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Impacts of Technology-guided Occupant Behavior on Air-Conditioning System Control and Building Energy Use

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Abstract: Occupant behavior is an important factor affecting building energy consumption. Many studies have been conducted recently to model occupant behavior and analyze its impact on building energy use. However, to achieve a reduction of energy consumption in buildings, the coordination between occupant behavior and energy-efficient technologies are essential to be considered simultaneously rather than separately considering the development of technologies and the analysis of occupant behavior. It is important to utilize energy-efficient technologies to guide the occupants to avoid unnecessary energy uses. This study, therefore, proposes a new concept, *technology-guided occupant behavior* to coordinate occupant behavior with energy-efficient technologies for building energy controls. The occupants are involved into the control loop of central air-conditioning systems by actively responding to their cooling needs. On-site tests are conducted in a Hong Kong campus building to analyze the performance of *technology-guided occupant behavior* on building energy use. According to the measured data, the occupant behavior guided by the technology could achieve "cooling on demand" principle and hence reduce the energy consumption of central air-conditioning system in the test building about 23.5%, which accounts for about 7.8% of total building electricity use.

Keywords: occupant behavior; occupancy detection; cooling demand control; energy consumption; HVAC system.

1. Introduction

The energy consumption of buildings is a major concern worldwide, which has increased rapidly in recent years due to the grown population, the increased demand on indoor environment control, the global climate changes, etc. Approximately 40% of global energy is consumed by buildings (Krarti 2003, Omer 2008). In the United States, buildings accounted for 74% of electricity use in 2010 (DOE 2011) and even more in Hong Kong (EMSD 2012). In non-residential buildings, the energy use of central air-conditioning systems can account for nearly 50% of total building energy use on average (Tang et al. 2018, Ding et al. 2019). Hence, it is necessary to find out the possibilities to achieve energy reduction and efficiency improvement of central air-conditioning systems.

Many factors influence the energy consumption of central air-conditioning systems, such as outdoor weather condition, building envelop, system operation performance, and occupant behavior. Among these factors, occupant behavior plays an important role in building energy use. It is influenced by quite a large number of factors, including: external factors (e.g., air temperature, wind speed), and internal factors (e.g., personal background preferences) as well as the building properties (e.g., ownership, available cooling/heating devices) (Andersen et al. 2009, Fabi et al. 2012). Energy-related occupant behavior as the simple form includes adjusting thermostat settings, opening/closing windows, dimming/switching lights, pulling up/down blinds, turning on/off HVAC systems and movement between spaces (Hong et al. 2016). Socolow (1978) first pointed out that the occupant behavior had a significant influence on the building energy use based on an investigation on energy consumption of a set of houses. Danny Parker of Florida Solar Energy Centre (2012) investigated the energy uses of ten identical houses and found that the occupant behavior led to the energy uses of studied houses varied, even though they were with the same floor area, located on the same street, built in the same year and with similar efficiencies of building systems. According to these studies, occupant behavior cannot be ignored when considering the building energy use.

Due to the uncertain characteristic, occupant behavior is difficult to be predicted accurately, which will lead to the actual building energy consumption deviated widely from the predicted/simulation results. Thus, many studies on the modelling of occupant behavior (Aerts et al. 2014, Gunay et al. 2014, Lee and Malkawi 2014, Hong et al. 2015) and the quantification of its impacts on building energy use (Azar and Menassa 2011, Mahdavi and Tahmasebi 2015, Pothitou et al. 2016, Delzendeh et al. 2017) have been conducted. Yan et al. (2015) pointed out that the improved resolution of occupant-related data could benefit the building energy prediction and the development of control strategies. Zhao et al. (2014) developed a practical data mining approach using office appliance power consumption data to learn the influences of occupant behavior on the building energy use of a medium office building. Sun et al. (2014) developed a stochastic model to analyze the impacts of occupant behavior of overtime working on the building energy use based on the measured data. Langevin et al. (2015) developed an agent-based model of occupant behavior considering seasonally acceptable thermal sensations, using data from a one-year field study in a medium-sized, air-conditioned office building.

Demand-driven control, in fact, is considered as an important part for demand-side management. But, occupants, as an important role at demand side in buildings, are sometimes unaware of influences of their actions on the energy use. This will significantly increase the building energy consumption by up to one-third of its design performance (Nguyen and Aiello 2013). Considering the facts that occupants cannot completely achieve energy-conscious behavior particularly in non-residential buildings, occupancy detection has to be adopted for demand-driven control to obtain information about occupant behavior. The occupancy detection always uses passive infrared and ultrasonic technologies to signal space occupancy based on changes of sensors in temperature or sound profile of detected spaces. Dodier et al. (2006) developed a network of passive infrared occupancy sensors in two private offices to determine the occupancy information. Page et al. (2008) proposed a model using Markov chains method to detect the occupancy state in private office. Overall, most of the studies on occupancy detection are very dependent on the data collected from sensors and the complicated algorithm for accurate prediction, which would lead to inevitable prediction errors and extra costs due to sensor installation.

To achieve the reduction of energy consumption in buildings, the coordination between the occupant behavior and the energy-efficient technologies are essential rather than separately focusing on the development of technologies and the modeling of occupant behavior. Meanwhile, due to the help of building automation systems, the advanced technologies for reducing the energy consumption and improving the efficiency of central air-conditioning systems could be implemented conveniently (Wang and Tang 2017, Tang et al. 2018). Therefore, it is necessary to adopt the technologies/control strategies of building energy systems (central air-conditioning systems) to guide the occupant behavior for the energy saving and the avoidance of unhealthy energy use in buildings. The control strategy is capable of guiding occupants actively adjusting the behaviors to feedback their needs to the control system. This can effectively make the occupants involved in the control loop of building systems and therefore considered as an alternative means for occupancy detection. However, few studies can be found in the literature to propose such coordination between occupant behavior and energy-efficient technologies and also few studies can be found to investigate its saving potentials on building energy consumption.

Facing the above challenges, a novel concept, *technology-guided occupant behavior*, is therefore developed in this study for the coordination between occupants and technologies/control strategies of energy systems in buildings. Case studies of on-site measurements in a Hong Kong campus building are conducted to investigate the impacts of *technology-guided occupant behavior* on the energy use of central air-conditioning systems. Based on the measured data, the energy saving of the building energy system is analyzed.

2. Description of technology-guided occupant behavior

The on/off control for the operation of a central air-conditioning system in non-residential buildings is usually based on a pre-set schedule. Normally, the central air-conditioning system is switched on automatically in the morning and the cooling provided by chiller plant is transported to the terminal units of air-side to cool down the air-conditioned spaces. In the evening, the central air-conditioning system is switched off to ensure almost all occupants leave their spaces. However, the main disadvantage of this scheduled control strategy is that during system operating period, it is very likely to provide the cooling to the unoccupied spaces if occupants forget to switch off the units when they leave spaces before the automatic off control is activated.

To obtain the information of occupants for optimal control of air-conditioning system and also to avoid the installation of many sensors, technology-guided occupant behavior, i.e., the occupants are guided by control strategies/technologies to actively respond their situations to the control system, is proposed. The occupants are engaged in the control loop to establish the interaction between occupants and system. The technology-guided occupant behavior could offset the disadvantage of the above scheduled control strategy of central air-conditioning systems. Three conditions for the operation of central air-conditioning system are categorized: operating condition (cooling service is providing in occupied spaces), non-operating condition (no cooling service is providing) and semi-operating condition (cooling service is providing in unoccupied spaces). The objective of technology-guided occupant behavior used in this study is to achieve the operation of central air-conditioning system as the principle of "cooling on demand" by avoiding the semi-operating condition. The interferences via technology on the control of systems stimulate the occupants involved into the control loop and hence the cooling needs of occupants can be obtained by their active reactions. The schematic of a kind of technology-guided occupant behavior is illustrated as an example in Fig.1. At an occupant-in-loop point, i.e., the time when the technology is activated to stimulate the occupants make reactions, the terminal units (e.g., fan coil unit) at the air-side of central air-conditioning system are switched off automatically. If occupants need cooling, the terminal units in the occupied spaces will be switched on. While the units in the unoccupied spaces will be kept at off status. Such methods can also be used as a means of occupancy detection.

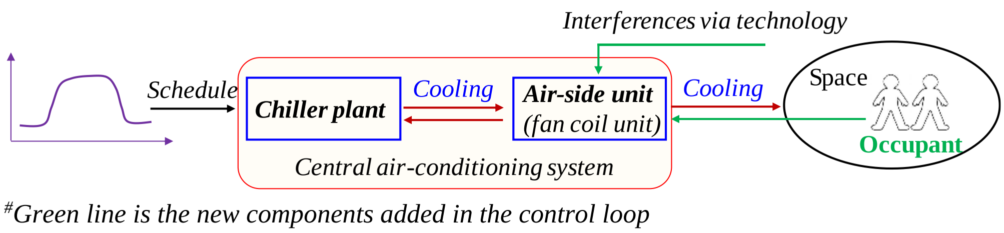


Fig.1 Schematic of technology-guided occupant behavior engaged into the system control loop

3. Test arrangement

3.1 Building description for on-site experimental tests

The building for the on-site tests is in The Hong Kong Polytechnic University. Hong Kong is a modern city with high power demand density and heavy use of air-conditioning systems. To support the routine university activities, the power demand is considerably high all year long due to the cooling requirements. The main campus of The Hong Kong Polytechnic University is located in the center area of Kowloon with a total site area of 94,600 m^2. The layout of this campus is shown in Fig.2. Twelve buildings, named 'Phase 1', 'Phase 2', etc., with different functions, such as classrooms, laboratories, offices and a library, are involved (Tang et al. 2019). In this study, the building of "Phase 8" is selected for the on-site tests and measurements.

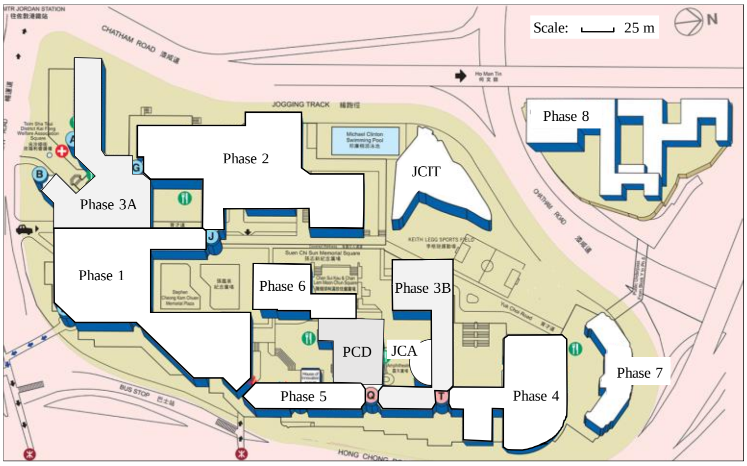


Fig.2 Campus map of The Hong Kong Polytechnic University

The building, i.e., Phase 8, has 12 stories with two basements. Its net floor area is 44,000m^2. The main functions of spaces include classroom, office, lab, and data center. A central chiller plant, located on the twelfth floor (12/F), is utilized for supplying cooling of the building. The chiller plant consists of four 800 refrigeration-tons (RT) centrifugal water-cooled chillers and one 300RT chiller of the same type. Each chiller is equipped with one constant speed primary chilled water pump. In the secondary chilled water distribution loop, variable speed secondary pumps are equipped to distribute chilled water. There are five water-cooled cooling towers and four remote radiators (air-cooled condensers) installed at the roof of the building for heat rejection. The detailed configuration of the chiller plant is shown in Table 1.

Table 1 Configuration of the equipment in the central air-conditioning system

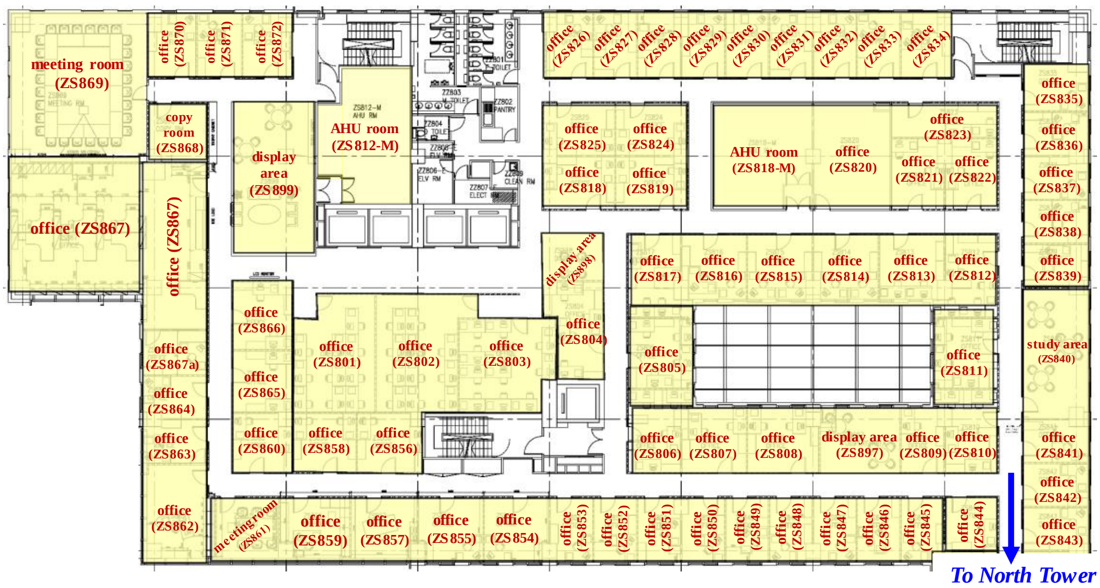
Water-cooled chillers (WCC 01-05)					
Designation	**Type of chiller**	**Power supply**	**Capacity** (kW)	**Flow rate** (L/s)	
				Evaporator	Condenser
WCC 01	Centrifugal	380/3/50	1055	46	59
WCC 02-05	Centrifugal	380/3/50	2812	122	157

Air-cooled condensers (Remote radiator) (RR-01 to 04) Test Condition: Inlet/outlet water temp. 45/40; Inlet/outlet air temp. 33/28			
Heat rejection (kW)	**Flow rate** (L/s)	**Air flow rate** (m^3/s)	**Power** (kW)

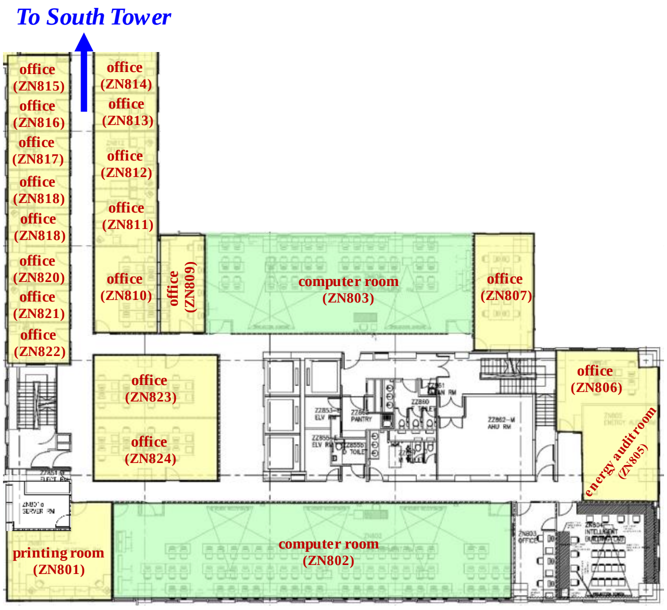
530	25.7	44.4	7.5X2

Water-cooled cooling towers (CT 01-05)				
Design condition: Inlet temp. 37ºC; Outlet temp. 32º C. Wet-bulb temp. 28ºC				
	Flow rate (L/s)	**Power** (kW)	**Voltage** (V)	**Current** (A)
CT 01	82.8	15	380	29.5
CT 02-05	167.5	22	380	42.8

The on-site measurements to study the technology-guided occupant behavior are arranged on the eighth floor (8/F) of this building. The test floor plan is presented in Fig.3. This floor is divided into two parts (i.e., south tower and north tower) and totally 101 rooms/areas are involved for the on-site tests. There are three AHU (air handling unit) rooms to provide the fresh air for this floor (two AHUs for the south tower and one AHU for the north tower). In the south tower of this floor, seventy office rooms, two meeting rooms, two AHU rooms, three display areas, one study area and one copy room (seventy-nine rooms/areas in total) are involved for the on-site tests. While, in the south tower of this floor, eighteen office rooms, one energy audit room, two computer rooms and one printing room (twenty-two rooms/areas in total) are involved. In these test rooms/areas, one fan coil unit is installed at least to meet the cooling needs.



(a) South Tower of 8/F



(b) North Tower of 8/F

Fig.3 Floor plan of 8/F in the building: (a) South Tower; (b) North Tower

3.2 Test arrangement

The technology used in this study for energy saving is named as “cooling on demand” scheme. The objective of this scheme is to guide the occupants to avoid the occurrence of semi-operating condition for cooling system operation. The terminal units, i.e., fan coil units, at the air-side of central air-conditioning system are controlled at occupant-in-loop points to guide the occupants on this floor to achieve the energy-saving controls. Before implementing the “cooling on demand” scheme, the fan coil units in the rooms on 8/F of the building are switched on at 7:45am automatically on weekdays and Saturdays. They are automatically turned off at 11:00pm during weekdays and at 6:00pm on Saturdays. On Sundays, they are turned on/off manually by operators, based on the requests of the users. During the operating periods, occupants can turn off the fans manually.

The “cooing on demand” scheme is implemented on this floor and the on-site experimental tests are arranged as follows: two occupant-in-loop points in the morning and afternoon of a weekday are selected to add the interferences via technology to the control system. On the afternoon of weekdays, when the “cooing on demand” scheme is activated, the power supply of fan coil units in the rooms/areas involved for the tests will be automatically cut off at 7:30pm except two computer rooms as highlighted by green colour in Fig.3. The power of fans in the two computer rooms will be automatically cut off at 6:30pm because these rooms are used as classrooms and the classes will be finished before 6:00pm. Then one minute later (6:31pm for two computer rooms and 7:31pm for other rooms/areas), the power supply to fans will be resumed and occupants in the rooms/areas can manually turn on the fans if they need cooling services. Otherwise, the fans will remain at off state. Similarly, on the morning of weekdays, the fan coil units are kept at off state till occupants arrive at the rooms and need cooling services. On Saturdays, the occupant-in-loop point is only conducted in the morning because the power supply of fans will be cut off at 6:00pm before the implementation of "cooling on demand" scheme.

To evaluate the influence of technology-guided occupant behavior (achieved by implementing the "cooing on demand" scheme) on energy use of central air-conditioning system, on-site measurements on 8/F are arranged before and after the implementation of "cooling on demand" scheme as follows: the power demands of air-conditioning system (A/C), the lighting and small power (i.e., socket power) in the south tower of 8/F, as well as the power demand of air-conditioning system in the north tower of 8/F were measured from 12th October 2018 to 15th November 2018. The time interval of measurements was 5 minutes. From 12th October to 28th October, the baselines of power demands before implementing the scheme were measured for the analysis and comparison with the measured results after "cooling on demand" scheme was implemented.

3.3 Instrumentation

Four power meters are used to measure the power demands of A/C (south tower and north tower), lighting (south tower) and socket power (south tower). The power meters, i.e., PQ3100 power quality analyzer, are three-phase four-wire and the detailed specification is presented in Table 2.

Table 2 Specification of power meters used for on-site tests and measurements

	Voltage Range	**Current Range**	**Power range**	**Accuracy**
PQ3100	1000V rms or DC	50mA~ 5kA AC	50W ~ 6MW	*Voltage:* ±0.2% of nominal voltage; *Current:* ±0.1%rdg. ± 0.1%f.s. + current sensor accuracy; *Active power:* (*DC*) ±0.5%rdg. ± 0.5%f.s. + current sensor accuracy;

	(AC) ±0.2%rdg. ± 0.1%f.s. + current sensor accuracy.

4. Results and discussion

In order to analyze the impacts of "cooling on demand" scheme on the fan power demand and the energy use of central air-conditioning system in the building, two weeks of measured data were selected, i.e., one week for the baseline measurement on 15^{th}~21^{th} October and the other week for the measurement under "cooling on demand" scheme on 5^{th}~11^{th} November. During the baseline measurement period, 17^{th} October (Wednesday) happened to be the Chung Yeung Festival. In order to remove the influence of holiday on the baseline measurement, the same type of workday on 24^{th} October (Wednesday) was used to replace the measured data on the Chung Yeung Festival.

4.1 Influence factors on building energy use

Considering that the baseline measurement and the measurement under "cooling on demand" scheme were carried out in two different weeks, the influence factors on the energy uses of fans and central air-conditioning system in the building were necessary to be analyzed for improving the accuracy of the comparison.

Outdoor weather condition during the test periods

Fig.4 shows the daily maximum and minimum outdoor dry-bulb temperatures during the two weeks of measurements. It can be found that the outdoor temperatures during these two weeks were reasonably high and hence occupants should require the fan coil units to provide the cooling to the rooms. According to the experiences of occupants in these two weeks, occupants would feel uncomfortable obviously if fan coil units in the rooms were switched off. This fact avoids the overestimation of energy reduction of fan power after implementing the "cooling on demand" scheme in the case that the occupants did not switch on the fan coil units without noticing the need of cooling after power supply was resumed. In addition, the outdoor temperatures of these two weeks were almost at a similar level. Hence, the outdoor weather conditions will not lead to an obvious influence on the energy uses of fan coil units on this floor and central air-conditioning system in the building during these two weeks of measurements.

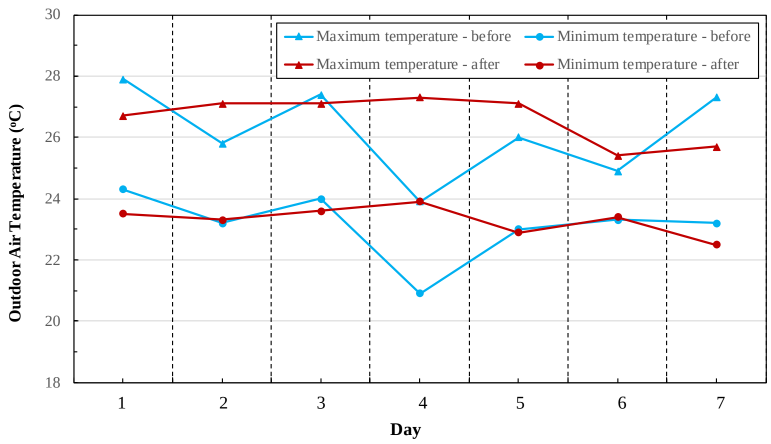


Fig.4 Weekly outdoor maximum and minimum temperatures before and after "cooling on demand" scheme implementation

Lighting and socket power

Fig.5 and Fig.6 present the weekly power demands of lighting and socket power before and after implementing the "cooling on demand" scheme, respectively. Actually, power demands of lighting and socket could respectively reflect the information on the rooms/area usage and the equipment usage of 8/F in the building (particularly for the power usage of computer because most of the test rooms were office rooms). These power demands are closely related to the number of occupants and the internal heat gain, which significantly influence the energy use of fans and central air-conditioning system in the building. Because the number of rooms/areas in the south tower accounted for over 75% of this floor for the on-site tests, the power demands of lighting and socket in the south tower were measured. Generally, no obvious differences in the power demands of lighting and socket power were observed after the implementation of "cooling on demand" scheme. It was concluded that the number of occupants and the usage of equipment (such as computers) in the south tower and even this floor were similar without an obvious change during two weeks of on-site measurements.

In addition, it is worthy of notice that, during the night period, the demand for socket power was rather high compared with that during the office hour. About 50% of power demand was still consumed during the night period. It was likely consumed by computers and some equipment in the offices, which were on standby or hibernation mode and not turned off after occupants left their offices. This could provide further energy saving by guiding the occupants to actively adjust their behaviors to avoid energy waste based on some technologies in the future study. And this is also demonstrated that there is a significant potential of building energy saving when using the technology-guided occupant behavior strategy.

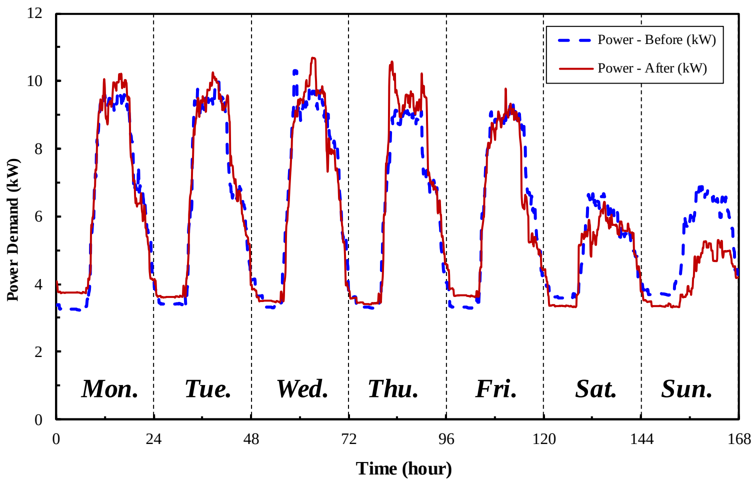


Fig.5 Weekly lighting power demand profiles before and after “cooling on demand” scheme implementation

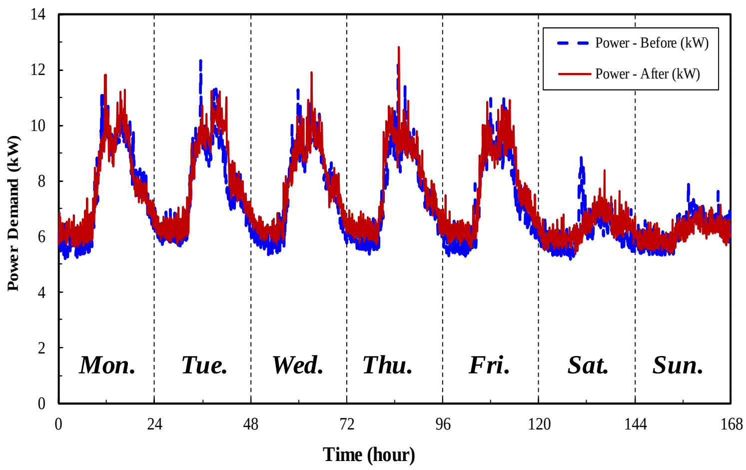
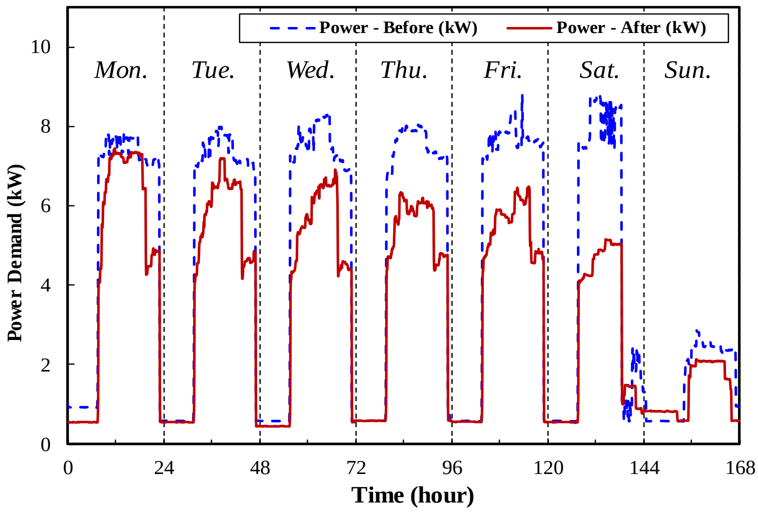


Fig.6 Weekly small power demand profiles before and after “cooling on demand” scheme implementation

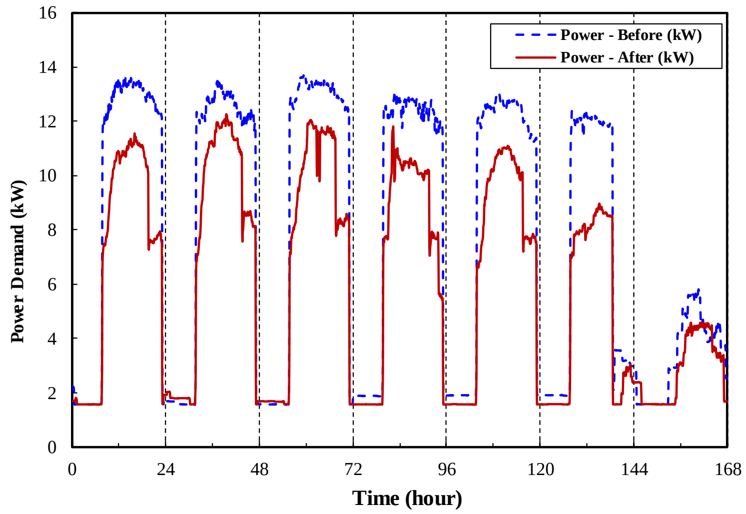
4.2 Energy use analysis of fans

Energy saving of fan coil units

Fig.7 shows the weekly power demand profiles of fans before and after “cooling on demand” scheme implementation in the north and south towers. Overall, a significant energy reduction on fan power demand was achieved after the scheme implementation. During the period from 7:30pm to 11:00pm on weekdays, the fan power demand was reduced significantly because the unnecessary energy use (semi-operating condition) was effectively avoided. (The power demands of fan coil units in the two computer rooms were cut off at 6:30pm but the reduction was not obvious due to the limited power consumed and the fact that the classes were not held every workday). Moreover, during the morning start period, the fans were turned on when occupants came to their offices rather than turned on automatically at 7:45am. Hence, the fan power demand during this period was also reduced significantly. *Note that* the measured power demand of fans includes the power demand of fan coil units and AHU fans for providing the fresh air on this floor. The AHU fans were not involved in the "cooling on demand" scheme and operated as the pre-set schedule. On Saturdays, the power demand of fans was cut off at 6:00pm during the two weeks of measurements, while on Sundays, the scheme was not implemented because fans were turned on manually based on the occupant needs. As a result, after 6:00pm on Saturday, the difference of fan power uses before and after implementing the scheme was not obvious on weekends.



(a) North Tower



(b) South Tower

Fig.7 Weekly fan power demand profiles before and after "cooling on demand" scheme implementation: (a) North Tower of 8/F in the test building; (b) South Tower of 8/F in the test building

Table 3 shows the daily energy consumption of fans before and after the "cooling on demand" scheme implementation. In general, after implementing the scheme, the total weekly energy reduction of fans was 479.1 kWh (about 23.5%) on the 8/F of the building. The reduction of energy consumption of fans was achieved because the scheme guided the occupants to actively make reactions to reflect their situations to the control system. Hence, the unhealthy energy use (i.e., semi-operating condition) that the occupants left the rooms but forgot to switch off the fans was avoided effectively. From Monday to Saturday, the daily energy saving of fans was around 70 kWh. Such energy saving is achieved only by guiding the occupant behavior to avoid energy waste without sacrificing their perceived indoor thermal comfort because the occupants can actively switch on the fans at once if they need cooling services after the fan power is resumed.

Table 3 Energy consumption and saving of fans before and after "cooling on demand" scheme implementation

	Daily Energy Consumption (kWh)		**Energy Saving (kWh)**	**Energy Saving (%)**
	Before	*After*		
Mon.	334.8	264.8	70.1	20.9%
Tue.	325.1	266.7	58.5	18.0%
Wed.	336.7	258.8	77.9	23.1%

Thu.	328.7	246.4	82.3	25.0%
Fri.	329.4	246.8	82.6	25.1%
Sat.	263.6	174.8	88.8	33.7%
Sun.	117.6	98.5	19.1	16.2%
Total	2035.9	1556.7	479.1	23.5%

Energy saving of fans during different time periods of a day

To analyze the energy consumption and saving of fans during different periods in a day after the implementation of "cooling on demand" scheme, a day was divided into four time periods as shown in Table 4, including: "morning start period", "normal system operation period", "evening system operation period" and "night period". During the morning start period, i.e., 7:45am-10:30am, occupants began to come to offices and hence the power demand of fans kept increasing. The rest of the system operation period was divided into two parts based on the time of occupant-in-loop point, i.e., 10:30am-6:30pm and 6:30pm-11:00pm. The time period of 6:30pm-11:00pm was when the power supply of fans in the rooms on the 8/F of the building was cut off for a minute by implementing the "cooling on demand" scheme. The night period was the period between 11:00pm and 7:45am when no power was provided for fans.

Table 4 Different time periods of a day

	Morning start period	**Normal system operation period**	**Evening system operation period**	**Night period**
Time period	7:45am-10:30am	10:30am-6:30pm	6:30pm-11:00pm	0:00am-7:45am, 11:00pm-12:00pm

Table 5 shows the weekly reductions of fan energy use during different time periods in a day before and after implementing the "cooling on demand" scheme. Generally, the reductions of weekly fan energy use during morning start period and evening system operation period were the most significant, i.e., around 30%. The fans were switched on based on the needs of the occupants rather than automatically turned on based on a given schedule. During the night period, the reduction of fan energy use was not obvious because most of the fans were off in this period in the original control schedule.

Table 5 Reduction of fan energy use during different time periods of a day after implementing "cooling on demand" scheme

	Energy Reduction (kWh)				**Total Energy Reduction (kWh)**
	0:00am-7:45am & 11:00pm-12:00pm	*7:45am-10:30am*	*10:30am-6:30pm*	*6:30pm-11:00pm*	
Monday	4.2	15.8	21.5	28.5	70.1
Tuesday	0.1	15.7	19.6	23.1	58.5
Wednesday	1.4	19.7	30.4	26.4	77.9
Thursday	4.1	15.0	33.0	30.2	82.3
Friday	4.2	18.8	32.2	27.4	82.6
Saturday	4.6	21.1	57.0	6.1	88.8
Sunday	-0.2	2.3	12.2	4.8	19.1
Total	18.5	108.3	205.9	146.4	479.1
	11.4%	32.7%	19.6%	29.8%	23.5%

4.3 Estimation of energy saving on the central air-conditioning system

The energy saving of the chiller plant in the test building, which always accounts for the largest part of energy consumption in a central air-conditioning system, is analyzed using a simple estimation method due to the data limitation of chillers. According to the percentage of fan power reduction of 8/F, the energy saving potential of chiller plant was estimated assuming the same percentage of chiller cooling load was reduced and the "cooling on demand" scheme was implemented in the entire building. Because the "cooling on demand" scheme was only implemented on the 8/F, not for the whole building. In order to quantify the energy saving for the whole building level using the scheme, such assumptions are therefore made for a simple estimation. The monthly power demand of chiller plant between 15th October 2016 and 15th November 2016 (the same period of the measurement in another year) was 315,191 kWh and this value was used as the reference/baseline. If assuming 25% of cooling was consumed by the data center and spaces requiring cooling essentially, about 55,552 kWh chiller plant energy could be saved in a month, i.e., 17.6%. The estimation did not consider the change of *COP* (coefficient of performance) of chillers due to changes in cooling load ratio. Similarly, based on the measured energy consumption of chiller plant in the entire year of 2016 (i.e., 3,559,821 kWh), the energy saving potential of chiller plant after the “cooling on demand” scheme implementation was about 627,418 kWh, which accounted for 5.7% of the electricity use of the whole building in 2016 (i.e., 11,001,725 kWh).

Assuming the same weekly saving of fan power in other floors (i.e., 479 kWh/floor) after implementing “cooling on demand” scheme, the annual fan energy saving of the building was about 229,920 kWh (the building was assumed to have ten same floors as the 8/F). In summary, when fully implementing “cooling on demand” scheme in the building, the estimated total annual energy saving (including the chiller plant and fans) was about 857,338 kWh., which was about 7.8% of the total annual electricity use in the building.

5. Conclusions

Occupant behavior is an important factor influencing building energy consumption, which attracts growing interests for facilitating the energy-efficient buildings. To effectively achieve energy efficient in buildings, the coordination between the occupant behavior and the energy-saving technologies would be considered. This study, therefore, develops a novel concept, i.e., technology-guided occupancy behavior, to make the occupants involved in the control loop of the cooling system by active feedback of their cooling needs. The technology-guided occupant behavior can achieve to some extent occupancy detection to make cooling supply based on the actual demand and avoid unnecessary energy consumption. On-site experimental tests were conducted in a Hong Kong campus building, which was equipped with a central air-conditioning system, to validate the importance of the technology-guided occupant behavior and to investigate the associated energy savings.

Results of on-site measurements show that significant energy saving was achieved by guiding the occupant behavior without sacrificing the perceived indoor thermal comfort. The weekly energy saving of fans was about 23.5% by guiding the occupant behavior using “cooling on demand” scheme. Moreover, the corresponding monthly energy saving of chiller plant was 55,552 kWh and the annual saving was 627,418 kWh, which accounted for 5.7% of the electricity use in the whole building. Furthermore, the total annual energy saving of central air-conditioning system in the test building was about 857,338 kWh, i.e., 7.8% of the total annual building electricity use.

This work proposes the new concept of technology-guided occupant behavior and demonstrates the need to make the occupants involved into the control loop of air-conditioning system. The method can also be used as an alternative economical way for occupancy detection and data collection of occupant behavior. The limitation of this study is that some assumptions are made to simplify the estimation of energy saving because of the limited data. In future work, an accurate model would be developed to predict the associated building energy saving achieved by the technology in terms of guiding the occupant behavior. Meanwhile, the advanced big data analysis methods will be used to make the technologies smarter to guide the occupant behavior and hence reduce the inconveniences of occupants due to the interference of technologies.

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