Demand-based Apportionment on Electricity Payment of HVAC Systems

(Extended Abstract)

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1. INTRODUCTION

Heating, Ventilation, and Air Conditioning (HVAC) systems account for a significant portion of power consumption in commercial buildings all over the world [1, 4, 5, 6]. Since HVAC systems are designed for centralized cooling supplies, power consumption in each room is inestimable. Therefore, administrators are motivated to apportion the electricity payment for actual users. The even apportionment is an intuitive way. Previous work implies that the even apportionment does not encourage people to reduce power consumption [2]. Some researchers investigate a variety of policies to apportion the power usage and then conclude that understanding the personal energy use is an incentive to reduce power consumption [3]. However, the pay-as-you-go based apportionment is unrealistic on HVAC systems because of the difficulty on measuring the individual power consumption.

In addition, climate differences cause the unfairness on the pay-as-you-go based apportionment. The reason is that the two rooms need various amount of cooling supplies to achieve the same indoor temperature. The difference on cooling supplies in the rooms is led by the environment. For example, a room in the top level always needs more supplies against the sun exposure. Under the pay-as-you-go based apportionment, no one wants to use the rooms in the top level. Therefore, we propose the demand-based apportionment to resolve the unfairness with providing an incentive to mitigate the power consumption. We think that the payment, which is derived from the demand-based apportionment, is more reasonable in terms of indoor temperatures.

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2. METHODOLOGY

To apportion the electricity payment of HVAC systems rationally, we provide the demand-based dynamic apportionment. Our apportionment satisfies the desirable properties, completeness and accountability [3]. The completeness describes that the sum of the distributive electricity payment should be equal to the original electricity payment. The accountability represents that the electricity payment which caused by an individual's action should reflect on his / her payment.

Since climate differences are ignored in the pay-as-you-go based apportionment, we utilize the heat based demand to resolve the drawback. When the sum of demands is larger than zero, we propose the demand-based apportionment as follows:

$$Payment(r) = \frac{Demand(r)}{\sum_{r \in R} Demand(r)} \cdot \sum_{r \in R} Usage(r) \cdot p \quad (1)$$

where p denotes the price of electricity per usage. Otherwise, if the sum of demands is zero, the total electricity is evenly apportioned by the volume of rooms.

Because power supplies are depended on peak loadings, how to reduce the loadings during peak hours becomes a known problem on power saving. We also know that if the unit price of the electricity is fixed all day, people do not have intention to curb the power usage. Therefore, we design a demand-based price mechanism as

$$p_t = (1 + \alpha \cdot \frac{\sum_{r \in R} Demand(r)_t - \sum_{r \in R} Demand(r)_{t-1}}{\sum_{r \in R} Demand(r)_{t-1}}) \cdot p_{t-1}, \quad (2)$$

where t represents a timestamp and α represents the discount factor. The price is higher when the total demand increases, and vice versa. Assume that people are rational. They would reduce the unnecessary demand during peak hours.

3. IMPLEMENTATION

In the algorithm, each room agent's behavior corresponds to the procedure of adjusting a controller, and the HVAC agent just likes a HVAC administrator. Let X and R denote a set of observations and a set of rooms respectively. The flow of the simulation is described in Algorithm 1. In line 4 to 7, the room agents provide their demand requests by considering the current price and the observations. In line 9 to 10, the HVAC agent decides the supplies in terms of the requests. In line 12 to 16, the room agents expend the supplies according to the structure of HVAC circuits. The remaining parts describe the payment calculation and the environment update. The payment is computed by Equation (1), and the price is updated by Equation (2). The benefit of the multi-agent formulation is the flexibility. The strategies of the agents could be very different and complex.

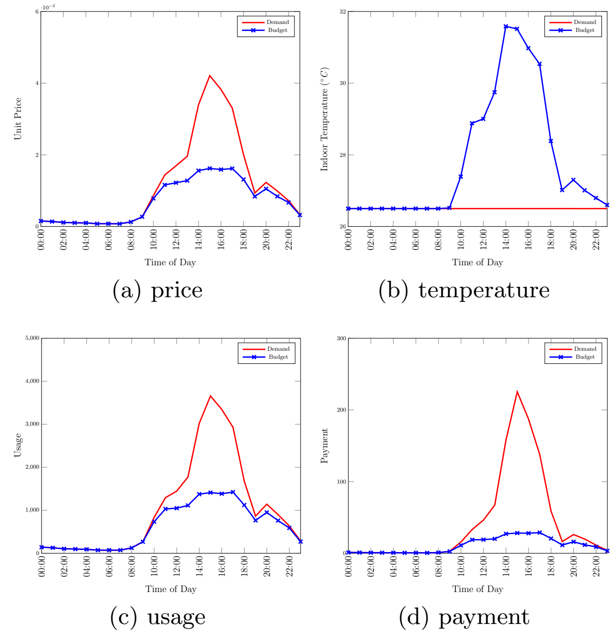
Algorithm 1 Simulation

```
 1: while true do
 2:     p ←HVACAgent.Price()
 3:
 4:     ▷ The demand request procedure
 5:     for all r ∈ R do
 6:         d̄_r ←RoomAgent_r.DemandRequest(p, X)
 7:     end for
 8:
 9:     ▷ The supply decision procedure
10:     S ←Supply(d̄_1, ..., d̄_{||r||})
11:
12:     ▷ The cooling expense procedure
13:     for all r ∈ R do
14:         d_r ←RoomAgent_r.Expend(S)
15:         UpdateSupply( S, d_r )
16:     end for
17:
18:     ▷ Measure the payment
19:     MeasurePayment(d_1, ..., d_{||r||})
20:
21:     ▷ Update the environment
22:     HVACAgent.UpdatePrice(d_1, ..., d_{||r||})
23:     UpdateObservation(X)
24: end while
```

4. EXPERIMENTS

The goal of our experiments is to show the effects of the demand-based apportionment. In addition, we investigate how a budget influences the demand-based price mechanism. The experiments were conducted by the NTU CSIE July 2012 dataset. To run the simulation, we utilize the outdoor temperature, the number of occupants and the initial indoor temperatures in the dataset. The results of the simulation are show in Figure 1.

Figure 1a reveals that the average price of the demand-based agents increases during peak hours, but the average price of the budget-based agents is restricted. By comparing to Figure 1b, we could observe that the indoor temperatures of the budget-based agents are relatively high. According to Figure 1c and Figure 1d, the average ratio of the usage to the payment on the demand-based agents is 76.73 and it is 89.25 on the budget-based agents, which means that the budget-based agents obtain more usage with less payment.



(a) price (b) temperature

(c) usage (d) payment

Figure 1: The hourly average of the payment and the usage

5. CONCLUSIONS AND FUTURE WORK

Since measuring the relation between the cooling usage and power consumption is difficult, the pay-as-you-go based apportionment is commonly used. However, this apportionment leads to the unfairness on climate differences. We introduce the demand-based apportionment to overcome this problem. In addition, the mechanism cooperates with the budget based agent to decrease the usage during peak hours and to improve the efficiency per unit price. The results figure out that the demand-based apportionment could resolve climate differences.

6. REFERENCES

[1] EMSD HKSAR Government. Hong Kong Energy End-use Data 2011. 2011.

[2] U. Gneezy, E. Haruvy, and H. Yafe. The Inefficiency of Splitting the Bill. *The Economic Journal*, 114(495):265–280, 2004.

[3] S. Hay and A. Rice. The Case for Apportionment. In *Proceedings of the ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, 2009.

[4] E. H. Mathews, C. P. Botha, D. C. Arndt, and A. Malan. HVAC Control Strategies to Enhance Comfort and Minimise Energy Usage. *Energy and Buildings*, 33(8):853–863, 2001.

[5] K. W. Roth, D. Westphalen, J. Dieckmann, S. D. Hamilton, and W. Goetzler. Energy Consumption Characteristics of Commercial Building HVAC Systems: Volume III, Energy Savings Potential. *TIAX LLC Report for US Department of Energy Building Technologies Program*, 2002.

[6] U.S. Department of Energy. Buildings Energy Data Book. 2010.