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Multi-zone building energy management using intelligent control and optimization

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ABSTRACT

Intelligent buildings are a trend of next-generation's buildings, which facilitate intelligent control of the building to fulfill occupants' comfort demands. The primary objective in building control is to achieve a comfortable building environment with high energy efficiency. By dividing the whole building into several zones, a multi-zone building model is built for developing an effective energy management scheme. This study proposes a multi-agent control system coupled with an intelligent optimizer for intelligent building control. Particle swarm optimization (PSO) is utilized to optimize the building energy management by enhancing the intelligence of the multi-zone building during its operations. A case study of multi-zone building control is carried out and the corresponding simulation results are presented in this paper.

1. Introduction

Intelligent buildings are a type of novel buildings which use advanced computer technologies to effectively control the building facilities and provide a productive and cost-effective environment (Sharples, Callaghan, & Clarke, 1999). The main objectives in intelligent building designs are to increase satisfaction of occupants and reduce the energy consumption (Clements-Croome, 2004). Intelligent buildings create a comfortable and productive environment for occupants and improve the operational energy-efficiency. Designing an intelligent building demands a careful consideration of environmental factors that may affect occupants' comfort, well-being and productivity (Duangsuwan & Kecheng, 2008). Thermal comfort, visual comfort, and indoor air quality (IAQ) are the three basic factors that determine the environmental conditions in a building (Dounis & Caraiscos, 2009). Thermal comfort in a room is determined by the indoor temperature and can be measured using temperature sensors. Illumination level can be taken as an index for visual comfort control. Indoor air quality can be improved by the ventilation system and generally the carbon dioxide concentration serves as an index for measuring the IAQ. To monitor and control the entire building energy consumption continuously as well as maintain the occupant's comfort effectively, numerous sensors, actuators and control units can be interconnected together to form actually a real-time sensor network. By employing renewable energy sources, buildings can become environmentally friendly. Such buildings can be seen as micro-grids since distributed generation, distributed storage, and controllable loads are all involved (Jiang, 2006). The overall micro-grid system can be connected to and disconnected from the upstream utility grid according to the current operating condition in order to minimize the disruption to the controllable loads (Hatziargyriou, 2008). The paper will discuss the intelligent control of buildings which are supplied from distributed energy resources when islanded from the utility grid.

In multi-zone building modeling, a building is represented as a network of zones (Tan, & Glicksman, 2005). A zone defines an air volume in which the space shares uniform environmental conditions. In general, each room in a building can be defined as a zone. However, multiple rooms can be combined and considered as one zone if they possess similar environmental conditions; and one space may be divided into several zones if the environmental conditions are not uniform in a space.

In this study, a multi-agent system is designed to control the building facilities in order to achieve a balance between the energy efficiency and occupants' comfort (Logenthiran, Srinivasan, & Wong, 2008). Multi-agent systems are composed of two or more agents. An agent is capable of making decisions autonomously, taking appropriate actions, and interacting with each other to achieve the overall control goal. An intelligent agent has several significant characteristics including pro-activity, reactivity and social ability, so that it is able to act independently while also being able to cooperate with others (Weiss, 1999). This paper presents how the agents cooperate with each other to control the building in an intelligent manner. In addition, particle swarm optimization (PSO) algorithm (Shi & Eberhart, 1998) is embedded in the control system for optimizing the building energy management.

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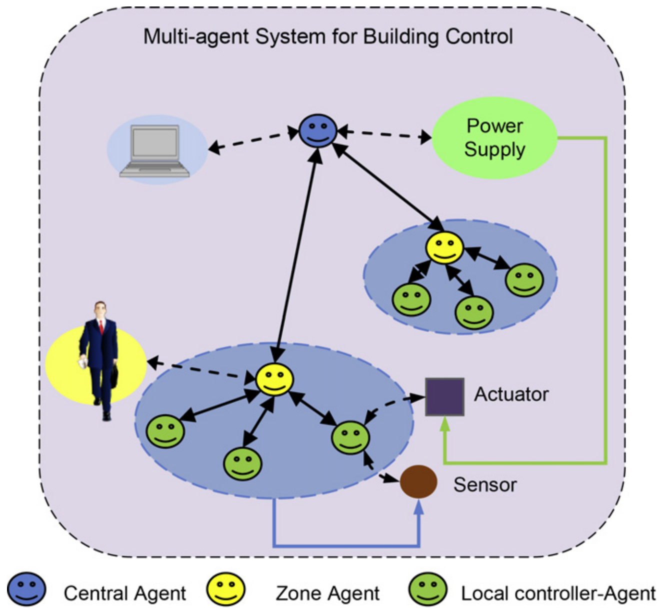

Fig. 1. Multi-agent control architecture.

2. Agent-based system for multi-zone building control

2.1. Agents and the multi-agent system

Agents in a multi-agent system are designed to accomplish complex tasks in a collaborative fashion. In a multi-agent system, to attain the capability of seamless cooperation between agents, they require abilities such as collaboration between individuals, coordination of actions, and resolution of conflicts by themselves (Ferber, 1999; Qiao, Liu, & Guy, 2006). Here collaboration deals with the distribution of tasks and resources among agents. Coordination is concerned about organizing the actions of different agents in time and space. In addition, resolution of conflicts usually requires negotiation techniques to enhance the system's performance.

2.2. Architecture of the designed multi-agent system

The control system for a multi-zone building model mainly focuses on maximizing the occupants' comfort while minimizing the energy consumption. It resolves the conflict between the energy consumption and the occupants' comfort, as well as the conflict between different zones' demands. The system obtains occupant's preference and makes decisions to determine the energy dispatch scheme for all the zones. Fig. 1 shows the designed multi-agent architecture for controlling a multi-zone building. The proposed multi-agent system comprises three types of agents: the central agent, zone agents and local-controller agents.

The central agent has two major functions: communication and decision making. The central agent communicates with the building manager to collect relevant information and helps the manager in monitoring the building operations through a human–computer interface. The central agent also needs to communicate with the zone agents and the energy resources to obtain the status of each zone and power supply for informed decision-making. The central agent makes corresponding decisions based on information collected and sends the decisions back to the zone agents and the building manager.

Each zone agent is responsible for energy management in its specific zone. Zone agent communicates with occupants and determines the amount of power that should be dispatched to each local controller-agent through a suitable control algorithm. In addition, the zone agent collects the environmental parameters from the local controller-agents to analyze the comfort condition of this zone and reports it to the central agent.

In each zone, three types of local controller-agents including local temperature controller-agent, local illumination controller-agent and local air quality controller-agent are utilized to control the thermal comfort, the visual comfort and the IAQ comfort, respectively. They are distributed locally in each zone for monitoring and controlling the building environment through corresponding sensors and actuators, and returning the environmental parameters to the zone agents. To implement control in the physical environment, heaters, air conditioners, electrical lights, blinds, and ventilators are utilized as actuators to control the zone environment.

3. Mathematical model and algorithm for agents

3.1. Central agent

The central agent aims at maximizing the building's overall comfort with a certain amount of energy supplied by the distributed renewable energy sources. Through a human–computer interface, the central agent receives the manager's instruction about each zone's priority, which is mathematically represented as a weighting coefficient. The central agent will make decisions regarding power distribution to each zone. The control objective is to maximize the overall comfort of the building and the control variables are a function of power distributed to each zone $P(i)$. A particle swarm optimizer is integrated into the central agent to optimize the control system. The fitness function is:

$$OverallComfort = \sum_{i=1}^{n} w(i)\,comfort(i) \tag{1}$$

subject to:

$$P(i) \leq Pdemand(i) \quad i = 1, \ldots, n \tag{2}$$

$$\sum_{i=1}^{n} P(i) \leq Pgiven \tag{3}$$

where *OverallComfort* is the overall comfort of the building; n is the number of zones in the building; $w(i)$ is the weighting coefficient for zone i, which is predefined by the building manager and the summation of all the weighting coefficients equals to 1; $comfort(i)$ is the comfort value in zone i, which is provided by each zone agent; $P(i)$ is the power distributed to zone i; $Pdemand(i)$ is the power demand of zone i. *Pgiven* is the available power supply from distributed energy sources.

3.2. Zone agent and local controller-agents

The comfort value of a zone is calculated by its zone agent via analyzing the environmental parameters and the occupants' preferences. The comfort value of zone i is represented as follows (Wang, Yang, & Wang, 2011):

$$comfort_i = \begin{cases} \mu t_i[1-|(T_i - Tset_i)/Tset_i|] + \mu l_i[1-|(L_i - Lset_i)/Lset_i|] + \mu a_i[1-|(A_i - Aset_i)/A_i|] & \text{if } A_i > Aset_i \\ \mu t_i[1-|(T_i - Tset_i)/Tset_i|] + \mu l_i[1-|(L_i - Lset)/Lset_i|] + \mu a_i & \text{if } A_i \leq Aset_i \end{cases} \tag{4}$$