimizer, the system gets the optimal comfort with temperature, illumination, air quality and power consumption.

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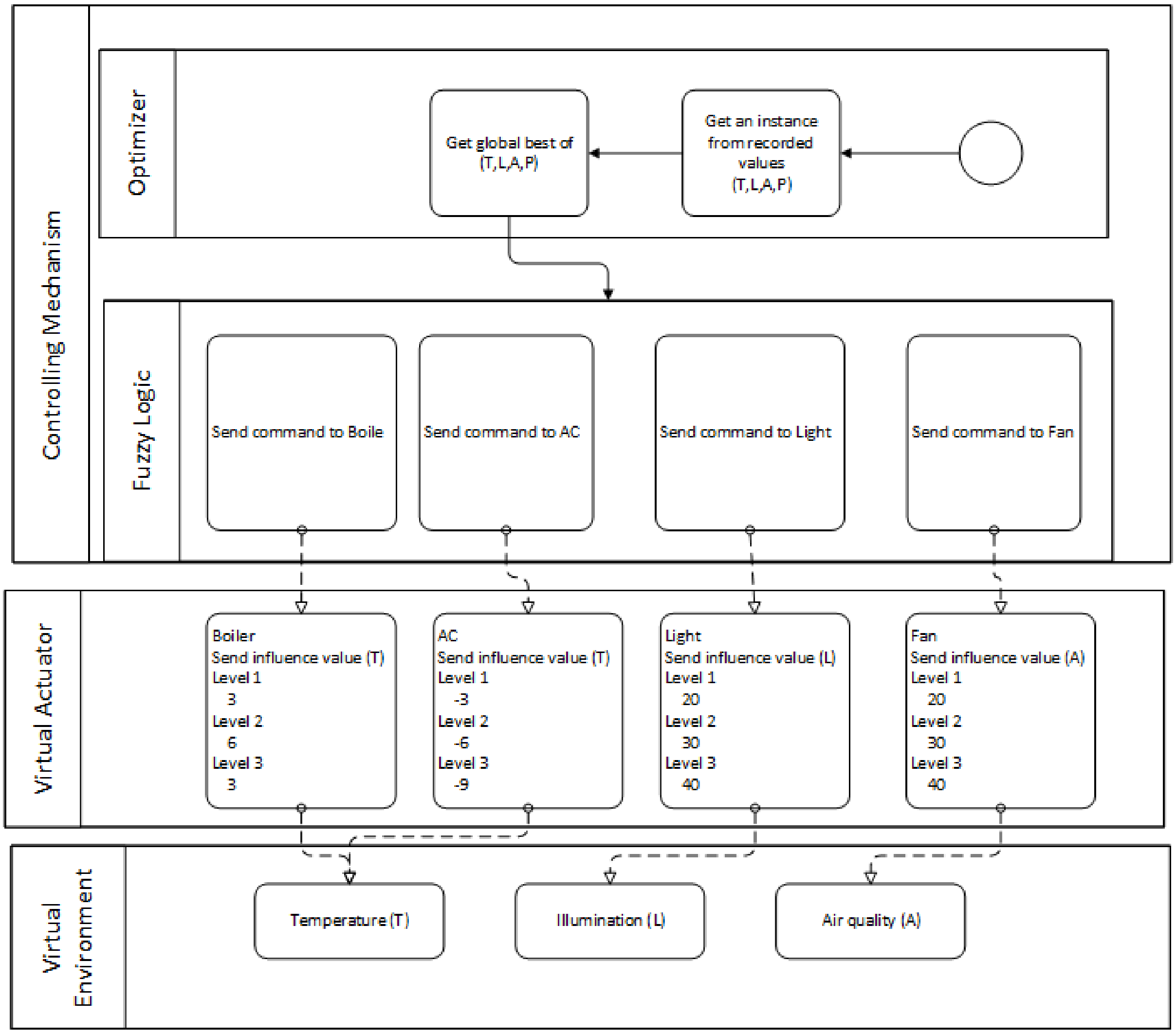

Figure 3. Flowchart of optimization and controlling

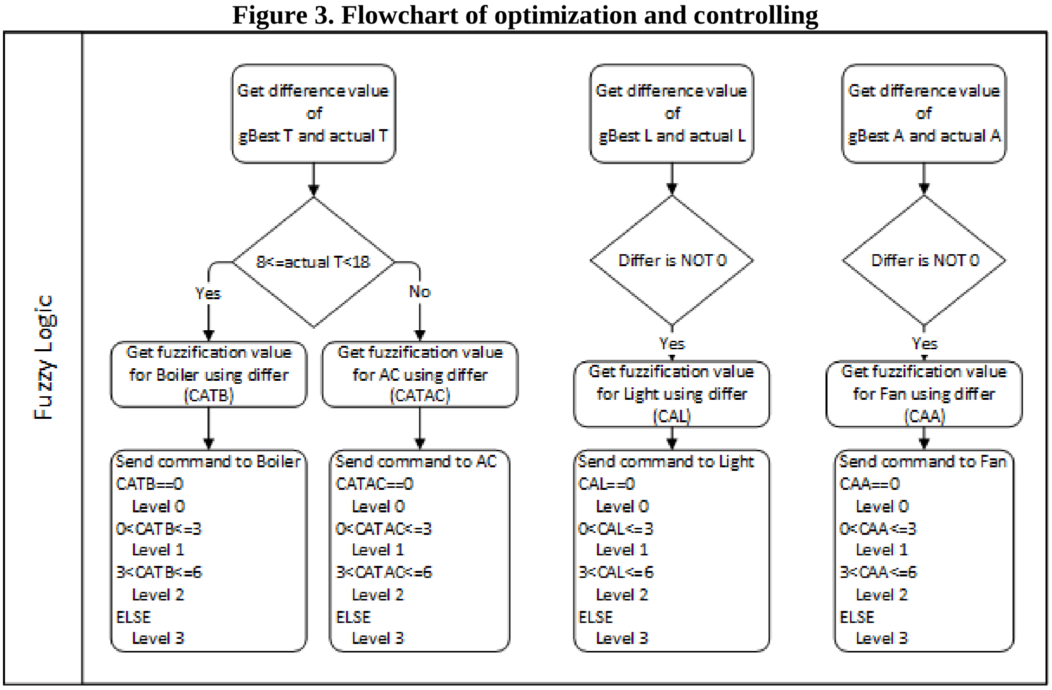

Figure 4. Flowchart of fuzzy based controlling process using user-defined set points

Figure 4 shows the flowchart of fuzzy based controlling process using user-defined set points. Once the comfort index is calculated, the optimal values of environment parameters are collected. Then the system can get the controlling factors through the fuzzy inference system for controlling the actuators. The values are included the messages which are used for controlling actuators.

The range of each controlling levels are defined by the user. For example, the defined range for controlling a boiler, the parameter set point 1 and set point 2 shall be defined by the user.

III. RESULT AND DISCUSSION

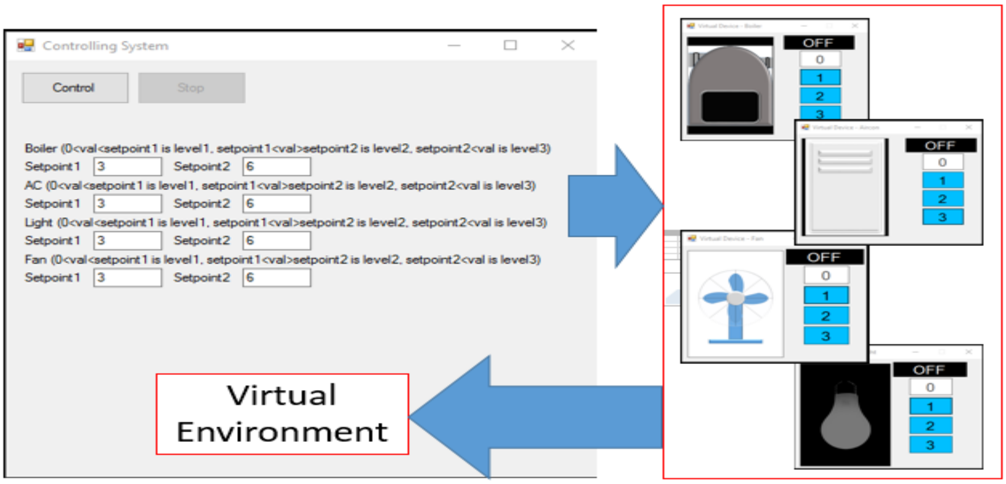

Figure 5. Implementation result for the proposed mechanism

For applying the proposed controlling mechanism using Fuzzy logic, the virtual environment including actuators is implemented. Figure 5 shows the simulation of a virtual environment that includes the environment simulator and actuator simulators. The applications are developed in c# using dot net framework. The virtual environment includes air conditioner, boiler, fan and light for environmental parameters. Each actuator is a standalone application that includes the socket for communicating with the virtual environment simulator.

The application of the virtual environment is a socket server that receives the message from the actuators for changing the environment parameters including air quality data, illumination data, and temperature data. The function of optimization and fuzzy inference system are included in this application to generates controlling factors for the actuators. The system is started with the user-defined set points to control the actuators for making comfort environment. The user-defined set points are used for range controlling levels for each actuator.

```
MamdaniFuzzyRule rule1 = fsOpTmp.ParseRule("if (eOpTmp is Small) then (OpTmpPower is Slow)");
MamdaniFuzzyRule rule2 = fsOpTmp.ParseRule("if (eOpTmp is Normal) then (OpTmpPower is Middle)");
MamdaniFuzzyRule rule3 = fsOpTmp.ParseRule("if (eOpTmp is Big) then (OpTmpPower is High)");
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Figure 6. Membership function of Mamdani fuzzy inference system using c# code

Figure 6 shows the implementation code for the membership function of Mamdani fuzzy inference system. The application is developed using c# with dot net framework. The presented code is the part of the virtual environment system. The outputs of PSO are the input of fuzzy function to get the factors to control actuators. The code defines the membership functions for controlling temperature through the boiler and air conditioner.The implementation of optimizer for the optimizing the comfort index in the virtual environment system is included the application. The presented code is the part of virtual environment system that is developed in c# using Dot net framework. The input of optimizer are values for air quality, illumination, and temperature, which are collected from the virtual environment.

Optimal values and the real values for each environment parameters are recorded by the proposed system. The power consumptions for each virtual actuator are recorded by the simulators. The power consumptions are calculated by the multiplying of controlling factors with 77.7. The controlling factors are the sending values to the virtual environment. For example, the fan is required to send 20 for level 1 then the controlling factor is 20.

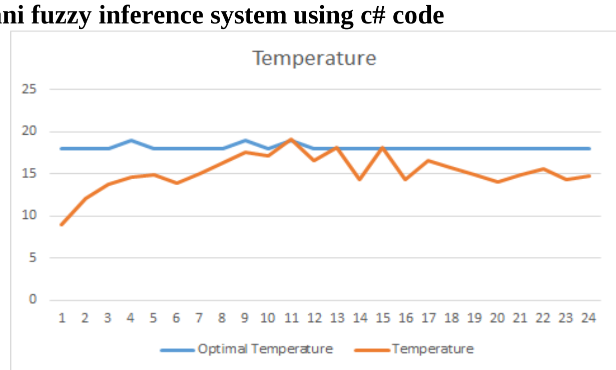

Figure 7. Temperature values of optimal versus real

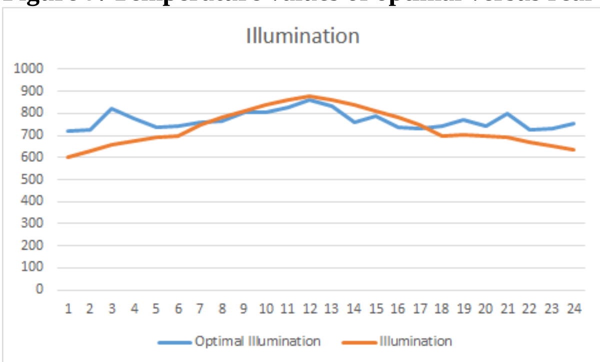

Figure 8. Illumination values of optimal versus real

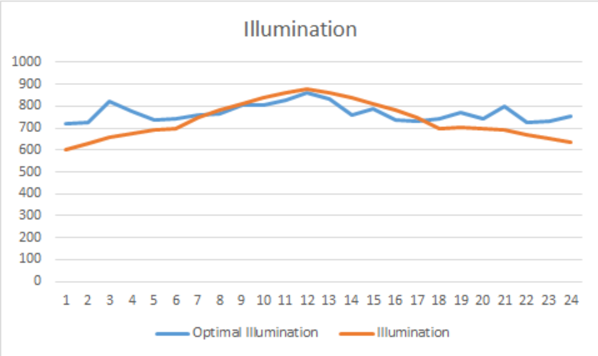

Figure 9. Air quality values of optimal versus real

Figure 7, 8, 9 shows the values of temperature, illumination and air quality which are generated in the virtual environment for 24 hours. The blue line illustrates the optimal values and orange line illustrates real values.

Figure 10 shows the power consumption of actuators which are developed for changing the virtual environment parameters. Those actuators are simulators which communicate with the virtual environment using the socket. The power consumptions are collected by each simulator. Those actuators are controlled by the virtual environment application which includes the optimizer and fuzzy inference to make decisions for controlling levels.

The air conditioner is used for decreasing the temperature value in the virtual environment. It has 3 levels which is controlled by the controlling system. As shown as the figure, it has not been turned on without 11th, 13th and 15th. The boiler is used for increasing the temperature value, which has 3 levels which are controlled by the controlling system. It has 3 levels which are controlled by the controlling system. As shown as the figure it has been turned on without 11th, 13th and 15th. The air conditioner and boiler affect the temperature index of virtual environment. The light is used for increasing the illumination value which has 3 levels which is controlled by the controlling system. The fan is used for increasing the air quality value, which has 3 levels which is controlled by the controlling system.

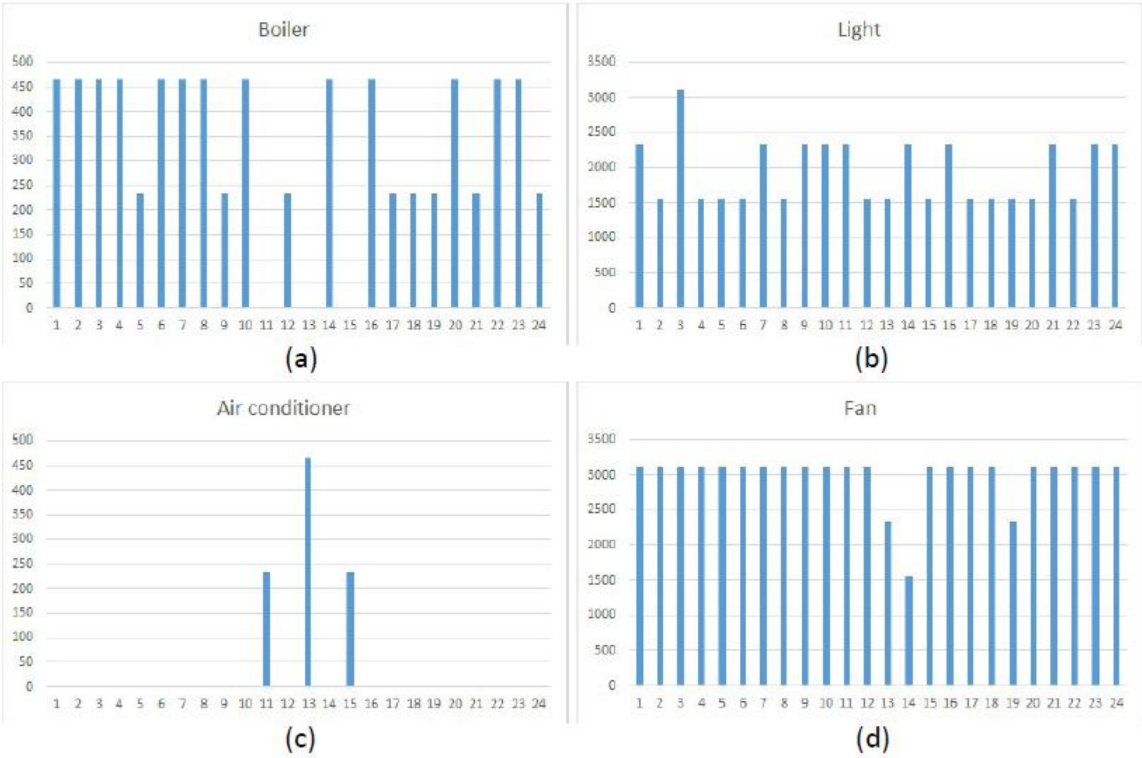

Figure 10. Power consumptions of actuators. (a) Simulator of boiler. (b) Simulator of light. (c) Simulator of air conditioner. (d) Simulator of fan.

IV. CONCLUSION

In this paper, we propose the real-time controlling mechanism using the optimization and fuzzy inference. The proposed approach uses comfort formula to get optimized environment values and get controlling values using the fuzzy logic. In the PSO based optimizer, initial velocities are sat as a position with randomly, and the fitness function is comfort formula. The weight is randomly generated value between 0 and 2, the c1 and c2 both are 2 and the criteria is the iteration loop as 30 times. The factors for controlling the actuators to change current environment parameters are generated based on outputs of the optimizer which are the optimal values in the virtual environment. The user-defined set point is used for ranging the membership functions of Mamdani fuzzy inference to control the actuators.

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