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Design and development of advanced fuzzy logic controllers in smart buildings for institutional buildings in subtropical Queensland

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ABSTRACT

Building management system (BMS) has the ability to monitor and control buildings' mechanical and electrical equipment namely heating, ventilating and air conditioning (HVAC), lighting, power, fire and security systems. BMS can also provide indoor thermal comfort within commercial buildings including industrial and institutional buildings and able to reduce energy consumption. However most of HVAC systems are controlled by using conventional controller whose functions are based on ON/OFF controller and Proportional-Integral-Derivative (PID) controllers. These controllers are not the ultimate solution to save energy because the operations of HVAC systems are nonlinear. Thus, the implementation of fuzzy logic controllers within smart buildings will be more efficient which consequently will save more energy and money. This paper reviews, investigates and evaluates the use of fuzzy logic controller in HVAC systems and light controllers for smart buildings in subtropical Australia as well as highlights the role of technology in saving energy, and its potential. Additionally, it highlights the recent developments in BMS controllers including its conceptual basis, capabilities and limitations.

Contents

1. Introduction

Commercial buildings consume a considerable amount of energy which has a direct impact on the environment. According to Yang et al. [1], heating, ventilation and air conditioning (HVAC) system and lighting system consume 60% of building's total energy and the rest 40% of the energy is consumed in different kinds of equipment depending on the functionality of the building. Australian commercial buildings are characterised by having a poor energetic performing design especially those more than 20 years old. The reason behind that is climate variation, low insulation levels, glazing materials, the presence of air gaps and the usage of expensive cooling techniques. Energy savings can be achieved through several

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ways, such as strict building regulations, better design and the installation of intelligent control and efficient appliances [2–4]; employment of renewable energy [5–7], low energy cooling technologies [8] and co-generation and co-generation coupled with thermal energy storage [9].

Recently, Australian building sectors are entering into a new epoch of change, with a focus to minimize operation cost and environmental impact by minimizing energy, gas emissions and environmental footprint of commercial and residential buildings. Therefore, proper energy management of HVAC systems and the lighting systems will have a significant amount of saved energy as well as maintaining the balance between buildings' energy efficiency and its occupants' comfort. In order to provide a suitable work environment for building occupants, the buildings' HVAC systems must provide thermal comfort level and healthy living environment. The main task of HVAC systems is to maintain indoor optimal comfort standard with minimal energy consumption and minimal negative impact on the environment. Yang et al. [1] reported that the quality of the indoor environment is controlled by four requirements as shown in Fig. 1; they are thermal comfort, indoor air quality (IAQ), lighting comfort and noise protection.

These four factors exclude noise protection and are mainly controlled through building management system (BMS). Building management system (BMS) main subsystems include HVAC, lighting systems, fire and safety system, and access control. BMS is able to reduce energy consumption and to improve thermal comfort within industrial or institutional buildings [10]. It also has the ability to monitor and control various facilities within the building as well as to offer its users or occupants with effective security, improved productivity, human comfort, and efficient energy management. However most of buildings are controlled using conventional controller whose function is based on process mathematical model. This type of controller is not suitable for systems with operating environment that are nonlinear as in the case of HVAC.

Thermal comfort is determined by the index predictive mean vote (PMV) [11,12]. PMV is an agreed relative assessment scale of thermal comfort in the indoor environment. The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) developed the thermal comfort index by using the values of PMV which range between -3 and $+3$. It indicates for example, -3 (cold), -2 (moderately cold), -1 (pleasantly cold), 0 (neutral), $+1$ (pleasantly warm), $+2$ (warm) and $+3$ (hot environment). When PMV equals zero it means a neutral environment, positive values of PMV means a warmer environment, and negative values of PMV means a colder environment. The PMV values are established by a mathematical expression or based on measurements of thermal comfort parameters and by considering activities and clothing of the occupancies as given in Eq. (1) [13].

$$PMV = e^{[MET] \times L} \quad (1)$$

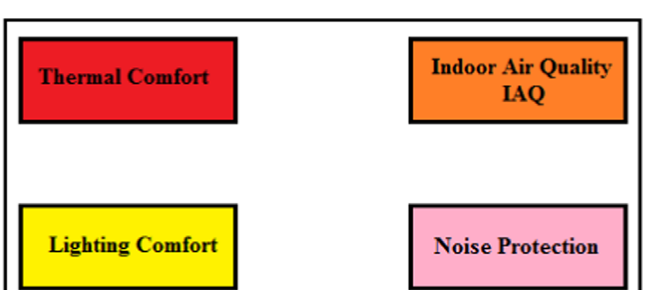

Fig. 1. Indoor environment quality groups.

where MET is metabolic rate in (Met), taking into account 1 Met = 58 W/m^2 and L is the dry respiration heat loss [°C/m^2].

Humans become alert for potential health hazards associated with poor indoor air quality and its negative impact on human production. This is due to gaseous or substances contaminants as well as biological and building particles released into indoor air and inadequate building ventilation. In addition poor indoor air quality can be exacerbated by the implementation of energy conservation strategies, the awareness of environmental issues associated with energy usage, sealed buildings, the wide spread of photocopiers and printers and other resources of air contaminators. It also can be indicated by the carbon dioxide (CO_2) concentration in a building [14,15]. In addition indoor air pollution is ever-present in different forms, ranging from smoke emitted from solid fuel combustion to complex mixtures of volatile and semi-volatile compounds like materials used in modern buildings.

Types of contaminants and pollutants can be different from one building to another depending on its nature and site such as the building's geographical position, the different materials which were used during its construction or operation and traffic volume around it. Indoor air quality is a major concern for building designers, developers, operators, tenants and owners because human exposure to poor indoor air quality may cause a high health risk; like respiratory illness, fatigue, nausea and allergies [13]. However, in most commercial buildings, ventilation rates have been reduced in order to control the cooling or thermal load to reduce energy consumption. Thus this contributes to a degradation of the indoor-air quality and will lead to what is known as sick building syndrome (SBS). This issue can be treated using Demand-controlled ventilation (DCV) system which offers an efficient solution for the optimization of energy consumption and indoor-air quality [15].

In addition, DCV is the technique of adjusting outside ventilation air depending on occupancy profile and the ventilation requirement that those occupants has created. DCV is one of the main parts of a building's management system (BMS) control strategy. Generally the main beneficiary buildings are the ones with high occupancy rates or buildings are normally partially occupied such as institutional buildings, gymnasiums, conference rooms, and theaters. DCV is a ventilation control techniques depends on the right amount of fresh air delivery to a cooled space that is needed by the occupants. The ventilation rates are improved based to the values of pollutant concentration such as CO_2.

Fuzzy based control systems which are able to adjust indoor comfort set points when buildings are occupied or unoccupied, will lead to energy conservation set points and able to shut down part of the building systems if necessary. Around the world, there are several ways of controlling indoor thermal conditions in buildings.

Since the early 70s, many researchers have conducted research in the area of building management system in an attempt to find more effective solutions to cater for the high demand of energy conservation while maintaining efficient building operation and services. At the early stages of the research work on this field there were traces of rapid improvement driven by the tremendous growth of microcomputer and later the personal computer (PC) [16]. As a result control strategies have evolved from pneumatic to conventional digitally driven controller. The development of direct digital controller (DDC) revolutionizes the way modern building is controlled. Its increasing capability and capacity to embed real-time controller has opened wide range of control strategies. The expansive readiness of open standard communication protocol has even placed the building control system to a higher level of automation. This situation permits the implementation of more sophisticated building control system [17].