Coordinating Energy Management in Mixed-Use Buildings

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Abstract: Reducing building energy consumption now is attracted many researches through increased sensor data and increased computational support for building controls. However, current building systems are inefficient in their energy usage, where the control systems often maintain for each building separately. Also, each systems such as heating system, water, air conditioning, etc., has a private controller to operate itself. Finding a coordinating method that can control and reduce building energy consumption dynamically is still a potential area. In this paper, we propose a coordinating energy management method that can reduce building energy by controlling both building energy and occupant comfort. Specifically, by employing our model, we improve 8% in energy consumption compared to the baseline

1. Introduction

There is more attention in reducing building energy consumption by placing a lot of sensors and computational system for building controls. Korea is one of the countries consumes highest electricity accounting on the capita. The report from World Bank in Figure 1 shows the amount of electricity consumption per capita. Thus, reducing energy is a critical issue in the future that the governments, companies and researchers focus on today and future. As report from World Bank [1], 40% of national energy consumption from building account, greater than the consumption of either the transportation or industrial sectors. Developing of Internet makes people spend a lot of time indoors more and more, reducing building energy will be more significant and critical.

However, to reducing building energy, the controller has to trade-off between the reward from saving energy and user discomfort. Cutting of air conditioner, hot water or heating system will make users uncomfortable. The more energy the system saves, more discomfort users have. Building energy and occupant comfort are therefore two critical parameters which are performed indoor environments. As mention in [2], the most critical systems of indoor buildings include heating, ventilation, and air conditioning (HVAC) systems, lighting systems, and electrical applicances and devices. In usual, these systems are operated separately in each building's energy policies.

Moreover, considering on multiple building, reducing building energy will be more complicated. When receiving energy demand response (EDR) signal, the controller should has a suitable decision that reduce the energy consumption on which systems and which building.

Our work address challenges and formulates the coordination energy management (CEM) problem as an optimization problem. Using decomposition method to solve CEM problem, we can reduce significantly amount of energy in EDR.

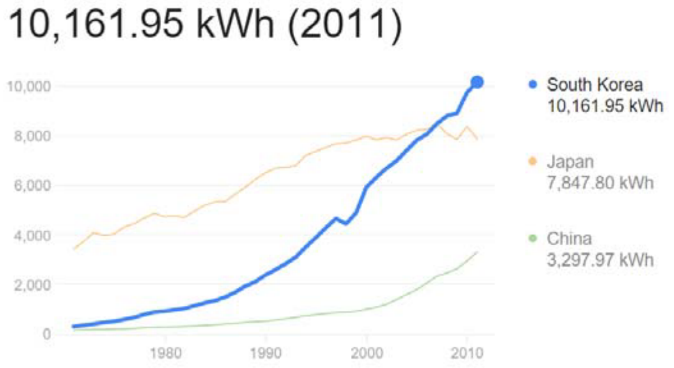

Figure 1: Electricity consumption per capita, reported by World Bank in 2011 [1].

2. Preliminaries

EDR indicates that the response is mandatory (with a significant penalty for non-compliance) for the participants, who are mostly paid for their availability for shedding loads even when no emergent signal is triggered [3-4]. Such programs are currently employed by many Independent System Operators, e.g., New England, where the customers' contracts can be established three years in advanced [4]. In detail, if there are some reliability issues (e.g., forecast capacity shortages), the load serving entity (LSE) will trigger a signal to customers from at least 10 minutes to one day in advance, and customers must comply with the notified reduction volume. In current practice, customers often participate in EDR using onsite backup diesel generators. However, relying totally on diesel generators is not cost effective. Furthermore, frequently using diesel can be environmentally dirty.

3. The problem formulation

Even though reducing the building energy has attracted much attention, there exists a critical trade-off issue between building energy reduction and user comfort satisfaction that dictates the performance of indoor environments. Generally, building energy is mainly contributed by: (a) HVAC system, and (b) lighting and electrical equipment, which constitute 43% and 30% of building energy usage, respectively [2].

In this work, we mainly consider the impact of HVAC system on user comfort. The HVAC system controls the temperature and air volume within a user comfort zone. In HVAC, the air handler unit is one of the main components that combines outside air and returned air from the building to create mixed air, whose temperature is denoted by T_{ma}. This mixed air is then cooled or heated to the specified supply air temperature, which is then re-distributed to each building zone using ducts and fans. The volume of this supply air, denoted by V, is used to adjust the zone air temperature to the indoor supply temperature, denoted by T, and provide fresh air such that user comfort is guaranteed [2]. According to [16], the energy consumption of an HVAC system mainly results from the sum of the fan distribution energy E_{fan} and chilled water cooling energy E_{chill}:

$$E_{hvac}(T) = E_{fan}(T) + E_{chill}(T).$$

Furthermore, we also have $E_{fan} = c_1 V$ and $E_{chill} = c_2 V(T_{ma} - T)$, where c_1 and c_2 are constants that determined by the efficiency of the ventilation fans and the coefficient performance of the chilled water production plant [16]. We see that both E_{fan} and E_{chill} depends on the required supply air volume V, which is calculated as follows [16]

$$V = \frac{1.1 V_z \Delta T + Q_z}{1.1(T_z - T)},$$

where Q_z denote the zone's total thermal heat load, ΔT is the desired change in temperature over time from the the current zone temperature (denoted by T_z) according to the zone volume V_z.

Even though user comfort is an abstract concept and heavily depends on individual tastes, we consider a generic model based on the indoor temperature T controlled by HVAC system to capture the common sense of user comfort. Specifically, during the occupied period of a day when user is often present in the building, e.g. k is from 7:00 AM to 12:00 AM, the supply air temperature2 is regulated within a comfortable range, e.g., [21; 25]^{0}C during the winter or [23; 27]^{0}C during the summer. On the other hand, during the unoccupied period when there is no user, e.g. k is from 12:00 AM to 7:00 AM, the supply air temperature can be adjusted in a wider range, e.g., [10; 40]^{0}C.

Therefore, denoting T_i^k the reference indoor temperature that the user are satisfied at time k, e.g., 25_C at 1:00 PM, the user discomfort can be captured as a "cost" modeled as follows:

$$C_{user}(T) = \frac{\omega_{user}}{2}(T - T_k)^2,$$

where ω_{user} is a monetary weight (i.e., \$/degree^2). This cost model reflects that the user discomfort increases quadratically with respect to the deviation of the controlled T from the comfortable T_k. We choose a quadratic function for user discomfort because a) it is widely used in many fields such as control, signal processing, communication networks, etc. to model a cost function [17], and b) it provides analysis tractability.

Considering with a set N building that has the coordinating controlling, we formluate CEM problem as follow

$$\min \sum_{i=1}^{N} \alpha E_{hvac}^i(T^i) + C_{user}^i(T^i)$$

$$s.t. \sum_{i}^{N} E_{hvac}^i(T_k^i) - E_{hvac}^i(T^i) = R,$$

where $T_i, T_k^i, E_{hvac}^i, C_{user}^i$ are the control temperature, threshold temperature, HVAC energy, and user discomfort cost of building i, respectively. R is the amount of energy responsed for EDR. And, α is the monetary term to convert energy to price.

4. Decomposition based for CEM

We apply the dual decomposition method [3] to solve the cost minimization problem in a distributed manner. We first have the augmented partial Lagrangian function of problem CEM as follows

$$L(T, \lambda) = \sum_{i=1}^{N} \alpha E_{hvac}^i(T^i) + C_{user}^i(T^i)$$
$$+ \lambda\left(\sum_{i}^{N}(E_{hvac}^i(T_k^i) - E_{hvac}^i(T^i)) - R\right)$$
$$= \sum_{i=1}^{N} C^i(T^i) + \lambda\left(\sum_{i=1}^{N} \Delta E^i - R\right)$$

where $E_{hvac}^i(T_k^i) - E_{hvac}^i(T^i) = \Delta E^i(T^i)$, $\mathrm{C}^{\mathrm{i}}(T^i) = \alpha E_{hvac}^i(T^i) + C_{user}^i(T^i)$, and λ is the multiplier Lagrangian variable of constraint. Based on this Lagrangian, the main operations of CEM, which are iterative with index t, can be decomposed into two sub-problems as follows:

HVAC sub-problem. At iteration $t+1$, the HVAC controller solves the following sub-problem, with given λ^t

$$\min C^i(T^i) + \lambda^t \Delta E^i(T^i)$$
$$s.t. T^i \geq 0$$

Dual update. Finally, DCEM updates the dual variable as follows:

$$\lambda^{t+1} = \lambda^t + \sigma \sum_{i=1}^{N} \Delta E^i(T^i) \quad ,$$

where σ is the step size.

5. Numerical results

In this section, we provide numerical settings and results for solving CEM problem in coordinating control temperature of three buildings. In terms of the monetary weights, α, ω_{user} are set to 0.1. We consider in 24 timeslots, and the threshold temperature T_k^i from 10^{0}C to 40^{0}C as shown in Figure 2.

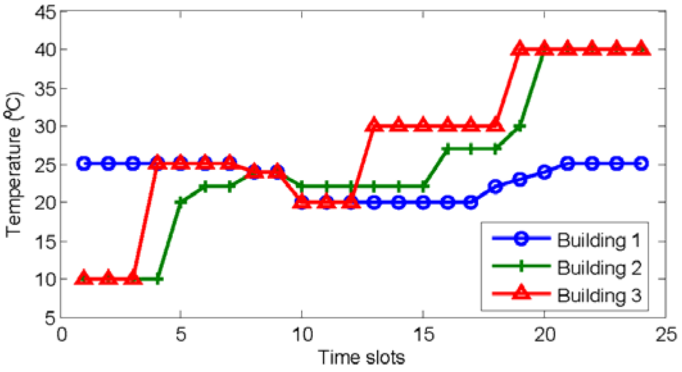

Figure 2: Trace of threshold temperature of three buildings.

Based on the trace of threshold temperature of three buildings, we make a comparison of total reducing cost between CEM and baseline (minimum amount of energy need to reduce from EDR). Our method can dynamically control the temperature with bold building energy and user discomfort to reduce 28% based on the minimum requirement.

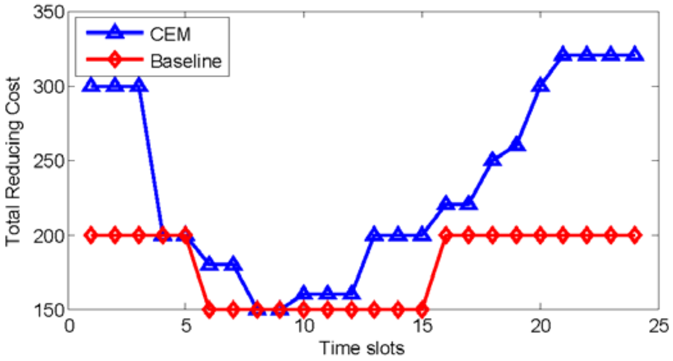

Figure 3: Comparison of total reducing cost between CEM and baseline

6. Conclusion

In this paper, we propose a coordinating energy management in multi-building. Using decomposition framework, we can control the temperature by distributed manner in order to reduce the energy in demand response. Our method can reduce 28% in comparison with baseline 1. The results in our method convince the efficiency of CEM, a novel can be applied in practical environment.

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