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Re-Investigating the Trends in the Field of Control for Energy Efficient Buildings

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ABSTRACT

Energy contributes the most important part of our universe. Energy as a fuel is essential for the economic development in any nation. Thus, it is required to increase the efficiency of utilization of electrical energy and in order to expand the availability of these resources fuels make the use of renewable energy sources. The premier objective of this survey is to analyze the control performance of various currently used energy efficient building techniques. In this paper an attempt have been made to discuss the techniques that focuses on heating, ventilation and air conditioning systems (HVAC systems) of building, where cooling and heating rely on centralized chilled water and hot water generation respectively. This paper deals with such control techniques whose incorporation would certainly enhance the future direction in energy efficient buildings.

Keywords: Building, Energy efficiency, Optimization, Estimation, Control, Illumination.

1. INTRODUCTION

The infrastructure sector is the biggest energy consumer in the world. The electricity consumption in commercial and public buildings has increased at a much faster pace compared to other sectors. Rethinking on the whole processes of design, construction and operation of a building is required to attain substantial energy reduction in infrastructure sector. The energy efficient building concept involves the combination of technology and energy systems inside the buildings. This intent for energy conservation, automation, adequate human comfort and resource management. This type of energy efficient buildings are the forthcoming trend for enabling environment sustainability, energy security and reliability.

Buildings are engaged in 40% of world's primary energy consumption, causing 30% of green house gases emanation. Thus, being economically competitive and to meet the environmental standard, in building sector it is yet an open challenge for researchers. In this paper we have shown our related work in a very systematic and organized manner and in the end concluded our analyses with the pros and cons with other discussed techniques. This paper is categorized into four segments. Introduction part which is followed by segment 2, in which the literature review of control for energy efficient buildings are reported and briefly discussed. In 3 segment the related work is analyzed and conferred in a well organized manner. Finally, in segment 4 we have concluded our findings with this analysis along with the future scope of work.

2. LITERATURE SURVEY

An attempt has been made to briefly review the previous works related to control strategies in energy efficient buildings.

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Yoon *et al.*[1] proposed Building Energy Management Systems (BEMS) that was based on Information Communication Technology (ICT) hardware and software systems in which automation and controls, high efficiency systems, equipments and energy management services were unified to improve energy efficiency. A new BEMS, EMM was also proposed that satisfied low cost, energy efficient and secure building energy management and control of buildings from remote control centre over Internet.

Wang *et al.* [2] proposed Particle Swarm Optimization (PSO) that would optimize the set points of control system which was employed to minimize the conflict in power consumption and customer's comfort in energy efficient and smart buildings. Multi-Agent Controllers at two levels were employed in this theory. Fuzzy logic was used to compare the output and PSO to tune the set point values to produce high comfort and less energy consumption.

Reena *et al.* [3] studied the occupancy driven energy efficient Building Automation Systems (BAS) that contributed in occupancy comfort and optimal indoor climatic conditions. Authors used occupancy sensors which operate relative to the occupants and was beneficial for maximum occupants. Authors also illustrated that for unoccupied spaces the above mentioned method won't work, whereas wireless-sensor-controller-actuator-network was assigned for every zone and SIMULINK was used for its control, thus fulfilling the objective.

Two strategies: (a) Delay Responsive Cross – Layer data transmission scheme (DRX); (b)Fair and Delay – aware Cross Layer (FDRX) data transmission scheme was proposed by Anbagi *et al.* [4]. In this authors discussed about the transmission of delay-critical data in smart grid through Wireless Social Networks (WSNs). DRX was used for data prioritization and delay-sensitive data transmission; wherein, if delay was above a threshold value, access of the node was given. On the other hand, FDRX was introduced which, along with reducing delay, provided access to other nodes, unlike DRX, as it allowed fair transmission. Authors also illustrated that these methods degraded when used in an outdoor substation when compared to underground transformer vault, due to more obstacles outside than inside.

Ferhatbegovic *et al.*[5] studied Model Based Predictive Control (MBPC) approach for increase of energy efficiency. MBPC Algorithm was presented for the efficient temperature control of solar-thermal system that consist of solar collector and heat exchanger which was based on physical lumped model. It comprised of prediction that was carried out during finite time horizon that relied on past inputs and output signals, in addition to the signals to be computed, in which temperatures were within defined limits and energy efficiency improved with no overshoots, unlike in PI Controllers.

High performance computing and distributed parameter control theory was proposed by Borggaard *et al.* [6], which provided computational algorithms for optimal placement of sensors and actuators which maximized controllability and observability. The methods used were :- (a) Simulation Based Design, wherein, the numerical model approximated physics and was used as a design model; (b) Holistic Fully Integrated Design, wherein, the design problem was abstracted and solved, after which it was approximated; (c) Hybrid Method incorporated both (a) and (b). It provided optimization, control and design of energy efficient buildings impacted energy cost and greenhouse gas emission.

Efficient Illumination design was proposed by Lakshmanan *et al.* [7], delamping the lights to save potential energy and control occupancy, which comprised of two methods: (a) Delamping Method, validated by photometric measurements, in which luminance required was calculated and accordingly extra lamps were removed; (b) Occupancy Control, where delamping was done, by calculating the number of hours in which, room was being occupied by the occupants, after which delamping was done accordingly. Authors observed that by using these methods good amount of electricity was saved.

Sheikh *et al.* [8] proposed multi-agent control system in combination with stochastic intelligent optimization. The methods used were: (a) The Multi-Objective Genetic Algorithm (MOGA) and (b) Hybrid

Multi-Objective Genetic Algorithm (HMOGA). In MOGA, authors used Genetic Algorithm to reach optimal pareto front and hence, reduced energy consumption. Whereas in HMOGA authors illustrated it had better fast convergence, which initiated at all trade-off solutions on pareto front returned by MOGA, further reducing the energy consumption as well as increasing comfort. The use of both gave the best optimal solution of reduced energy consumption and increased comfort.

Wei *et al.* proposed management and application of battery storage for energy efficient buildings. A system-level approach was introduced to co-schedule battery storage usage so as to reduce consumption charge, battery cost and peak demand charge. Authors also introduced to reduce energy cost of EV charging through solar PV and battery usage. Authors proposed ARM processor based programmable embedded battery management system to monitor battery status, battery protection etc. An MPC based algorithm was also proposed to co-schedule the HVAC control with the usage of battery storage system to reduce energy consumption, peak demand charge and battery cost as well as maximized efficiency and performance.

Lilis *et al.* [10] developed SRC (System of Resistances and Capacitances), a finite element based hydro-thermal building simulation program. In this authors used resistances as building elements and capacitances as temporal thermal storage. Authors further illustrated that resistances and capacitances were used to define operation schedules of building openings which achieved energy savings while preserving thermal comfort in interiors of buildings. Authors used MATLAB and C programming to estimate the temperatures of building zones to be calculated and thermal effects of openings. Authors concluded that satisfactory results were obtained for thermal comfort and could be further extended to multiple zone buildings.

A novel model of automation was given by Zucker *et al.* [11], of which the foundation was in cognitive automation due to uniqueness of energy sources, architecture, usage, location etc. Authors employed two significant properties on functional buildings: first, control systems to handle their complexity that had advancements in complex control system architecture and second, advanced analysis of large amount of data. Authors illustrated that the main challenge remained to identify smart algorithms that were capable of extracting information from data and Project. ECABA (Energy Efficient Cognitive Autonomous Building Automation) was proposed which aimed at minimizing consumption of energy by maximizing exploitation of renewable energy sources.

Vergini and Groumpas [12] proposed the concept of Zero Energy Buildings (ZEB). Performance was improved and consumption was reduced by the energy management and intelligent control. ZEBs connected to the grid consumed energy higher, equal or less than the produced energy, where Fuzzy Cognitive Maps (FCMs), combined of Fuzzy Logic and Neural Networks, were used to manage and control the produced and consumed energy.

Goyal *et al.* [13] proposed three control algorithms:- (a) POBOC, wherein, a model of hygrothermal dynamics of zone and accurate prediction of accuracy was required for computing the control inputs-supply air flow rate and amount of re-heat.; (b) OMBOC, wherein, dynamic model and occupancy measurement was required and was used for short term horizons and; (c) Z-DCV, that comprises only of accuracy measurement and feedback based algorithm, which divided flow rate based on measured occupancy. Model Predictive control framework to compute optimal control inputs was used in the first two algorithms in which temperature was allowed to drop to minimum values, whereas, in Z-DCV, the temperatures were maintained through re-heating.

Stauffer *et al.* [14] studied energy flux optimization as a solution for increase in power demand; the effects of which were pressure on power grid and rise of electricity power bills. Authors used solar panels to solve the former problem to an extent but were not proved efficient in relieving grid as it had a fluctuant nature, due to which the flux optimization comes into being. For the latter, energy fluxes, internally and externally, equipped with an electrolyzer system, a control station, a battery, solar panels and a fuel-cell powered car, were optimized.

Singh *et al.* [15] presented an approach called Energy Efficient Measures (EEMs) to save energy as well as cost on lightning and air-conditioning systems. They incorporated three methods for lightning:- (a) Delamping, where lights were removed where area was unoccupied; (b) Use of Signage and Lightning Control Systems such as sensors were employed, that automatically sensed the inoccupancy and switched off the lights; (c) Relamping, wherein, use of LED lamps of same efficiency were inculcated to reduce energy consumption. Two methods for air conditioning were: (a) EEMs for Air Conditioning Systems that replaced low efficient air conditioning with a high efficient one; (b) EEMs for Chiller Plant Air Conditioning Systems, where, a low efficient compressor was replaced with an highly efficient compressor. These methods proved helpful in energy as well as cost saving.

Ddewurtel *et al.* [16] presented a method called stochastic model predictive control strategy for building climate control that takes into account weather predictions to step up energy efficiency since buildings accounts for about 40% of global energy usage, while respecting constraints resulting from desired occupant comfort. Authors investigated a bi-linear model under stochastic uncertainty with probabilistic, time variable constraints. In this authors focused on integrated room automation, an automatic lightning system and a blind positioning system. The control which was required in building was to keep the room temperature and CO_2 within the specified limits. In this paper three types of controllers are assessed to deal with the inherent uncertainty due to weather prediction- (i) Rule based control (RBC), (ii) Model predictive control (MPC), (iii) Performance bound (PB). In MPC, two schemes were considered, first one to simply neglect the uncertainty in the problem and therefore called as certainly equivalence (CE) and second strategy was to take into account the uncertainty in the controller directly and solve a stochastic MPC (SMPC) problem. SMPC showed better results than RBC as well as predictive non-stochastic controller (CE) and the more benefits of using SMPC were easy tunability with a single parameter tuning describing the level of constraint violation as well as comparatively small diurnal temperature variations.

3. CONCLUSION

The various advantages observed during the survey in regard to the objective, include intelligent automatic diagnosis for the required operation, consideration of customers' preference in case of comfort, increasing zone-wise efficiency, efficient MPC for servo or regulator problems, energy saving by occupancy control, robustness to disturbances in case of data analysis, energy and cost savings by automatic switching off of lights by signage as well as by use of renewable energy. Disadvantages in context of zone-wise efficiency are that the reduction of occupancy leads to reduction in comfort level. All the techniques used have different advantages and different disadvantages so it's hard to say which technique is the best one. Techniques which are mentioned in segment 2 can be used according to the zone we taken, what type of building we are using for energy saving etc.

The future scope may include implementations of (a) SCADA for practical applications; (b) non-linear MPC to increase efficiency of systems; (c) sensors for Occupancy control; (d) consideration of external parameters like weather changes that affect the internal surroundings. Further improvements can be done by the use of Artificial Intelligence(AI) as well as computer software simulator for the efficient control, energy and cost saving of buildings, which may be extended in case of commercial buildings as well. Other advantages, disadvantages as well as future scope have been illustrated in the reviews above.

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