Sustainable Cities and Society 13 (2014) 41–45

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Stochastic optimized intelligent controller for smart energy efficient buildings

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A R T I C L E I N F O

Keywords:
Smart building
Energy management
Stochastic optimization

A B S T R A C T

Smart buildings are rising concept for energy resource management in the buildings to reduce energy consumption and wastage. Energy management and control system comprises of variety of technologies, which affect human working comfort. The challenging task of the building control is to achieve interior building environment comfort with high-energy efficiency. In this study, multi-agent control system has been developed in combination with stochastic optimization using genetic algorithm (GA). The corresponding simulations of effective management of energy and consumer comfort are presented. The developed control system provides significant improvement in energy consumption and interior environmental comfort in smart buildings.

1. Introduction

The increasing demand for energy and the requirement of environmental comfort in the interior of intelligent buildings is an open multi-facet problem. The human's productivity, morale and satisfaction are largely affected with the well-being of comforts in the building. Buildings annually around the world (Benjamin, Julien, Stephane, & Monique, 2011) consume about 45% of the primary energy. The progressive reduction of fossil resources has raised the awareness to decrease energy consumption and utilize more sustainable resources. Energy efficiency and management has become essential for intelligent buildings to meet the requirement of reduced energy consumption and improved comfort index. There are three basic comfort factors such as thermal, visual and air quality, which determine the inhabitants' quality of living in buildings (Dounis & Caraiscos, 2009). The temperature, illumination levels and CO_2 concentration are used to specify the above factors respectively. The physical environment control employs ancillary heating and cooling system, lighting fixtures, and ventilator systems as actuators.

The intelligent control system is intended to minimize total energy consumption, thus to make effective use of limited energy resources to meet the inhabitant's comfort demand. The prime function of a building energy management system is to provide service to its occupants and plays a vital role in the design of the control system. The distributed control structure has been employed for simplicity and effective control of each subsystem. It also coordinates efficiently to solve possible conflicts and achieve control goal (Yang & Wang, 2012) designed a controller with multi-agents in order to manage energy demand in buildings with distributed subsystems and deployed agents for controlling and coordinating among subsystems. This intelligent controller considers these agents with a certain degree of intelligence, including capability to respond the changes in environment, autonomy, and communicating effectively (Jiang, 2006; Pipattanasomporn, Feroze, & Rahman, 2009). The preceding studies conducted in developing Multi-Agent Systems for Building cOntrol (MASBO) (Liu, Nakata, & Harty, 2010). The interaction between the users and spaces in the building control system employed semiotic organization methods. The framework of building control consists of distributed agents to learn and adapt consumer's activities and requirements for decision-making. It employed central agent, local agent, personal agent, and monitor and control agent for building management system for personalized control of a space. An Epistemic, Deontic and Axiological (EDA) knowledge based model permits the agent to make informed decisions. Liu's work addresses personalized control through pervasive monitoring of human behaviors (Wang, Wang, & Yang, 2012; Wang, Yang, & Wang, 2011) proposed multi-agent controller structure to manage energy consumption and occupants comfort. It employed particle swarm optimization (PSO) at the central agent to observe the trade-off solutions for informed decision-making. Yang et al. (2011) reported graphical

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http://dx.doi.org/10.1016/j.scs.2014.04.005
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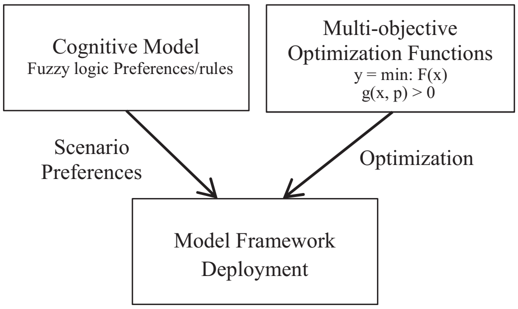

Fig. 1. Entire system framework.

user interface (GUI) for user has to manage building operations and comforts.

But the overall comfort including all three comfort factors is not negligible and needs to be further investigated. In Dounis and Caraiscos (2007), a 3D fuzzy model was developed to represent the overall comfort considering all the three comfort factors. This model provided a possible approach to model the human decision-making, but it did not consider how to properly combine the three comfort factors. The proposed system employs a new overall comfort index model by appropriately combining multiple comfort factors including temperature, illumination level and CO_2 concentration. Moreover, particle swarm optimization is utilized in the proposed control system to find the optimal set points according to customer preferences and outdoor environmental information.

In present study, the decentralized control system has been developed for achieving balance between the energy consumption and wellbeing interior environmental conditions. This control system helps to develop the functions for energy consumption of the actuator system. It also devises the scheme for energy distribution in order to achieve maximum possible comfort. In addition, the control system has also been embedded with an evolutionary genetic algorithm for optimizing energy management of the buildings. Thus, the control system initializes both maximum interior comfort and minimum energy consumption objectives.

2. System framework model

The whole system framework of intelligent building employing an intellectual fuzzy model as multi-agent technology with heuristic multi-objective algorithm, used to control the comfort index and to manage energy dispatch in building depicted in Fig. 1. The detailed system architecture is shown in Fig. 2 illustrates a multi-agent control system. This classifies into two levels, the lower level is termed as sub-ordinate agents and upper level called as supervisor agent controller.

The main task of supervisor controller is to balance power supply and the customer demand in buildings. It also utilizes customer preferences and outdoor information. Whereas, the sub-ordinate controllers are employed to control the indoor building temperature, air quality and illumination levels (Dounis & Caraiscos, 2007). The supervisor generates the signal to determine the activity of lower level agents. The responsibility of supervisor agent is to coordinate each sub-ordinate agent incorporating consumer preferences and collaborate with optimizer in order to maximize occupants comfort rapidly. The interactions of the hierarchical agents utilize two communication modes (Wang, Dounis, Wang, & Yang, 2011; Wang, Yang, et al., 2011), classified as direct and indirect modes. The important information from agents has been send to the database and returned to agents after processing to make actions accordingly. The communication system demand in very less time and thus online monitoring and control could be achieved.

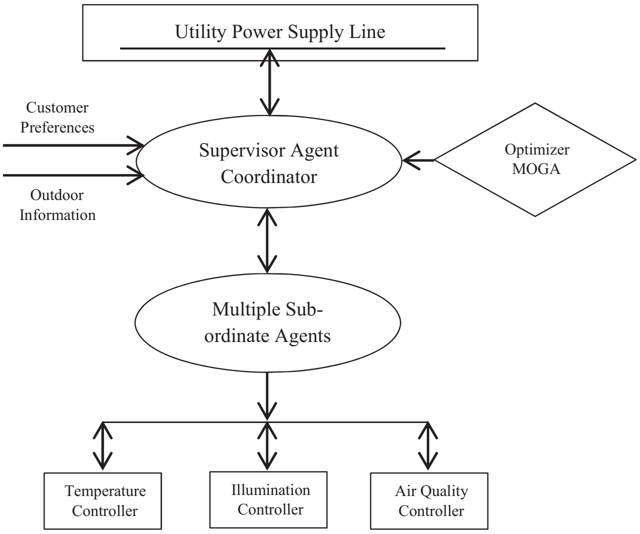

Fig. 2. Detailed architecture of multi-agent control system.

2.1. Supervisory controller agent

The supervisor agent has been employed to communicate with the occupant's and the utility supply, to take actions for the building control accordingly. The user interface can be aligned for the configuration of user preferences and the visualization of entire operation status in the building. In order to communicate with sub-ordinate controllers, the principal coordinating agent receives updates about interior environmental factors and the power demand for each decentralized control task. This agent computes the interior comfort demand based on the received information. The comfort function is defined in Yang and Wang (2012) and is the overall comfort in the building, constituted in the range of [0, 1] as follows:

$$Comfort = \partial_1\left[1-\left(\frac{e_{Thermal}}{Temp_{set}}\right)^2\right]+\partial_2\left[1-\left(\frac{e_{lux}}{Lux_{set}}\right)^2\right]+\partial_3\left[1-\left(\frac{e_{CO_2}}{AQ_{set}}\right)^2\right] \tag{1}$$

$$Overall\ \ comfort=\sum_{i=1}^{n} w_i\cdot comfort_i \tag{2}$$

The prime control goal is to maximize comfort under variable operating conditions. ∂_1, ∂_2 and ∂_3 are the consumer defined weighting coefficients of importance. They are in the range of [0, 1] and is generally expressed as $\partial_1+\partial_2+\partial_3=1$. Whereas, $Temp_{set}$, Lux_{set} and AQ_{set} are the set points of temperature, illumination and indoor air quality respectively. The user preferences and adaptive rules, which reflect the human behavior pattern to determine three set points. $e_{Thermal}$, e_{lux} and e_{CO_2} are the differences between the measured and set point values of the each comfort demand factors. Whereas, w_i is the weighting co-efficient for each comfort parameter and "n" is the number of comfort parameters and in our case these are three (thermal, visual and air quality comfort).

The power requirement function will be computed at the local control level, but as the demand rises by the individual agents. The