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Recent Developments of Advanced Fuzzy Logic Controllers Used in Smart Buildings in Subtropical Climate

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Abstract

Building management system (BMS) has the ability to monitor and control buildings' mechanical and electrical equipment including 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. Additionally, it highlights the recent developments in BMS controllers including its conceptual basis, capabilities and limitations.

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1. Introduction

Australian commercial buildings are characterized 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 strict building regulations, better design, efficient appliances, and the employment of renewable energy and the installation of intelligent control.

Recently, Australian building sectors are entering into a new epoch of change, with a focus to minimise operation cost and environmental impact. In order to provide a suitable work environment for building

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occupants, the buildings' HVAC systems must provide thermal comfort level and healthy living environment. According to [1] the quality of the indoor environment is determine by four requirements; thermal comfort, indoor air quality (IAQ), lighting comfort and noise protection.

These four factors excludes noise protection are mainly controlled through Building Management System (BMS). BMS main subsystems are HVAC, Lighting, fire and Safety Systems, and Access Control. BMS is able to reduce energy consumption and to improve thermal comfort in buildings [2]. It also has the ability to monitor, control various facilities within the building and provide its users with effective security, improved productivity and human comfort. 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.

Poor indoor air quality can be exacerbated by the implementation of energy conservation strategies [3]. Furthermore in most commercial buildings, ventilation rates have been reduced to minimise energy consumption. This issue can be treated using Demand-controlled (DC) systems which offer an efficient solution for the optimization of energy consumption and indoor-air quality [3].

At the early stages of this research field there were successes due to significant growth of microcomputer and the development of direct digital controller (DDC) which revolutionizes modern building control as a result of control strategies which have evolved from pneumatic to conventional digitally driven controller. The expansive readiness of open standard communication protocol has even placed the building control system to a higher level of automation [4].

The development of intelligent building management and automation system (IBMAS) has been motivated by today's challenges including the continuous increase of organizational complexity, economic activities, oil price and comfort demand. Consequently, many researchers take part in an innovative design of IBMAS that can provide solution to some of the above mentioned problems. Although significant research activities in the field of IBMAS have been published to the past years, still there are many potential improvements that can be made. For this reason, this research work tries to investigate and evaluate the use of fuzzy logic controller for buildings HVAC system and light controllers

2. High level program controllers (Fuzzy Logic Controllers)

In Classical controllers a thermostat is used to provide feedback to controllers which control the indoor temperature by switching cooling system on and off in order to minimize energy usage [5]. One of the main disadvantages of these types of controllers is that the overshot of controlled temperatures cannot be eliminated which might lead to more energy consumption. In order to solve this issue Proportional–Integrate–Derivative (PID) controllers are used [3, 5].

Predictive optimal control is mostly used in industry where a large-scale supervisory system is employed [6]. Predictive control function is based upon the assumption of future reference point (set point), which can lead into optimal control law to provide improved tracking characteristics and smaller actuator changes. References [6] have considered predictive control to be very important due its characteristics which includes a model for future cooling load (heat gain e.g. solar gains, presence of humans, etc.). It also improves thermal comfort mainly by reducing overheating but especially through using night and passive cooling techniques. Adaptive controllers are also able to regulate and adapt itself with the local climate conditions. These controllers are considered as the most promising control systems for buildings. Fuzzy Logic is a mathematical tool that was introduced by Lotfi Zadeh in the 1965, to deal with uncertainty. The concept of Fuzzy logic control has been applied in various areas e.g. BMS, flight systems and etc. Application of Fuzzy logic to the control buildings was started in the 1990s [3]. The synergy of the neural networks technology, with fuzzy logic, and the algorithms used in Computational Intelligence (CI) is the basic concept behind the most of smart buildings. The results of calculating PMV is nonlinear and to overcome this kind of results time delay, system uncertainty, advanced control algorithms have been incorporated with fuzzy adaptive control which are briefly described below [7].

2.1. Fuzzy systems and evolutionary computation

Researchers have been motivated to develop intelligent management system in buildings by energy savings, while maintaining suitable comfort conditions for occupants taking into account users' preference mainly for large buildings. Fuzzy systems are designed to monitor and control building's characteristics and microclimates. Consequently, a large number of activities regarding the application of fuzzy techniques on Building Intelligent Energy Management Systems (BIEMS) have been introduced.

Building a mathematical model of a building operation is always an obstacle in traditional control methods. Thus intelligent systems are not required for such model. This fact is a general innovation in the development of automatic control systems [3]. By interacting new-type, higher-level variables that define comfort standards into the intelligent controllers such as PMV, it was possible to control comfort parameters without going into the regulation of lower level variables such as temperature, humidity and air speed. Fuzzy logic control has been used in a new generation of furnace controllers that apply adaptive heating control in order to maximize both energy efficiency and comfort in a private home heating system.

2.2. Synergistic neuro-fuzzy techniques

This is a hybrid system consists of neural network techniques and fuzzy logic technology. An example of this technology is Adaptive Neuro-Fuzzy Inference System (ANFIS) which has been used to predict and control buildings' lighting systems by introducing variations of the natural lighting. A suitable combination of the predictive control strategy with a non-linear modelling of the building, occupants behaviour, and climate parameters allowed ANFIS system to save energy and while maintaining comfort. ANFIS controllers are used often to control hydronic sub-systems of heating, solar energy and other renewable energy sources [8].

2.3. PI-like fuzzy logic controllers

Fuzzy based PID controllers are classified into two categories based [3,7]. Firstly fuzzy PID controllers whose involves fuzzy logic controllers (FLCs) realized as a set of heuristic control rules [8]. The second category of fuzzy PID controllers are consists of the PID controllers with a set of fuzzy rules and a fuzzy reasoning mechanism to tune the PID gains online [30]. PD-type FLCs are suitable for a limited class of systems. They are not suitable when measurement noise and sudden load disturbances exist. PID-type FLCs are rarely used because of the difficulties associated with the generation of an efficient rule base and the need for tuning its large number of parameters. The advantage of a fuzzy PI controller is that it does not have an operating point.

2.4. Fuzzy P controllers

Several options exist to use fuzzy logic in closed-loop control. The most common way is to use the measured signals from the process as the inputs to the fuzzy logic controller and the outputs of the fuzzy logic controller to drive the actuators of the process. This type of controllers is called fuzzy P controllers. The input of fuzzy P controllers is PMV, ambient temperature, CO_2 concentration, daylight Glare Index

(DGI), and light illumination (ILL). While the controller outputs are auxiliary heating (AH), auxiliary cooling (AC), and ventilation opening angle (AW) set points [3,4,6]. In the rule design, priority is given to passive techniques to obtain indoor comfort. During moderate seasons, the fuzzy rules allow natural cooling effect by allowing windows to open in order to cool down the conditioned space. In case of indoor lighting, fuzzy rules are designed to give the priority to natural lighting first. The electric lighting is on when indoor illumination is weak especially during night times and in cloudy days. Hence when indoor illumination is increased the electrical light is then turned off and shading devices govern the indoor visual comfort which will lead to energy savings [3].

3. Discussion

Despite the advancement made in BMS controllers which includes its design, nature, function, manufacturing and programming, HVAC and Lighting control systems is still not efficient enough due to the utilizing of conventional controllers which leads to higher energy consumption. Consequently, researches in this area have been motivated by energy savings to improve controller's functionality using different inputs, outputs and system feedback. Fuzzy logic based controllers' inputs, outputs and feedback are commonly real life events such as natural light illuminations, natural ventilation, number of occupants, the usage of passive cooling techniques and etc.

4. Conclusion

In Australian subtropical regions, demand on HVAC is rising which leads to more electricity consumption. Smart buildings and buildings' intelligent control systems have the ability to save energy by applying a set of rules which are based on real life events such as weather data, sun radiation, occupant's density and etc. Accordingly this article presented a review on fuzzy logic based control systems for smart buildings. The paper firstly defined the issue, where energy, comfort and control are conditions of operation. Then the paper presented current and conventional control systems and their disadvantages. Finally it highlighted the development of intelligent control systems to improve the efficiency of control systems in buildings. The upgrading of building management and control systems now a day is a necessity to save energy and to minimize its negative impact on environment.

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