Agent Based Modeling of Smart Grids in Smart Cities

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Abstract. The goal of the study is to explore Smart Grids with a system of multi-agents and aspects related to the Internet. Smart cities are created at a high level of information and communication technologies (ICT) structures capable of transmitting energy, information flows multidirectional and linking another sector that includes mobility, energy, social and economic. Smart cities concern the connection of subsystems, the exchange and evaluation of data, as well as ensuring the quality of life and meeting the needs of citizens. We have different models of transport systems, energy optimization, street lighting systems, building management systems, urban transport optimization, but these models are currently being considered separately. In this article, we present an overview of the concept of an intelligent city and discuss why multi-agent systems are the right tool for modeling intelligent cities. This article represents simulation results with a Smart Grid as a case study of Smart City.

Keywords: Smart grid · Smart City · Multi-agents · Agent based modeling

1 Introduction

The development of Smart City is now directly related to the concept of energy and energy potential. Energy to a greater or lesser extent has always been the locomotive of urban development, but it is quite obvious that, with the advent of the Smart City concept, its role is constantly increasing. Mankind has faced a serious challenge. The population of the earth is growing steadily, while the specific consumption of energy per capita is increasing, all the more so because the reserves of the main energy source (organic fuel) are steadily falling. From the fact whether alternative sources of energy will be found, and also on how effectively society will use energy, the prospects for sustainable development of modern civilization depend. In this regard, energy efficiency and energy saving is one of the priority areas of Smart City.

In recent years in the West in the electric power industry the concept of Smart Grid (smart/intelligent networks) is developing very actively. First of all, it covers

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transmission and distribution, but it has something to do with generation. The term Smart Grid became known from the middle of the 2000s and immediately became so popular that it overgrew many different properties and meanings. Now it is very capacious, not without a hint of marketing brilliance, a term that is also interpreted differently in different parts of the world. It is rather a kind of vision of what the future of the electric power industry should become, its new innovative model, which in many respects differs from the modern one both by the principles of functioning and by the technological basis.

"Smart grids" refer to "breakthrough" technologies and innovations. Like classic breakthrough technologies and innovations [1, 2], they are able not only to significantly change the technical and technological basis of the industry, but also the markets, the composition and roles of the subjects, the fundamentals of the economy of the electric power industry. Their potential influence on the markets of energy carriers, auto-billet building, information and communication technologies (ICT) and electrical engineering is also significant, mainly due to new opportunities for the development of renewable energy sources (RES) and electric vehicles, the formation of complex intellectual infrastructures based on advanced software and hardware solutions. In addition, the long-term functionality of smart networks in the field of reliability and quality of electricity is fundamentally important for the development of a high-tech industry and a sector of high technology services.

The value of technology is confirmed by the scale (40–70 billion US dollars in 2012–2014) and rapid growth (average annual growth rates for the next decade - up to 20%) of smart grid markets [3, 4]. According to the estimates of the International Energy Agency, during 2014–2035, the volume of investment in intellectual solutions can range from 340 billion to about 1.17 trillion US dollars (in 2012 prices, the scenario "New Energy") [5].

2 Background

2.1 Smart Grid

The concept of "Smart grid" or "intellectual network" does not have a clear definition. It can be defined as a concept for the modernization of energy systems by integrating electrical and information technology. However, to determine the concept of "intelligent network" it is better to use the capabilities and performance of the network instead of certain technologies. Typically, an intelligent network means an increase in the degree of auto-matting and a gradual upgrade of the electrical networks of many owners for the transmission and distribution of electricity with traditional distributed and especially renewable generation units and batteries connected to the point of consumption. The same customer can be both a producer and an energy consumer. This requires a two-way flow of energy both at the junction point and in other parts of the supply grid.

In the developing DOE8 (U.S. Department of Energy) [6] concept of Smart Grid, the diversity of requirements is reduced to a group of so-called key goals (key goals) of the new electric power industry, formulated as:

availability - providing consumers with electricity without restrictions, depending on when and where they need it, and depending on its quality paid by the consumer;
reliability - the ability to withstand physical and informational negative impacts without total disconnections or high costs for restoration work, the fastest recovery (self-recovery) of operability;
economy - optimization of tariffs for electric energy for consumers and reduction of system-wide costs;
efficiency - maximizing the effectiveness of the use of all types of resources, technologies and equipment in the production, transmission, distribution and consumption of electricity;
organic nature of interaction with the environment - maximum possible reduction of negative environmental impacts;
safety - prevention of situations in the electric power industry that are dangerous for people and the environment.

In the European Union, among the key values are [7]:

flexibility in terms of response to changes in consumer needs and emerging problems with electricity supply;
availability of electricity for consumers, in particular renewable energy sources and high-efficiency local generation with zero or low emissions;
reliability of electricity supply and quality of electricity while providing immunity to hazards and uncertainties;
economy through the introduction of innovation, effective management, rational combination of competition and regulation [8].

2.2 Microgrid

The wide interest in renewable energy sources presents new challenges. Placing generating capacities (solar, wind, based on heat exchange or combining electricity and heating) in close proximity to the consumer requires a completely new approach to managing the electricity grid. One of the new approaches is the MicroGrid concept. Microgrid, in a simplified form, is considered as a physically distributed structure, which is characterized by the following features:

– the fulfillment of the main task
– life support or production process;
– Power Supplies
– Distributed (decentralized) production of electric energy, including renewable energy sources [9];
– territorial limitation-the concentration of all electrical devices in a user-defined area;
– human presence
– a user or an expert (a microgrid manager) who can make adjustments to the management functions of individual subsystems or the entire facility [10].

The desire to create the most comfortable conditions for a person has led to a high degree of saturation of microgrid electrotechnical, electronic and other technical devices and systems, control and regulation of operating parameters is carried out by specialized control systems. The microgrid control system is an information and intelligence system that integrates information coming from a variety of heterogeneous microgrid components, such as: alternative power supplies, loads, sensors and characterized by different types of physical data. Such a system is created to control energy resources taking into account the user's wishes.

3 Proposed Architecture

The architecture of our control system of the energy and network systems of the building is illustrated in Fig. 1. In our study, we consider the Smart and Micro Grid system for building energy management based on multiagent technologies. The system consists of three types of agents. The first control system is a grid system that is responsible for connecting to the Utility Grid and Microgrid, which is controlled by the Switch State Agent, Fig. 1. Next level of the building energy management system (BEMS) is the Multiagent system. There are different types of agents that are used to manage the entire system. Another part of the system is the Management system, that is responsible for the management of HVAC, grid control and electrical lighting.

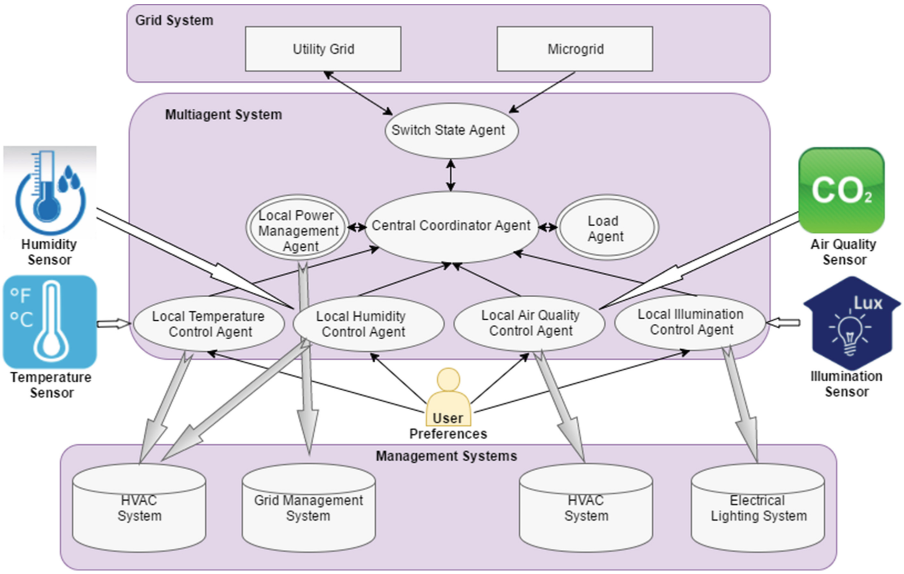

Fig. 1. Architecture of the proposed multi-agent control and management system.

In our study, we consider two types of energy sources: a utility grid and a microgrid. The utility grid takes energy from the main grid of the city. Microenvironments are supplied with renewable energy sources. The second part of the system is a multiagent system. Since each agent assumes a high level of intelligence for making a local solution, the system requires a new architecture of the agent model. The multi-agent system takes data from sensors and passengers as input data and decides on the introduction of control over the drives. Control systems are the systems that must be controlled and supplied with comfort and energy.

The sensors are distributed throughout the building to monitor its operation. Three types of data, including environmental, user settings and energy data, can be obtained from the sensor network. Environmental data refers to the environmental parameters of the building, such as indoor and outdoor temperatures, light levels, CO2 concentration or even the detection of intrusion or fire alarm signals. The filling data usually includes the number of passengers and the presence or absence of passengers. The energy data is mainly focused on the status of energy supply, such as the state of the utility network, the price of electricity and the availability of renewable resources. These measured data will be used by various local agents to determine their behavior.

To realize an effective, user-oriented control over the building system, another important element for the multi-agent system is the passenger behavior model. Personal agents in the multi-agent system are designed to study and predict the preferences of residents through their behavior. Studying of preferences of inhabitants is carried out by observation of their behavior and definition of the person who has carried out these actions. By providing the identity of a particular user to a personal agent and respecting his behavior, the personal agent will be able to find out the preferences of this particular user, rather than all the residents of the building.

The central coordinator-agent is the coordination of all agents and the built-in optimizer to maximize the composite comfort index, which can be determined in several ways based on the specific needs of the clients. In this study, we define the terms “general comfort index”, “comfort index”, “comfort level” and their ratio from the point of view of the mathematical model.

Based on this information, the central agent manages the regional agents to distribute the available capacity in the area of the building in which comfort is provided. Regional agents turn control over local agents. Consider the assessment of comfort in buildings and zones based on the index of comfort (CI) [11] and general comfort (OC) [12]. These figures can range from 0 to 1 and record information about temperature, light and CO2 concentrations in the building zones. The comfort index CI characterizes the internal environment of certain sections of the building and is determined by the method of combining comfort information using the average level of ordered aggregates. Mathematically, comfort index can be written as:

$$CI = OWA(\delta_T, \delta_H, \delta_L, \delta_A) = \sum_{j=1}^{n} \omega_j b_j \quad (1)$$

where OWA is an ordered weighted average,
$\delta_T, \delta_H, \delta_L, \delta_A$ are the parameters that construct comfort level for inhabitants. In our case comfort parameters are temperature, humidity, lighting, and air quality into the indoor environment;
ω_j is corresponding comfort index; $\omega_j \in [0, 1]$

Formula 2 computes comfort level of the people depending of four comfort parameters.

$$Comfort\ Level = \delta_T\left(1-\left(\frac{e_T}{T_{set}}\right)^2\right)+\delta_H\left(1-\left(\frac{e_H}{H_{set}}\right)^2\right)+\delta_L\left(1-\left(\frac{e_L}{L_{set}}\right)^2\right)+\delta_A\left(1-\left(\frac{e_A}{A_{set}}\right)^2\right) \quad (2)$$

Here, $T_{set}, H_{set}, L_{set}, A_{set}$ – temperature set, humidity set, luminance set and air quality set, respectively.

e_T, e_H, e_L, e_A – Temperature error, humidity error, luminance error, and air quality measuring error, respectively.

$\delta_T, \delta_H, \delta_L, \delta_A$ – Parameters that construct comfort level for inhabitants.

4 Experiment Results

In this case study, we will consider the utility grid mode. Carrying out experiments with the mode used and measuring the required power, we can further predict the ability of the micro network to supply the building with energy.

In the simulation, the comfort ranges of residents for various management tasks are set in the illumination range from 750 to 880 (lux), air quality ranges from 400 to 8,800 parts per million, and temperature and humidity ranges are based on international European standards and ISO recommendations/FDIS 7730 [13] (Fig. 2). These comfort

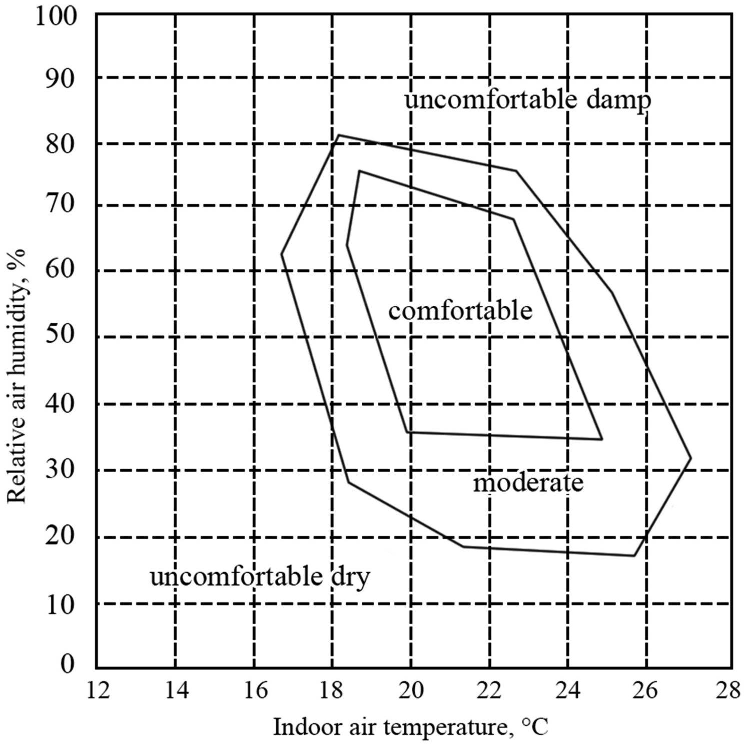

Fig. 2. Comfort data of the premises, given based on international European standards and recommendations ISO 7730 [13].

ranges serve as limiting constraints in the stochastic multipurpose genetic optimization algorithm to optimize the optimal setting of the given points at each time step. The set points for each comfort parameter are set in Tset = 22 oC, RH = 50%, Lset = 800 lux and AQset = 800 ppm, and the same weight factor for each comfort parameter is set to one fourth (1/4).

Figure 4 demonstrates comparisons of conventional system and our proposed system for comfort temperature into the room. As illustrated in the figure, temperature changes of the proposed system belong between 21 and 25.5 °C, while temperature of the conventional system went out of the comfort area with the indexes between 26 °C and 29 °C, most of the explored time (Fig. 3).

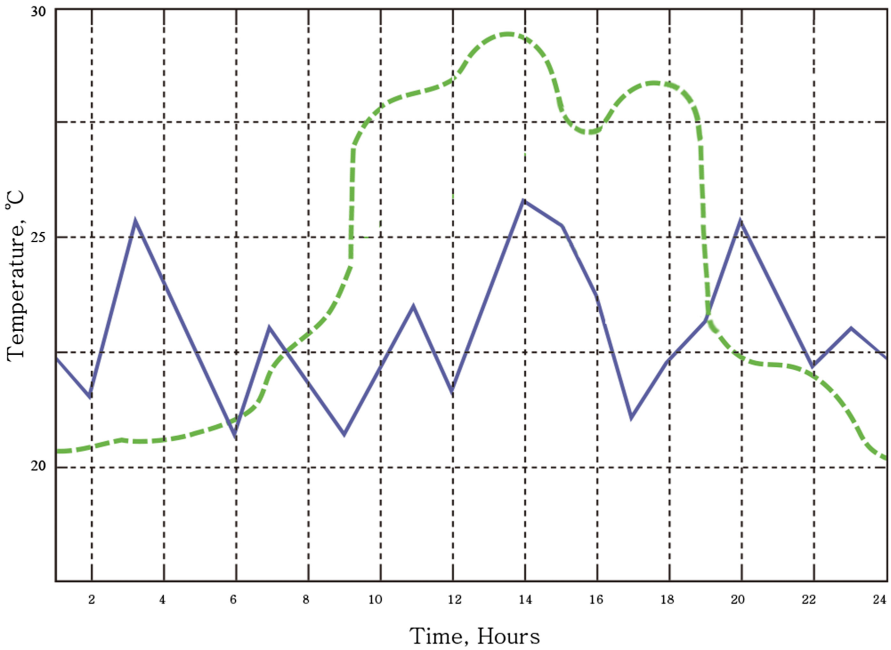

Fig. 3. Temperature set points comparison (Blue line: temperature changes using our approach; Green line: casual temperature changes;) (Color figure online)

Figure 4 demonstrates the humidity changes by applying two different systems as a conventional and the proposed system. There, we can observe that, the proposed system humidity changes between 30% and 40%, when a conventional system shows a very dry microclimate.

Results of the experiment with indoor illumination level were given in Fig. 5. The proposed system gives much more comfort illumination level comparing the conventional lighting level. Also, the figure shows, that it easier to control illumination level than the other comfort parameters.

Figure 6 illustrates air quality level of indoor environment when using the two different systems. In our study, we consider CO2 level as an indicator of air quality.

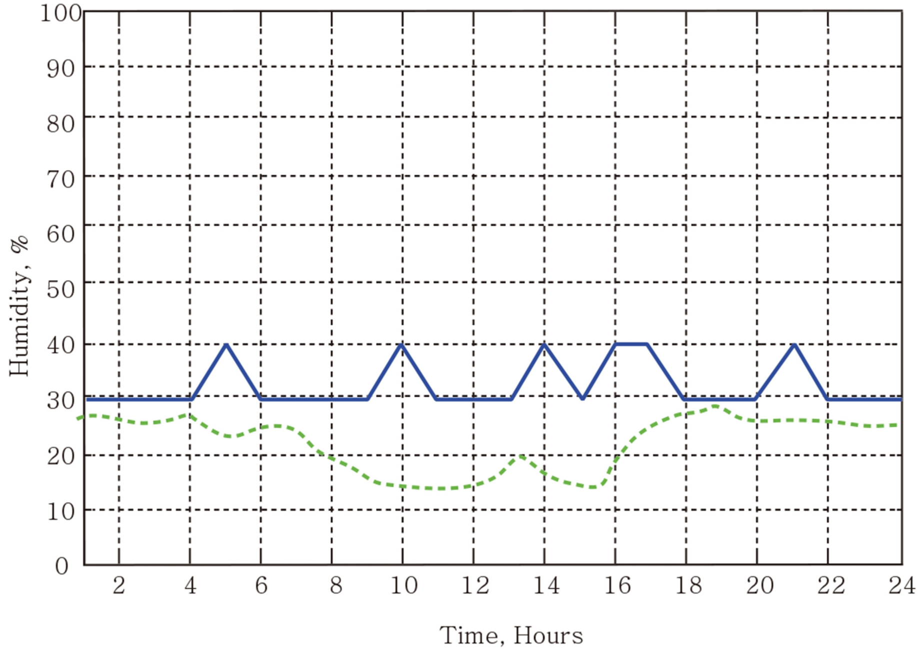

Fig. 4. Humidity set points comparison (Blue line: temperature changes using our approach; Green line: casual temperature changes;) (Color figure online)

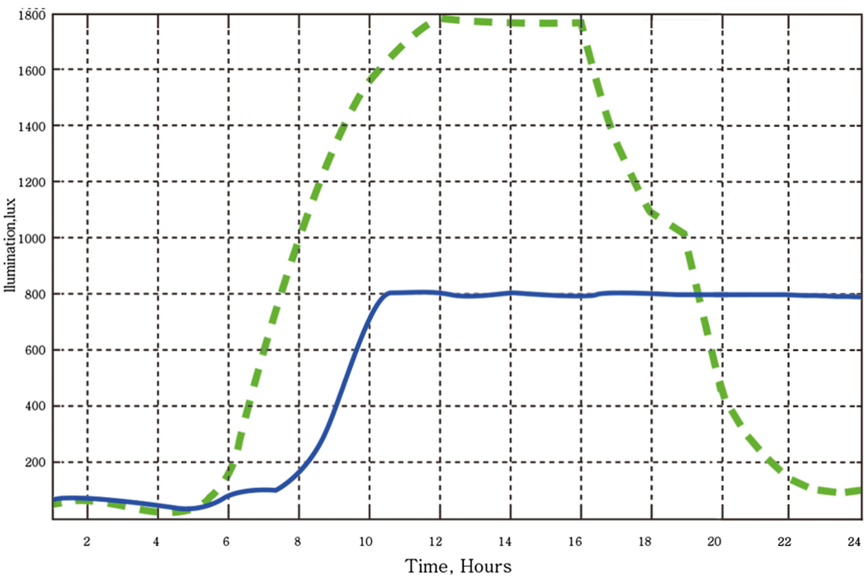

Fig. 5. Illumination set points comparison (Blue line: illumination using our approach; Green line: casual illumination;) (Color figure online)

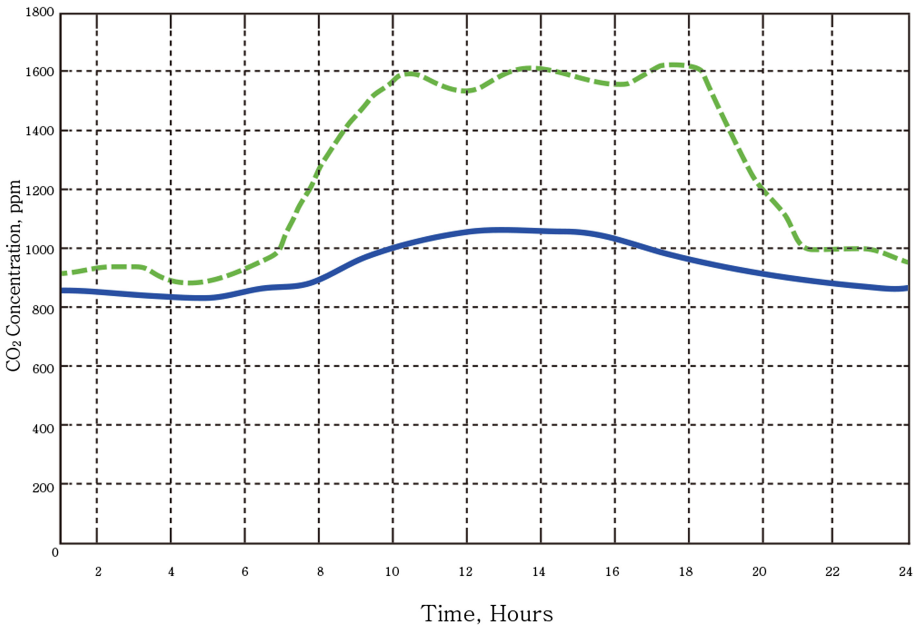

Fig. 6. Carbon dioxide set points comparison (Blue line: carbon dioxide level using our approach; Green line: carbon dioxide level using conventional system;) (Color figure online)

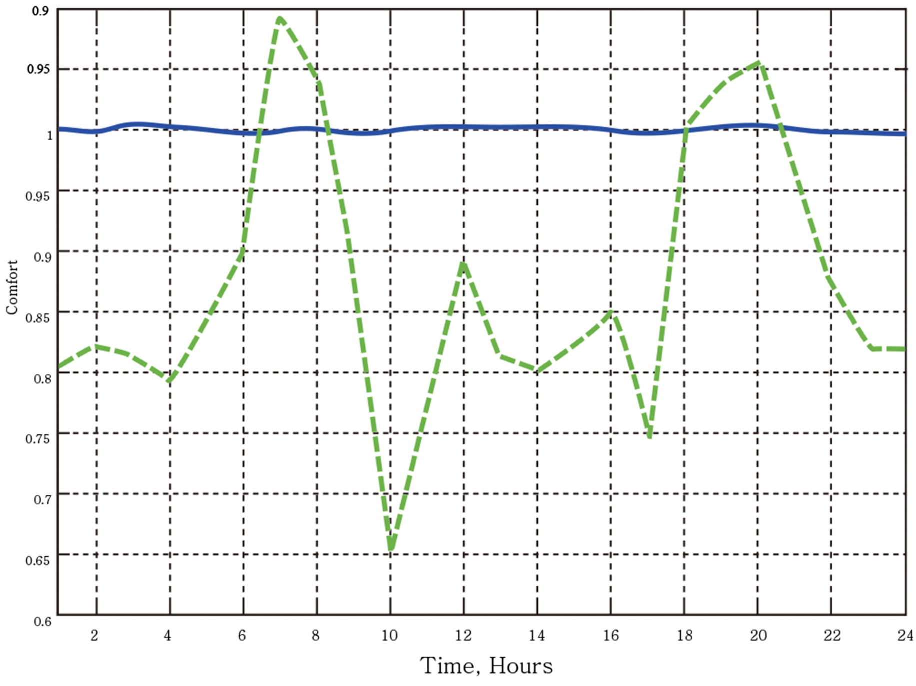

Fig. 7. User comfort level set points comparison (Blue line: user comfort level using our approach; Green line: user comfort level using conventional system;) (Color figure online)

When using our system we kept the indoor air quality index in acceptable level, while the conventional system shows worse result. It can be explained that, by increasing the people in the room, CO2 level will increase and it needs control every time and immediately react for changing the air quality level. In the conventional systems does not control the CO2 level, and, in most cases, people are not able to estimate air quality level into the room. For this reason, CO2 level should be controlled by the system.

Figure 7 shows the comfort level into the room considering all the parameters. The results demonstrate that the proposed system comfort level is over 1 that means, comfort for the people. Conventional system comfort level changes between 0.65 and 1, while most of the experienced time less than 0.9.

Figure 8 demonstrates power expenditure comparison of the two systems. There, we can observe that, the proposed system shows less power consumption comparing the conventional system excluding 8.00 to 10.00, even that time, the proposed system does not spend more energy that the conventional system. Spending more energy between 8.00 to 10.00 can be explained with the proof that, the given time is start of working day, and all the heating, ventilation and air conditioning systems starts to preparing ensure the comfort microclimate. After, they continue working in normal mode.

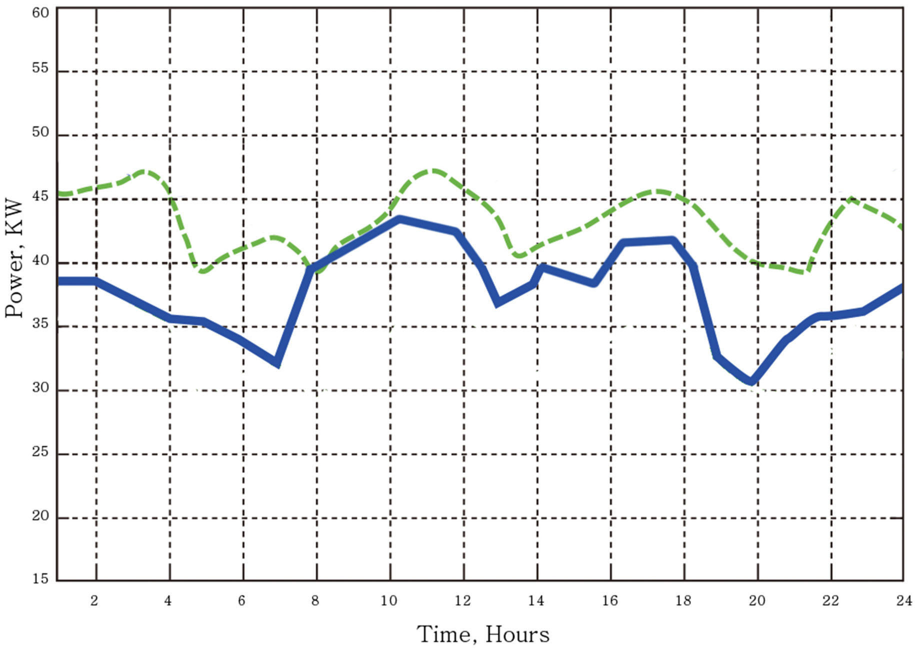

Fig. 8. Power expenditure comparison of two systems (Blue line: power consumption using our approach; Green line: conventional system power consumption) (Color figure online)

5 Conclusion

This study developed an intelligent multi-agent energy management and management system with heuristic optimization, and it was shown that it is capable of achieving management objectives by coordinating several agents and an optimizer. The proposed structure of the multiagent based smart grid system can optimize basic tools to achieve energy efficiency, providing thermal comfort in the room. In the future, we intend to improve the proposed model by applying algorithms of machine learning and using the training agent to make decisions based on controlled learning.

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