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# Intelligent multi-objective control and management for smart energy efficient buildings

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ABSTRACT

Energy management in buildings has become an increasing trend in their transformation to smart and efficient in utilizing energy resources. The potential affinity of these buildings is coping energy sustainability, security and reliability. Building energy management has been primarily associated with development and implementation of an efficient control scheme. The challenging task of building controls is to achieve indoor building environment comfort with improved energy efficiency. In this study, multi-agent control system has been developed in combination with stochastic intelligent optimization. The multi-objective genetic algorithm (MOGA) and hybrid multi-objective genetic algorithm (HMOGA) are used as optimization algorithms. The corresponding case study simulations of effective management of energy and user comfort are presented. The developed control system provides substantial enhancement in energy efficiency and indoor environmental comfort in smart buildings. An energy efficiency of 31.6% has been achieved with an 8.1% improvement of comfort index using the HMOGA technique.


## Introduction

The smart buildings concept involves the integration of technology and energy systems within buildings. This aims for energy conservation, acceptable human comfort, automation and resource management. These buildings are an upcoming trend for the future construction, enabling environment sustainability, energy security, and reliability. Buildings consume 40% of world's primary energy, causing 30% of greenhouse gas (GHG) emissions [1]. While more than 90% of the people spend most of their time inside buildings [2]. Building environment plays vital role for inhabitants' productivity, morale and satisfaction. Therefore, being competitive economically, and meeting increasing environmental standards in building industry is yet an open challenge for researchers.

Building energy resource management (BERM) can help to meet the critical objectives of improving environmental quality and energy conservation in building operation. This allows inhabitants to cut their energy bills and improve quality of living comfort. Generally, three parameters determine the building's indoor comfort conditions: thermal, visual and air quality [3]. Thermal comfort is indicated through temperature index of inhabitants; the auxiliary heating and cooling system has been used for maintaining a comfortable indoor temperature. Visual comfort is indicated with the brilliance level; the natural as well as artificial lighting fixtures are employed for required indoor visual comfort level. Air quality indicates the $CO_2$ concentration index; the natural and mechanical ventilation systems have been employed for an acceptable $CO_2$ concentration level in buildings.

It is well known that thermal comfort is determined by Predictive Mean Vote (PMV) index that is generally dependent on temperature, airflow rate, humidity, mean radiant temperature and clothing. PMV however, varies between $-3$ and +3 on scale and fluctuates between $-0.5$ and +0.5, thus causing satisfaction of 90% of users [4]. Since, temperature being the most important factor in computing PMV index and is easy to measure, it has been indicated as thermal comfort factor for this study. Similarly, Visual comfort is determined through brilliance level measured in lux; other factors that include, glare, wall color reflections, etc. are subjective and difficult to measure. Indoor air quality has mainly been influenced by pollutants concentration in control space. However, it has been indicated that $CO_2$ concentration can be represented with user's presence and various other pollution sources in the building [5].

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The presence of an intelligent control system for building energy management (BEM) is very important. The objective of such a control system is to minimize the energy consumption and the indoor discomfort level with optimal usage of outdoor environmental conditions. Two factors affect these two objectives, that are, the user's preferences and outdoor climatic conditions. In addition, BEM systems have recently been studied [6] for modern smart buildings and control systems.

Various studies for comfort control have been presented. Conventional ON/OFF and proportional integral derivative (PID) controls are widely used [7]. Prior measures were for temperature regulations inside building, that caused more energy consumption due to frequent overshoot and oscillations in comfort parameter set points. This control generally does not perform well and neither provides optimal strategy. Feedback PID controllers with constant parameters and no information of control process, usually give poor performance with large time delay in the presence of noise and nonlinearities [8]. Other advanced control schemes or artificial intelligence [7] include predictive [9], adaptive [10] and optimal [11] controllers. These were ensuring thermal comfort and limit comfort set point overshoots. Adaptive control with pole placement optimal regulator has been implemented for temperature control [12]. Predictive control with weather prediction has been employed for heating, ventilation and air-conditioning system (HVAC) using mathematical model along with energy saving potential [13,14]. Fuzzy logic for visual comfort was developed by Dounis et al. [15], however, day lighting linked with lighting control is discussed in [16]. Robust airflow rate control strategy is investigated in [17], along with air quality control using fuzzy reasoning has been developed in [18]. Various other computational methods such as artificial neural network (ANN) and neuro-fuzzy systems [19], genetic algorithm (GA) [20] have been proposed for optimized control. Building system optimization includes weighted fuzzy rule base [21], empirical models [22], simulation optimization [23] and online adaptive control [24]. Control systems integration employing genetic algorithm, optimized fuzzy control for interior climate [25,26] and rule base system with occupancy prediction and behavior modeling have also been developed and tested [27,28]. Furthermore, the detailed study for the optimized control systems for building energy and comfort management of smart sustainable buildings can be referred at [29].

Optimization techniques of direct and gradient-based methods possess some common drawbacks which include lack of generality and are trapped pertinently at local optimum. They are also facing challenges in solving discrete optimization problem. Multi-objective optimization is proposed to instantaneously deal with multiple objective functions, probably in contradiction with each other.

Evolutionary algorithms turned to be the most popular tool for resolving multi-objective problems; within these, genetic algorithm (GA) is the most common computation method. GA being the meta-heuristic, population based technique can instantaneously explore and exploit various solution space regions. It is very suitable for Pareto optimality set in complex spaces. Various multi objective genetic algorithm techniques exist for fitness assigned, maintaining diversity and preserving elite solutions. Multi-Islanded genetic algorithm (MIGA) and simple genetic algorithm (GA) has been used for energy conservation and comfort management developed in [30]. This employs at the input fuzzy parameters optimization for environmental difference. A multi-agent controller structure to manage energy consumption and occupants comfort was developed in [31]. It employed particle swarm optimization (PSO) at the central agent to observe the trade-off solutions for informed decision-making. Wang et al. reported graphical user interface (GUI) for user preference inclusion in building operations and comfort management. Consequently, indoor comfort index parameters (thermal, visual and air quality) that were handled in [32–34] using genetic algorithm for optimization of comfort parameters properly. In addition, an hybrid genetic algorithm is proposed which is the advancement of our previous work thus, further allows the reduction in building energy consumption and also offers mandatory control action. The hybrid genetic algorithm is used in the control system to search the optimal set points according to user's preferences and outdoor environmental information.

In present study, the hierarchal control system has been developed for achieving balance between the energy consumption and wellbeing indoor 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 multi-objective genetic algorithm (MOGA) and hybrid multi-objective genetic algorithm (HMOGA) for optimizing energy management of the buildings. Thus, the control system initializes both maximum indoor comfort index and minimum power consumption objective functions.

## System framework and agent controller modeling

The master agent controller is liable for coordinating all peripheral agents. It integrates the personal occupant's preferences and liaises with the optimizer in order to optimize the peripheral agent comfort set point to user comfort set value as quick as possible. The evolutionary optimization algorithm utilizes the outside network information and allows customer to specify preferred comfort range to tune and update the best set points in each step. Its function is to optimize and update the set point values of master and peripheral agent controllers, thus, adding intelligence to the control system. Its main idea is when the peripheral controllers cannot achieve the desired target; the master agent will offer more power for achieving the desired set value quickly. The entire system framework is depicted in Fig. 1.

The Users could set their different comfort range based on their preferences, which is represented as, $[C_{\min}, C_{\max}]$. "$C$" denotes the required comfort parameter. In this study, the parameters selected are thermal, visual and air quality comfort. This signifies the optimizer to achieve the targeted comfort in contrast to its best capabilities ensuring all the indoor and outdoor information satisfying their needs.

These control agents acquire adjusted set points from the master agent controller and real time indoor environmental parameter. It provides the actual power demand for the actuator system to maintain the required comfort level. However, fuzzy rule base and membership function helps to compute the required power in uncertain circumstances.

The withdrawn power in the building model will allow actuator system to cause variation in the indoor environmental parameter of the building. The main aim of the entire automation process is to achieve the required comfort index in the building. The level sensor sub-system will generate feedback to the environmental variation for calculating the error input to the fuzzy system. This feeds back the power demand to the master agent controller to determine future power adjustment.

### *Master agent modeling*

This controller agent computes the indoor comfort requirement and power demand based on the received network and sensor information. The comfort function is defined similar to [31] and is the overall comfort in the building, constituted in the range of