Case studies: the effect of occupant behaviors on evaluating the adaptability of district cooling system

Guangwei DENG[1], Da YAN[2☆], Rui YU[2]

1College of Architecture and Civil Engineering, Beijing University of Technology, Beijing, China
2Department of Building Science, School of Architecture, Tsinghua University, Beijing, China
Corresponding author[☆]. Tel.: +010-62789761E-mail address: yanda@tsinghua.edu.cn

ABSTRACT

This paper takes two real residential communities as example, shows the district cooling's current utilized situation and common problems, and explains how occupant behaviors affect evaluating adaptability of district cooling. Based on investigation data, paper simulates district cooling working performance utilized in residential and office community under four different occupant behavior modes, explaining occupant behavior's effect on district cooling system and showing reasons of low system efficiency.

KEYWORDS: occupant behavior, district cooling, adaptability of technology

1. Introduction

As one kind of the clean energy and high energy utilization efficiency technology, district cooling system (DCS) is considered as development direction of traditional cooling forms by some researchers. Existed DCS are mainly in the United States, Japan, France and some Northern Europe developed countries [1], and some of them like DCS in Stockholm [2], Shinjuku Xindu Area [3] works pretty well. In China, the history of DCS is less than 30 years, typical large-scale DCS is like Beijing Zhongguancun West District Cooling System[4], Guangzhou University City [5].

Compared to decentralized cooling system, DCS has many advantages such as it takes full advantage of economy of scale and diversity of cooling demand of different buildings, reduces noises and structure load, saves remarkable equipment area[6][7].But in practice, DCS usually equals to low system efficiency and high operating cost, and this situation becomes much worse when DCS is used in residential buildings[8].

Occupant behavior has a great influence on building cooling load which finally affect the DCS energy efficiency. Chinese occupants' saving and personalized character leads to low intensity and dispersed cooling load. In this situation, system has to work under low load rate which leads to low chiller efficiency. At the same time, pumps will work under a "big water flow, small temperature difference" situation, and also leads to low pump efficiency which is the most serious and common problem of residential building DCS.

2. Problems of district cooling system for residential buildings

Jinyuan (JY) and Modern City (MC) are two residential building projects which both utilized water heat pump for district cooling. A detailed research and test about the DCS has been held between July and August 2012. The basic information about the projects is shown in Table 1.

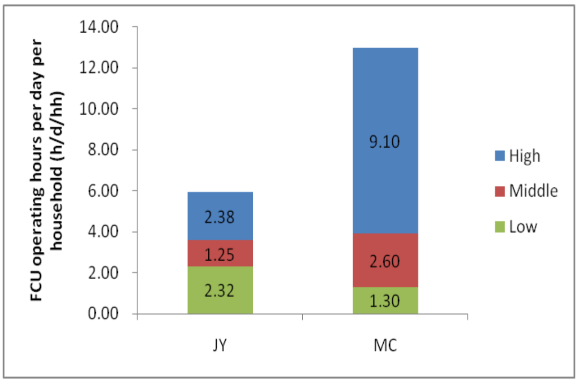
Table 1 basic information of the projects

	JY		MC	
Location	Lingbao, Henan		Wuhan, Hubei	
Completion time	March, 2009		November, 2009	
Building area	$41200m^2$		$50000m^2$	
Building composition	12 buildings, each 5 layer		5 buildings, each 18 layer	
Number of households	294		413	
Occupancy rate	75%		85%	
System form	District cooling by water source heat pump, terminal FCU		District cooling by water source heat pump, terminal FCU	
Water system	Constant primary flow system, FCU without electric valve		Constant primary flow system, FCU with electric valve	
Equipment parameters	1# heat pump	Cooling capacity1463kW, Power226kW	1# heat pump	Cooling capacity633kW, Power112kW
	2# heat pump	Cooling capacity542kW, Power89.7kW	2# heat pump	Cooling capacity633kW, Power112kW
	circulating pump	Flow 190m3/h, head38m, Power37kW, 2with 1prepared	circulating pump	Flow 160m3/h, head 32m, Power22kW, 2 with 2 prepared
	diving pump	Flow 80m3/h, head 50m, Power30kW, 2 with 2 prepared	diving pump	Flow 60m3/h, head60m, Power13kW, 2 with 2 prepared
Running time	24h		24h	

Saving is Chinese traditional habit which includes saving energy, saving money and saving everything can be saved. Especially in the building which equipped the household heat-metering system and charge as residents use, people are used to reduce the FCU operating time or choose a lower gear. This behavior leads to a low cooling load level obviously.

But, it's hard to predict the occupant behavior is saving or not in one specific project which will lead a huge load difference. Figure 1 shows the ratio of different FCU gears operating time of JY and MC projects. Occupant behavior in JY and MC project is quite different. In JY project, the FCU high gear operating time ratio is only 40% which is 70% in MC project, the total FCU operating hours per day per household is 5.95h/d/hh which is 13.0h/d/hh in MC project.

The DCS installed capacity of JY and MC are almost the same. But, behavior of occupants in JY project has typical saving characteristic which leads to low average load rate at 31%. It shows that exact judgment about the occupant behavior is really necessary during the system design stage. Saving or not may lead to completely different adaptability evaluating result.



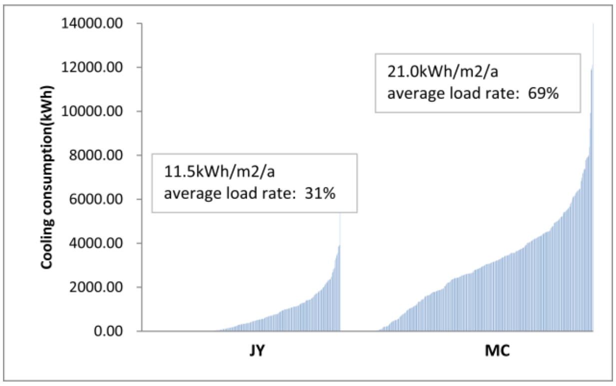
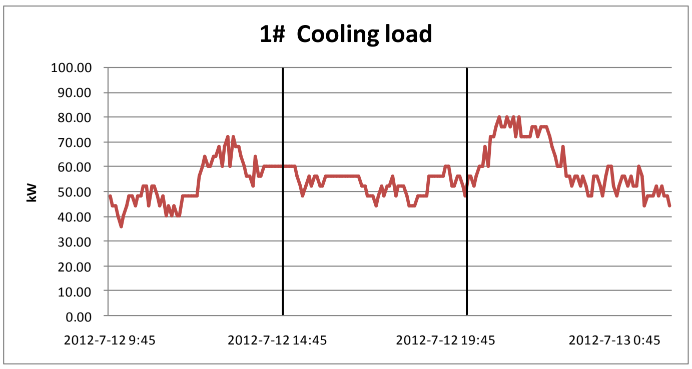
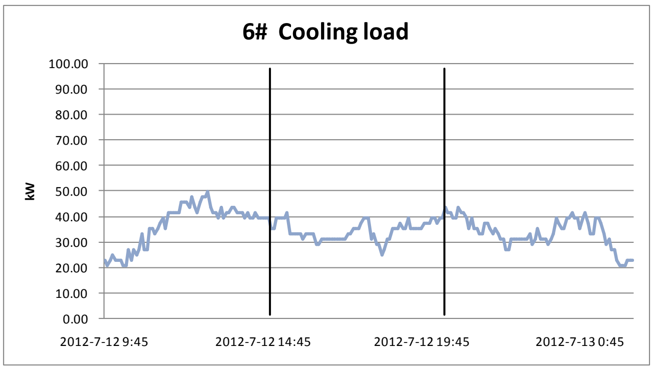


Figure 1FCU average operating time

Figure 2 Apartment Cooling consumption in 2011

Occupant behavior's saving character affects the system average load level, and its personalized character affects system hourly load rate. Take JY project as example, Figure 3 shows the typical buildings' hourly cooling load (9:00 12/7/2012～3:00 13/7/2012, Thursday, workday). It shows that different building has different operating time, different load level and different peak load time. These differences' combination leads to a "ladder-shaped" system hourly load: steady and low intensity. This situation forces DCS works under low load rate for all day long. This is another reason for DCS low system efficiency utilized in residential buildings.





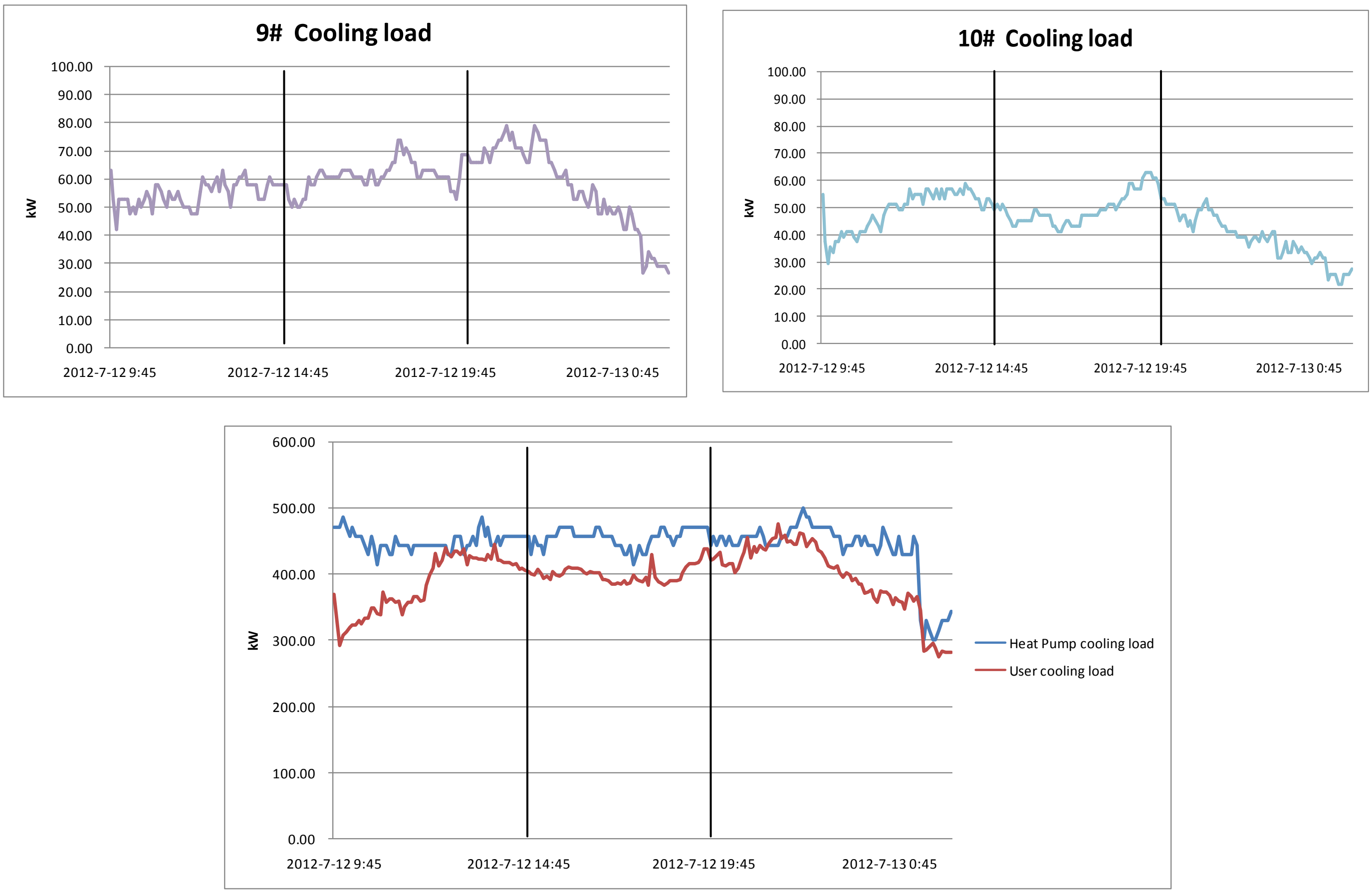


Figure 3 Typical residential building and system cooling load curve of JY

DCS operating parameters are shown in Table 2. With a higher load rate because of the difference of occupant behavior, DCS in MC project performs much better than JY project. DCS in MC project has higher system efficiency, lower electricity consumption when supplies twice cooling than JY, better economic efficiency. We can find how deep the occupant behavior's effect on DCS working performance.

On the other hand, even as good as MC project, the system EER is lower than 3.0 which means the DCS more or less equals to split system and worse than independent central system (EER=4.0～6.0). The main problem is the low pump efficiency. DCS's huge supply area forces it to equip the pumps with big flow and high lift. When system works under low load rate, the cooling load needs to transported is small while pump's power is almost the same high. That's why DCS's pump efficiency comes low.

Table 2 System operating parameters

		JY	MC
System efficiency	Average load rate	0.31	0.69
	Average heat pump COP	2.87	4.38
	Average pump efficiency	1.84	8.75
	Average EER	1.12	2.84
System	Cooling consumption per unit area per year	11.5	21.0

energy consumption	kWh/m²/a		
	Cooling electricity consumption per unit area per year kWh/m²/a	9.9	7.4
	Cooling unit-price Yuan/kWh. cooling	0.78	0.35

3. Simulation analysis

A simulation program named DeST is used here to calculate the residential and office building cooling load and system energy cost. The building models shows in Figure 4.

Model input data comes from actual research and test including building envelope parameter, meteorological parameter, indoor thermal parameter, occupant and equipment working scheme. Main information for simulating is shown in Table 3. Building cooling load simulation result for single building is shown in Figure 5 and Figure 6. The DCS load is combination of all buildings cooling load. The coincidence factor is shown in Figure 7.

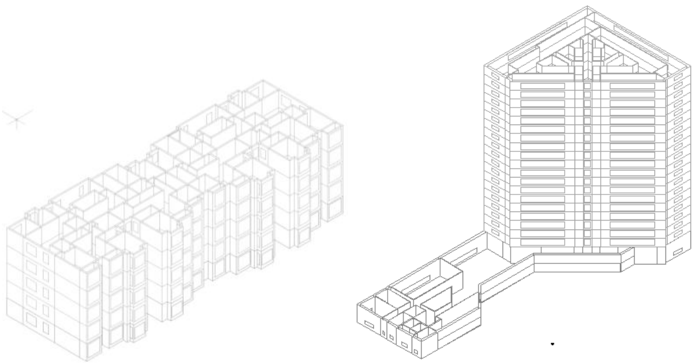


Figure 4 DeST models of residential and office building

Table 3 Parameters of district cooling system building and equipment

		Residential Building	Office Building
Building parameters para	Number of buildings	10	10
	K of Exterior wall W/(m²·K)	1.5	1.0
	K of Roof	0.6	0.6
	K of External window	2.5	2.0
	Sc of External window	0.83	0.75
Water source heat pump	Rated cooling capacity kW	372	3208
	Rated power kW	74.4	628
Chilled water pump	Flow m³/h	130	265
	Head m	25	30
	Power kW	15	31
Chilling water pump	Flow m³/h	150	310
	Head m	30	35
	Power kW	17	34

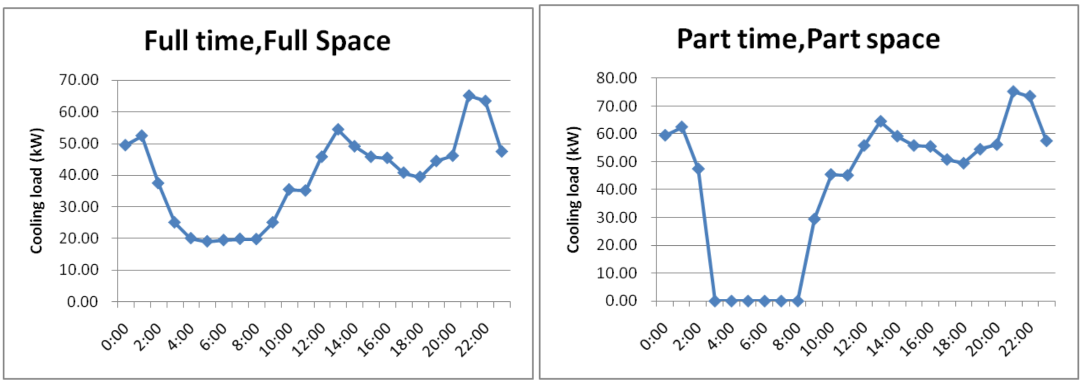


Figure 5 Cooling load curve of single residential building (typical day, 12/8/2011)

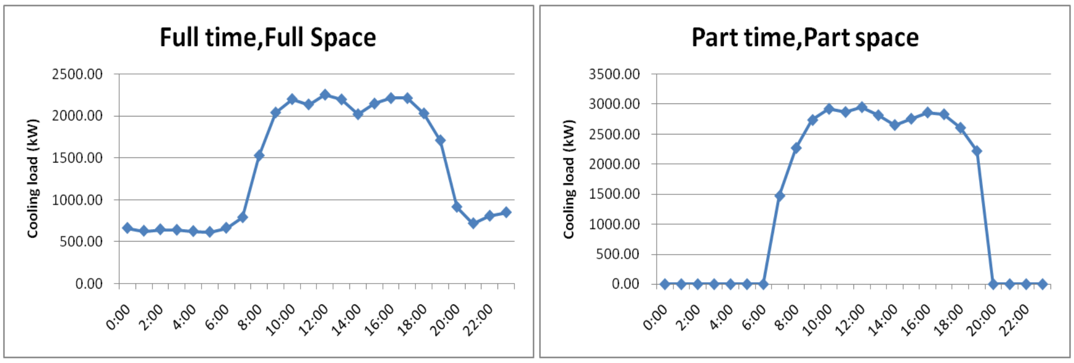


Figure 6 Cooling load curve of single office building (typical day,12/8/2011)

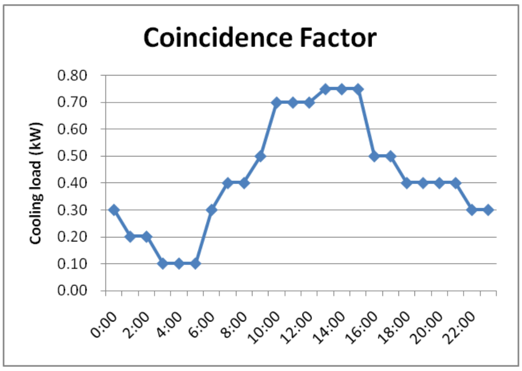


Figure 2 District cooling coincidence factor

In order to research occupant behavior's effect on DCS working performance, 4 different behaviors shown in Table 4 are considered. Mode 1: Full time full space, synchronizing at load. Mode 2: Full time full space, desynchronizing at load; Mode 3: Part time part space, synchronizing at load; Mode 4: Part time part space, desynchronizing at load. If load is synchronizing, coincidence factor is fixed at 1 for all day time. If load is desynchronizing, coincidence factor is shown in Figure 7.

Table 4 Simulated working conditions comparison

	Mode1	Mode2	Mode3	Mode4
Full time, Full Space	√	√		
Part time, Part Space			√	√
Load sync	√		√	
Load out of sync		√		√

The simulated results are shown in Figure 8. It can be concluded that:

1) The system efficiency is low when the load ratio is low at night, which causes that system efficiency of "full-time & full-space" mode (Mode1, Mode2) is lower than "part-time & part-space" mode (Mode3, Mode4).
2) Under the same load mode, namely all are "full-time & full-space" mode or all are "part-time & part-space" mode, the system efficiency is higher when the load is synchronous.
3) The pumps' Low efficiency is the main reason of district cooling's low efficiency. When the buildings' load is not synchronous, the load ratio is low. Meanwhile the pumps' control ability is limited. As a result, high flow & small temperature difference happen frequently, which leads to low efficiency of pumps. It is one of the most common reasons of pumps' low efficiency.
4) Compared with office building, residential building has less demand, so its load ratio and heat pumps' efficiency are low. At the same time, for residential building is more decentralized, the system has to install larger pumps. Oversized pumps and low load ratio result in low efficiency of pumps of residential building's district cooling system, which affect efficiency of the whole system severely. In that case, when district cooling is adopted on residential building, factors like load ratio, pump efficiency and so on should all be considered, and otherwise it is not recommended.

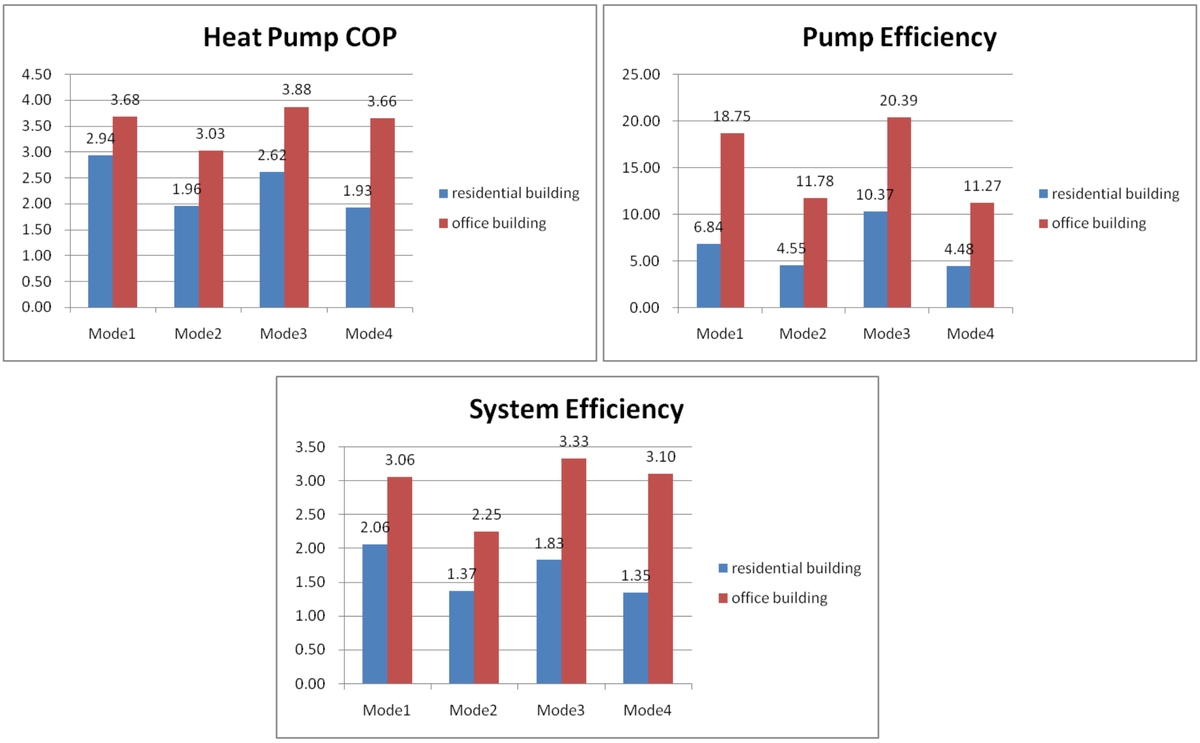


Figure 8 Simulation Result

4. Conclusion

1) Human behavior has a direct effect on building load, load's distribution and proportion among a cluster of buildings, which will affect system operation's energy consumption and efficiency by way of load ratio. District cooling system

should take the effect of human behavior on building load into account, so as to get most scientific and reasonable design scheme.

2) The biggest disadvantage of actual district cooling is low load ratio and problems such as low efficiency of transmission, chillers and system which is caused by low load ratio. To make an excellent district cooling system, it is necessary to know more about human behavior, optimize the equipment and improve the auto-control system.
3) Residential buildings has characteristics of low cooling load, personalized load distribution and decentralized building layout, which makes it difficult to get a good operating condition. Compared with office buildings which has high load, concentrated operation management of air-conditioning and centralized building layout, it is more difficult for residential buildings to apply district cooling system.

5. Reference

[1] Goran Momhe, Thomas R. Casten. Innovation in district heating and cooling 1984-1994 and their economic impact[J].ASHRAE Trans, 1995, 101(1): 911~916

[2] Jacques Dellbes. The District Cooling Handbook. Brussels: European Marketing Group of District Heating and Cooling, 1999.

[3] T.T.Chow. Applying district cooling technology in HongKong[J]. Applied Energy, 2004, (8): 23-26

[4] Wang Gang, the Swedish district cooling technology to China, Enlightenment[J], Building Energy, 2004, (3): 24-29.

[5] The international association for combined heat and power. District heating and cooling. Brnssels: Enroheat&Power, 2005.

[6] Lam Carl. The development of district cooling system in Hong Kong. In: Proceedings of Shenyang–Hong Kong joint symposium, Shenyang, China; 2004. p. A48–56.

[7] Enstro ¨m Henrik, Lei Tan. District cooling and its impact on environment, health and building architecture. In: Liu Junjie, Zhang Tengfei, ZhaiZhi-qiang(John), editors. The first international conference on building energy andenvironment proceedings, Tianjin, China; 2008. p. 1601–8

[8] Shuzo Murakami, Mark D l, Hiroshi Yoshino .Energy consumption, efficiency, conservation, and greenhouse gas, mitigation in Japan's building sector[R] . Lawrence Berkeley Laboratory , 2006: 56