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Load Management in District Heating Operation

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Abstract

Smooth operation of district heating system will avoid installation of expensive peak heat boilers, improve plant partial load performance, increase the system redundancy for further network expansion and improve its resilience to ensure security of supply during severe heating seasons. The peak heating load can be reduced through building demand side management. The building thermal mass can be used to shift the heating supply under the circumstance without jeopardizing the consumer thermal comfort. In this paper, the multi-agent framework is applied to a simplified building dynamic model to regulate the heating supply to a cluster of buildings. The aim is to level out the total heating supply under a reference temperature and meanwhile maintain the consumer thermal comfort.

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1. Introduction

District heating (DH) supplies heat from the central heating plants to a large number of consumers via the heating network. The operation of a DH system often faces large heating load variation [1]. The peak heating load may be due to room heating, hot tap water, preheating of ventilation air in commercial buildings or due to the on-set of room heating after night setback [2].

Through the reduction of peak heating demand, the DH utilities can achieve economic benefit by avoiding installing expensive peak heating load boilers. Such boilers are designed to operate only on a short period during very cold winter period. Correspondingly, the heating network can be designed with smaller capacity.

Reducing the heating load variation will improve the heating plant partial load performance. It can avoid frequently start-up and stop the heating plants. For a DH system with a large share of renewable energy and waste heat, the intermittent nature of renewable energy generation and the distinct load pattern from different types of waste heat sources will also demand the system have the capacity to regulate the peak load demand and balance the discrepancy between supply and demand in a certain time period.

Peak load saving will increase the system redundancy and allow more users to connect to the network. Meanwhile, reducing the peak heating load will improve the network resilience to ensure the security of operation during extreme cold period or during the period of heating plants power failures.

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The peak load reduction can be achieved through building energy renovation, active thermal storage units or through the building demand side management (DSM). In the building heating supply, the aim of DSM is to plan, monitor and operate individual consumer use of energy to produce a favorable effect on utility heat production profile with respect to load shape, time pattern and peak load. DSM can achieve significant peak load reduction and energy saving for both individual building and a cluster of building mix [3][4][5].

The building structure store thermal energy and prevent large variation of room temperature. In general, it is possible to reduce the peak heat load by allowing small room temperature fluctuation without notification of consumers. Meanwhile, it is difficult to adjust the DHW load or turned down the DHW temperature.

The DSM requires real-time monitoring, control and decision support to coordinate various components in the DH system. In recent years, there has an increasing use of multi-agent (MA) frameworks to model complex environments. MA is ideally suited to representing problems that have multiple problem solving methods, multiple perspectives and/or multiple problem solving entities. MA is known as best suited for distributed and concurrent problem solving. MA approach has been applied in the field of distributed energy generation [7], building energy [8], as well as in DH system [9]. In this paper, the MA approach is applied to smooth the DH load for a cluster of buildings through utilization of the building mass for thermal storage.

2. Control building load shifting

A simplified building heating dynamic equation is applied to test the building heating load control strategy. The model assumes a homogeneous temperature for the whole building thermal mass. The heating supply comes from room heating units. Solar heat and internal heat gain are neglected in the model.

$$\sum_i \rho_i V_i c_i \frac{dT_{room}}{dt} = \dot{Q} - (\sum_i U_i A_i + \rho c_p V_p)(T_i - T_o) \quad (1)$$

The room temperature can be solved as:

$$T_i = \frac{\dot{Q}}{\sum_i U_i A_i + \rho c_p V} + T_o + \left[T_s - \frac{\dot{Q}}{\sum_i U_i A_i + \rho c_p V} - T_o \right] \exp\left(-\frac{t}{\tau}\right) \quad (2)$$

The building time constant is expressed as:

$$\tau = \frac{\sum_i \rho_i v_i c_i}{\sum_i U_i A_i + \rho c_p V} \quad (3)$$

The numerator is the building heat capacity which includes the exterior and internal walls, roof, floors and furniture. The denominator is the steady-state heat loss coefficient including heat transfer through building envelope and air ventilation/infiltration. It was reported combing distributed heat capacities into a lumped capacity lead to overestimation of the building time constant [6]. Though in the paper, time constants are prescribed for typical buildings.

A heating load factor x is introduced as the ratio between actual heating supply (\dot{Q}) and the heat required to maintain the current room temperature (\dot{Q}_s). When $x=1$, the current room temperature is maintained. The room temperature will below the room temperature at the previous time step when $x<1$, or exceed the previous temperature when $x>1$. Figure 1 shows room temperature variation under different heating load ratio at constant ambient temperature.

$$T_i = \frac{x\dot{Q}_s}{\sum_i U_i A_i + \rho c_p V} + T_o + \left[T_s - \frac{x\dot{Q}_s}{\sum_i U_i A_i + \rho c_p V} - T_o \right] \exp\left(-\frac{t}{\tau}\right) \quad (4)$$

Equation 7 is used to predict the room temperature variation under different heating load input. For each time step, the room temperature is calculated as:

$$T_i^{t+1} = (T_i^t - T_0^t)\chi^t + T_0^t + (T_i^t - T_i^t\chi^t + T_0^t\chi^t - T_0^t)\exp(-\Delta t/\tau) \tag{5}$$

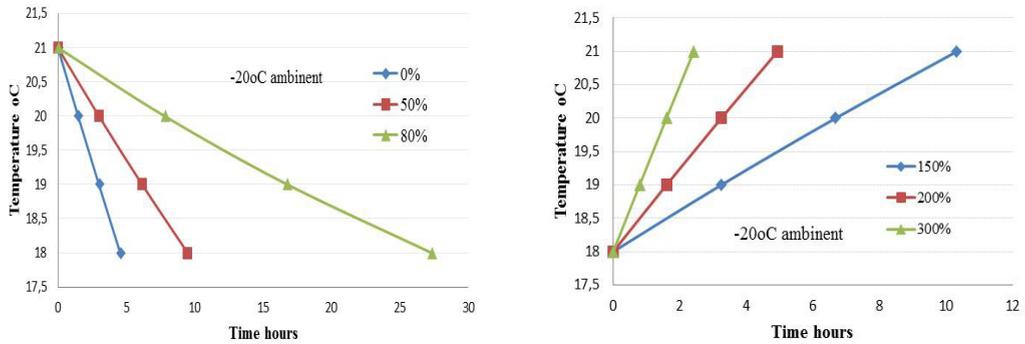


Figure 1 Room temperature variation under different heating load factor (Left: $x < 1$, right: $x > 1$)

3. Agent based control

Agent based models use a class of computational models includes physical or virtual entities to intelligently interact in the built environment. It is suitable for intelligent DH system control and management due to the inherent modular, decentralized changeable, ill-structured, and complex characteristics[10]. The system structure of this MA based system is shown in Figure 2 . It contains two main layers: system layer and entity layer.

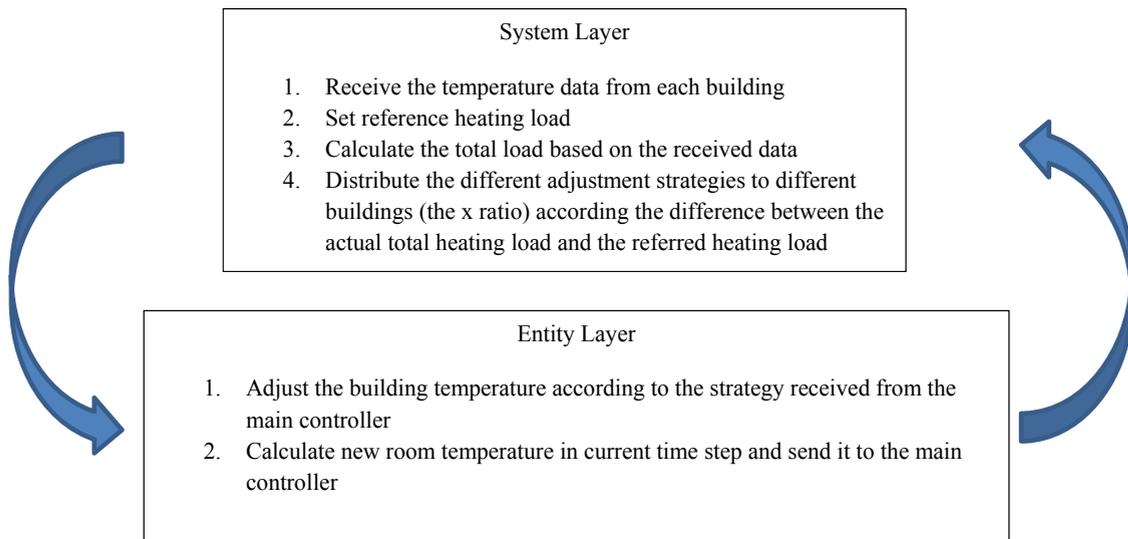


Figure 2 Multi-Agent based system structure

4. Results and analysis

A cluster of buildings are tested with 5 different groups classified by 5 time constants: 40, 60, 80, 100, and 120. It ranges from normal building to heavy construction type of buildings [2]. It is assumed the thermal comfort temperature can be adjusted within $\pm 1^\circ\text{C}$ around the optimal indoor temperature at 21°C .

In the paper, the MA control approach tends to smooth the DH load under different ambient temperatures. -12°C and -10°C are set as the reference temperatures.

As the starting point, all buildings are assumed with uniform room temperature at $T_{set}=21^{\circ}\text{C}$. The system layer calculates the required total heating load reduction and distributes it to different buildings according to their thermal storage capacity and room temperature.

If the building temperature is lower than $(T_{set}-1)^{\circ}\text{C}$, the building heating load factor is greater than 1 in order to maintain the acceptable comfort room temperature. If the building temperature is higher than $(T_{set}+1)^{\circ}\text{C}$, accelerated heating load reduction will be taken.



Figure 3 Distribution of the cluster of buildings

Through adjustment of the heating load factor, the MA approach levels out the total DH heating load corresponding to the reference temperature. Figure 4 shows the heating load factor x variation under different ambient temperatures for different type of buildings. It can be seen that x varying the same trend as ambient temperature variation: when the ambient temperature decrease below -12°C , x becomes less than 1 to reduce the heating supply to buildings. When ambient temperature increases above -12°C , the x will exceed 1 to charge the building with extra heating supply. The building with highest thermal mass (type 5) have the largest x factor variation which indicates buildings with large thermal mass will play more roles in the load shifting management.

For each time step, each building is regulated to achieve similar room temperature so that the consequence of load management strategy can be fairly distributed to each consumer. Figure 5 shows the room temperature variation at different reference temperature -12°C and -10°C . Higher reference temperature requires a higher degree of load shifting regulation which results relative lower room temperature.

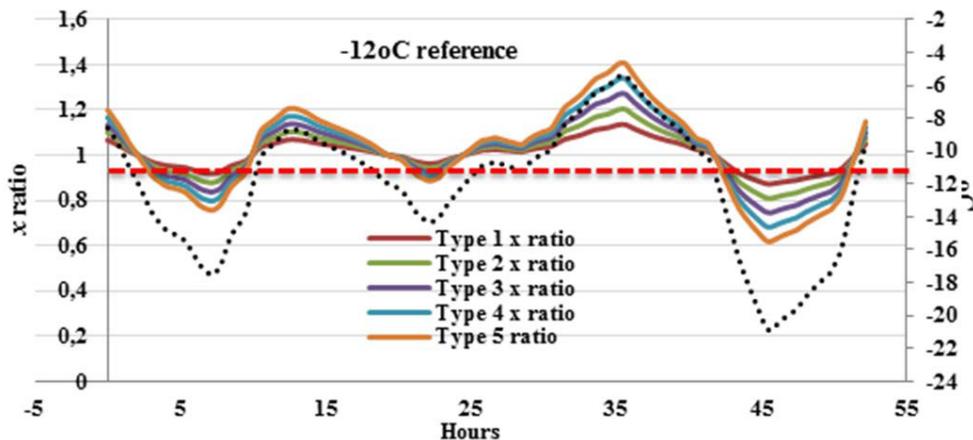


Figure 4. Heating load factor for different type of buildings at different ambient temperature

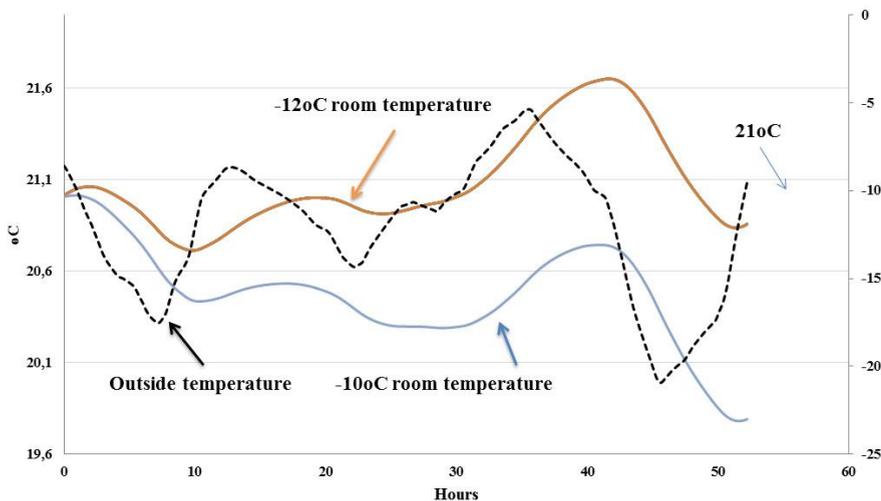


Figure 5. Room temperature variation under different reference temperatures

5. Conclusion

In this paper, the building heating load management is performed through the MA method with a simplified homogeneous building dynamic model. 5 different types of buildings with different thermal time constants are considered. It shows that the total building heating load can be leveled out to a certain value corresponding to a prescribed reference temperature by discharging and charging the building thermal mass. The paper presents an approach to control DH load through a bi-directional data communication between system layer and entity layer in the MA structure. Future work will focus on more detailed building dynamic simulation and overall system performance control and management.

6. Copyright

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Biography

Hongwei Li is a senior researcher at the Department of Civil Engineering, Technical University of Denmark, Denmark. His research interests are DHsystems, building energy, heat transfer and numerical simulation.

Stephen Jia Wang is Program Director in Interaction Design, Department of Design, and Director, ITIDLab, Monash University, Australia. He has research interests in Tangible Interaction Design and behavioral changes for sustainable energy use.