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INFLUENCE OF OCCUPANT BEHAVIOR ON THE EFFICIENCY OF A DISTRICT COOLING SYSTEM

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ABSTRACT

The related researches about district cooling systems are very limited in China, which leads to several misunderstandings and improper applications in engineering practices. Under this background, a real project with the district cooling system in a residential community is analyzed in this paper, and the equipment performances are discussed. It is found that the occupant behavior has a key influence on the efficiency of a district cooling system. Through the simulation which accounts for the different use modes of residents, the applicability analysis about the application of district cooling systems in residential buildings is conducted. Through the research, it can be concluded that the district cooling system can only be high efficiency with a concentrated terminal load profile. And for the popular occupant behavior in residential buildings in China, it's worth examining whether the applicaition of district cooling systems is suitable.

INTRODUCTION

Energy-saving technologies for regional buildings have raised widely concern for its advantages in promoting the reasonable allocation of regional energy resources and the large-scale integrated application. As one kind of new energy-saving technologies, the application of distirct cooling systems is increasingly popular in recent years (Yang, 2010). District cooling systems can satisfy the cooling requirements for multi-buildings at the same time. This kind of cooling-supply mode have the advantage of applying refrigeration equipment with large capacity and high efficency, and compared with split air conditioning system, installed power of equipment can be reduced (Jiang et al, 2010). However, several problems exposed durting the application of district cooling systems. On one side, for the influence of short application time, there is lack of the measurement data about actual operating effect of the district cooling system, so the estimation about actual application effect remains to be proven; on the other side, how to make a reasonable forecasting about regional buildings' load situation has become a key element effecting the application effect of district cooling system.

As the foundation for the applications of district cooling system in real cases, load forecasting methods for regional buildings have caused many attentions. In the real engineering practice, load density indexes method is widely used in China. However, this method would lead to an overestimation of the total cooling load (Long, 2008). Other load forcasting method are also raised by different researches, including neural network method, Archetypes method, Samples method and so on (Swan and Ugursal, 2009). Among all the methods, neural network(NN) is one kind of widely used load prediction method (Issa et al., 2001; Sakawa et al.,2001; Dotzauer,2002; Marin et al., 2002). However, possibly due to the computational and data requirements or the lack of physical significance of the coefficients relating building characteristics to total energy consumption, the use of NN methods in modeling energy consumption has historically been limited (Swan and Ugursal, 2009). The application of Achetypes method is also quite popular (Mavrogianni et al., 2009; Nuria et al., 2012; MacGregor et al., 1993). However, currently, there has no standard method for buildings' classification, and based on existing measured data, the characteristics of cooling/heating load for the same building category have large discrepencies. From the literature review, it can be found that among all the different simulation methods, the key elements which effect the regional buildings' load profile are still under discussion.

Based on the analysis above, this paper focuses on a real project with the district cooling system in a residential community. The technical approach in this paper is shown in Figure 1. Measurd data are analyzed and taken as the inputs for the building energy modelling program DeST. The simulation results are compared with measured data to complete the calibration. Based on the model, sensitive analysis are conducted. The influence of occupant behavior on the load profile of regional buildings is analyzed, and the applicability of the district cooling system in residential buildings is discussed. The research results could have implications for load forecasting methods used in regional buildings and the researches about actual operating effect of district cooling system.

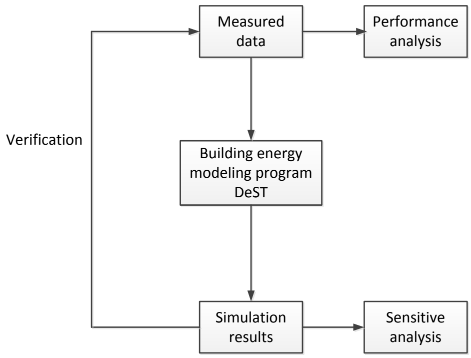

Figure 1 Technical approach

MEASURMENT AND ANALYSIS

Basic information

JY residential community is located in Henan province in China. The community covers an area of 27944m^2 with a residential floor area of 41200m^2. As Figure 2 shows, the residential community includes 12 buildings with 294 households, and each building has five floors. The occupancy rate is 75%.

Figure 2 Typical construction and flat graph for layout of JY residential community

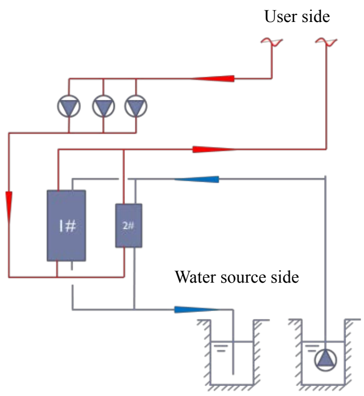

Figure 3 Schematic diagram of cooling system

The schematic diagram of the cooling system is shown in Figure 3. Two screw water source heat pump units are taken as central air-conditioning equipment with the cooling capacity of 1463kW and 542kW separately. The fan coil units (FCU) are taken as air terminals with no control in waterside. The water pumps in the water system are constant-speed, and the pumps include two circulating pump and two submersible pumps.

Measurement results

Table 1 shows the statistical results of JY community in the cooling season of 2011 (July to October). The electricity consumption in the cooling season is 7.6 kWh/m^2, which is composed of the consumption of heat pump (4.4 kWh/m^2) and water pump (3.2 kWh/m^2). The comparison of electricity consumption in the cooling season among different air-conditioning system is presented in Figure 4. The consumption of JY community is almost 2-3 times larger than that of split air-conditioning system and VRF system.

From the measurement data, the cooling consumption is 7.5 kWh/m^2. So the system efficiency which equals the total cooling consumption divides by the total electricity consumption is only 1 (=7.5/7.6), which is much less than the efficiency of split air-conditioning system (COP=2.3). Therefore, from the view of system efficiency, the operating situation of the district cooling system in the JY community is not good.

Table 1 Energy consumption of JY community in the cooling season of 2011(July to October)

TOTAL ELECTRICITY CONSUMPTION	7.6 kWh/m^2
COOLING CONSUMPITION	7.5 kWh/m^2
ELECTRICITY CONSUMPTION OF HEAT PUMP	4.4 kWh/m^2
ELECTRICITY CONSUMPTION OF WATER PUMPS	3.2 kWh/m^2

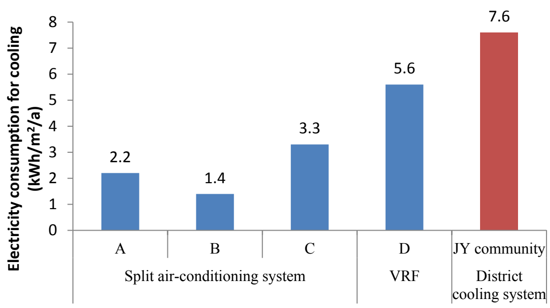

Figure 4 Comparison of electricity consumption among different air-conditioning system （Li and Jiang, 2008）

PERFORMANCE ANALYSIS

From the measured data, the system efficiency of the district cooling system is only 1. It is mainly caused by three aspects:

1) Occupant behavior about air-conditioning

The total cooling consumption of JY community in the cooling season is 7.5 kWh/m^2, which is under a low consumption level. Through measurement and survey, it is found that the main reason for this is the occupant behavior about air-conditioning. In JY community, residents used to open the air-conditioning part-time and part-space. Through the household cooling metering system, the service time of FCU terminal under different fan speed is counted in Figure 5. From the statistical results, the air-conditioning use-mode of different residents are quite different. The actual service time of FCU termials are much shorter than the design situation (24h), and they have huge discrepancies among different rooms.

The proportion of FCU terminal service time under different fan speed in different room type is calculated in Figure 6. The service time proportion of each room type is commonly small. The highest open proportion happens in living room, but the proportion is only 7%. Figure 6 proves that the residential air-conditioning use-mode in reality differs from that of design situation, which lead to the discrepancies between the actual operating efficiency and the design condition. In order to predict the operation situation of community district cooling system accurately, it is necessary to conduct reasonable forecasting about user load profile.

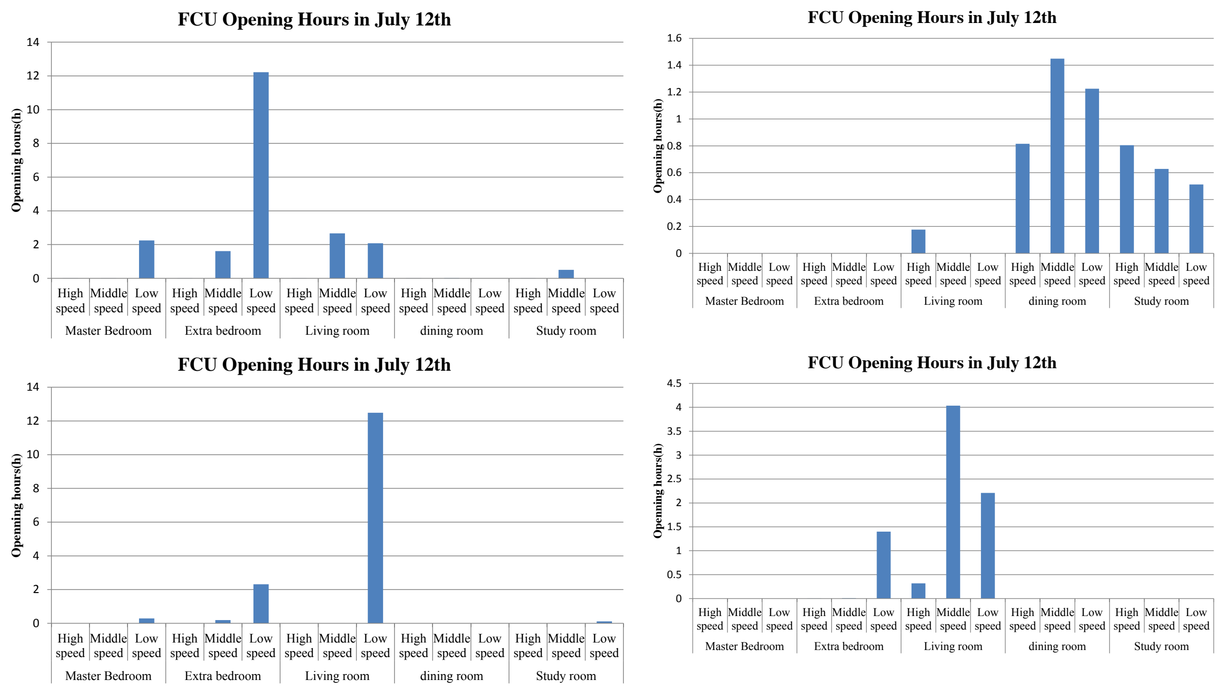

Figure 5 Statistical result of FCU terminal's service time of four typical residents

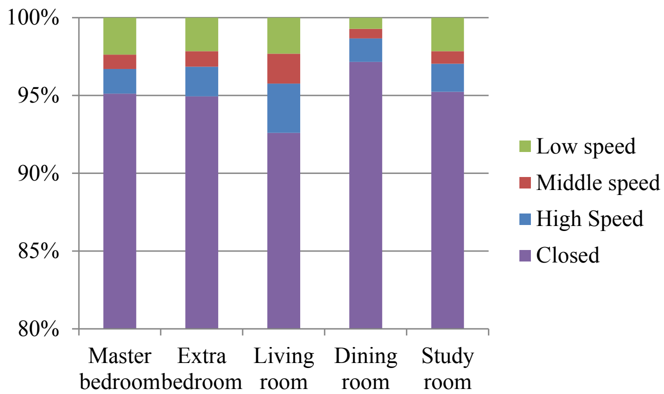

Figure 6 Service time proportion of FCU terminal

2) COP of the heat pump

Because of the occupant behaviour about air-conditioning, the cooling load requirement in the community is low, and this leads to the low load ratio of heat pumps. From measured data, when the load ratio is 36%, the COP reaches the maximum value 3.24, and when the load ratio decreases to 17%, the load ratio is the minimum value of 2.0. All of the measured COP are far smaller than the rated value of 6.4, and the main reason for this is that the system under low load ratio during all the service time.

3) Electricity consumption of water pump

The water pumps in the district cooling system are constant-speed. Under the low load ratio, the water system would work under the situation with large water flow rate and small differences between supply and return water temperature. From measurement, the electricity consumption of the water pumps can account for 42% of the total electricity consumption, which is 73% of the consumption of the heat pump. The electricity consumption of the water pumps occupies a large proportion.

SIMULATION AND VERIFICATION

In order to conduct the sensitive analysis, the simulation model of JY community is built， and the inputs are based on the measured data. The simulation results are compared with the measued cooling consumption to complete the verification.

From the metering system in JY community and the measurement in the typical househlods, 5 kinds of air-conditioning use-modes can be extracted in Table 2, and the proportion of each use-mode can also be concluded, as shown in Table 3. The air-conditioning use-modes differ from the aspects like when the air-conditioning would be open, what is the setting air temperature and so on.

The measurement is from July 11th to July 14th, and the ourdoor air temperature is shown in Figure 7. During the measurement, the lowest outdoor air temperatue is 22.1 ^{o}C, higest value is 36.9 ^{o}C, and the average value is 29.6 ^{o}C.

Table 2 Five kinds of air-conditioning use modes

USE-MODE	**DESCRIPTION OF USE-MODE FOR AIR-CONDITIONING (T is short for temperature)**
1	Living room: Open T: 29℃, setting T: 28℃; Bedroom: Open T: 29℃, setting T: 27℃. Air conditioning would only be opened at night.
2	Living room: Open T: 30℃, setting T: 26℃, open time: at noon and at night; Bedroom: Open T: 29℃, setting T: 26℃, open time: at night;
3	Living room: Setting T: 26℃; Bedroom: Setting T: 27℃; Air conditioning would be opened all day long.
4	Living room: Open T: 29℃, setting T: 27℃, open time: only related to indoor T; Bedroom: Setting T: 27℃, open time: all day long.
5	Air-conditioning would be opened all day long, and the setting T is 24℃ in both living room and Bedroom

Table 3 proportion of different use-mode

USE-MODE	Non use	Use-mode 1	Use-mode 2	Use-mode 3、4、5
PROPORTION	60%	10%	10%	20%

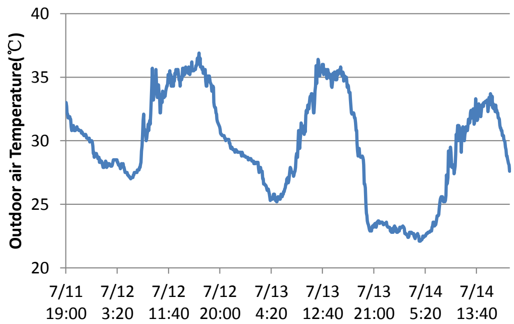

Figure 7 Outdoor air temperature

Based on the information above, the DeST software developed by Tsinghua University (Yan et al., 2008; Zhang et al., 2008) is used to conduct the simulation. 12 building models in the JY community are built and other survey information like building information (indoor heat gain, envelope information et al.), operating hours (10:00 am to 3:00am in the next day), features of water system (no control in water flow rate) and so on are taken as input parameters. The cooling load of JY residential community are calculated and compared with measured data, as Figure 8 shows. The data edges of this quartile graph are the data points at the probabilities of 95% and 5%. From the comparison, it proves that this simulation model has the ability to reflect the main characteristics of real situation.

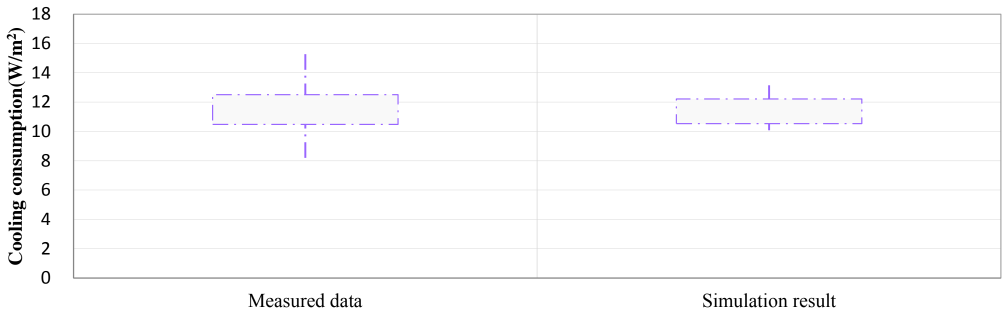

Figure 8 Comparison between simulation result and measured data

SENSITIVE ANALYSIS AND DISCUSSION

With the simulation model, further analysis is conducted to reveal the applicability of district cooling systems.

Optimization of design scheme

To exclude the problems involved during design stage, the optimization of design scheme is conducted. The terminal flow rate can be bypassed according to the load requirement in the new design. The peaking load is calculated based on the use-mode of number 5, in which the air terminal would be used all day long, and the setting temperature is 24^{o}C. In this way, the chosen cooling capacity of the chiller is 997kW. The design difference between supply and return water temperature is 5^{o}C, with the assurance coefficient of 1.1, so the rated flow rate of circling pump is 188m^3/h. According to the plane graph of community and related engineering design manual, the rated pump head is designed to 38m. The efficiency of circulating pump is assumed to 0.7, and the rated electricity consumption of circulating pump is 28kW. There is lack of the information about submersible pump, so the measured electricity data is applied here. The chiller model in the equipment library of DeST is used. The rated COP is 6.4, which is the same with the measured situation. Under the new design, the rated distribution efficiency is 10.87, and the rated efficiency of the district cooling system can reach 4.09.

The influence of terminal occupant behaviour

Building load situation and average daily air-conditioning operating hours under the 5 kinds of occupant behaviors (listed in Table 2) are calculated and shown in Figure 9. The quartile graph refers to the left coordinate, and the triangles in the figure corresponds to the right coordinate, which represents the average daily cooling hours. From the simulation results, it can be found that the cooling loads under different use-modes have large discrepancies, as well as the average daily cooling hours.

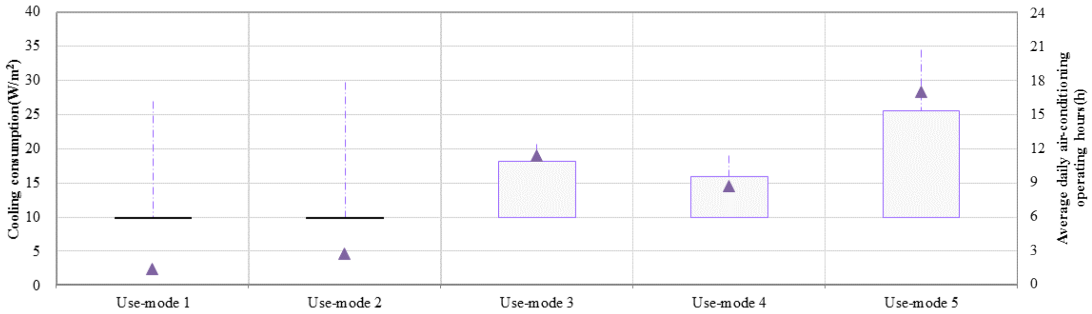

Figure 9 Building load situation and average daily cooling hours under different use-mode
Note: The blue boxes show the first and third quartiles; the vertical dashed blue lines show the range

Under the new design, the influence of different terminal occupant behavior on the system consumption and efficiency can be calculated and compared, which is shown in Figure 10 and Figure 11. Under different occupant behavior, the enenrgy efficiency has large differnces. Under the district cooling system, as the increase in load level and concentration degree, the COP value and ditribution efficiency is improved. It reveals that only under certain terminal load situation, can the system reach high efficiency. Influencd by the high electricity consumptio of water pumps, even under the use-mode 5 which represents the high air-conditioning use frequency, the average system comprehensive efficiency is lower than 3. Otherwise, from the electricity consumption simulation result in Figure 11, it can be found that, under the district cooling, the high system efficiency corresponds to the high electricity consumption, namely the total energy consumption increases as the system efficiency. This finding reveals that the district cooling systems cannot decrease the total energy consumption efficiently, and there exists suitable condition for the high system efficiency. When the cooling load requirement amount is larger, the system would be more energy-saving. Under the low cooling load requirement, the district cooling system cannot exert its advantages, even leading to the waste of resources.

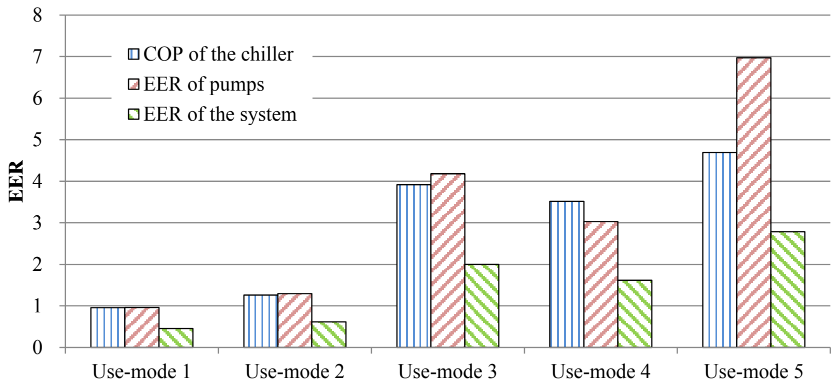

Figure 10 Energy efficiency under different use-mode

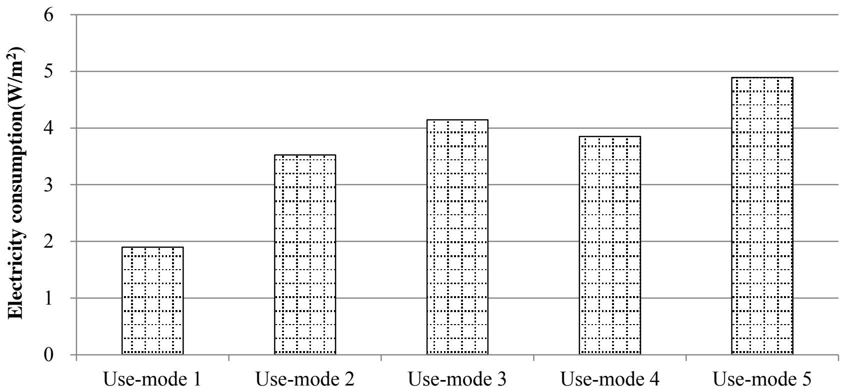

Figure 11 Electricity consumption under different use-mode

CONCLUSION

Based on the analysis of the measured data from a district cooling system in a residential community, this paper discusses the system efficiency and enenrgy consumption of the district cooling system under different occupant behavior. The main conclusions include:

1. From the measurement, the system efficiency of the district cooling system in the residential community is only 1.
2. Through performance analysis, it is found that the occupant behavior has a large influence on the efficiency of the district cooling system. Under the low cooling load requirement, the district cooling system cannot exert its advantages in system efficiency.
3. Through sensitive analysis, it can be concluded that different use-modes in the same building category would lead to huge discrepancies in the cooling load. It is necessary to take the occupant behavior into consideration in order to conduct an accurate load forecasting about regional buildings.
4. For the huge influence of the occupant behavior, the suitable technology or system type should be chosen according to the service objects.

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