Available online at www.sciencedirect.com
ScienceDirect
Energy and Buildings 38 (2006) 1302–1307
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

# A questionnaire survey on sleeping thermal environment and bedroom air conditioning in high-rise residences in Hong Kong

Zhongping Lin [a], Shiming Deng [b,*]

[a] Institute of Heating, Ventilation, Air Conditioning and Gas Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China
[b] Department of Building Services Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China

**Abstract**

This paper reports on the results of a questionnaire survey on sleeping thermal environment and bedroom air conditioning in high-rise residential buildings in Hong Kong. The survey aimed at investigating the current situation of sleeping thermal environment and bedroom air conditioning, in order to gather relevant background information to develop strategies for bedroom air conditioning in the subtropics. It focused on the use patterns and types of bedroom air conditioning systems used, human factors such as the use of bedding and sleepwear during sleep, preference for indoor air temperature settings in bedrooms, ventilation control at nighttime with room air conditioner (RAC) turned on, etc. The results of the survey showed that most of the respondents would prefer a relatively low indoor air temperature at below 24 °C. Most of the respondents might however not be satisfied with the indoor air quality (IAQ) in bedrooms in Hong Kong. On the other hand, 68% of the respondents did not use any ventilation control intentionally during their sleep with their RACs turned on. A lack of knowledge of the ventilation control devices provided on window type room air conditioners (WRACs) indicated an urgent need for user education.


*Keywords:* Questionnaire survey; Sleeping thermal environment; Room air conditioner; Ventilation control; IAQ

## 1. Introduction

With rising living standards and expectations for better thermal comfort, residential air conditioning is becoming widely accepted as being necessary and routine. Consequently the increased use of residential air conditioning has a significant impact on the total electrical energy use in residences. For example, air conditioning accounts for 18% of residential electrical energy use in the U.S. and is the primary component of peak load [1]. In subtropical Hong Kong, summers are hot and humid, and may last for over 7 months. The diurnal variations in ambient air temperature are comparatively small: the mean daily range in summer is only 4.95 °C, and the relative humidity remains high at over 70% for most of the time [2]. Air conditioning is by far the largest single electricity-consuming end-use, accounting for, on average, 36.8% of the total residential electricity use in HK [3]. Bedroom air conditioning is to primarily maintain an appropriate thermal sleeping environment and there has been a growing concern on increased energy use for residential air conditioning and its impacts on the environment. Therefore, it is necessary to understand the current situation of bedroom air conditioning and the indoor thermal conditions in order to evaluate the further trend of residential energy consumption for bedroom air conditioning and to provide information to energy system planning and environmental policy-making.

A number of earlier studies [4–6] suggested that the user behavior would significantly affect air conditioning energy use among similar dwellings. Over the past decades, there have been studies on indoor thermal environment in residential buildings and the use patterns of room air conditioner (RAC) through questionnaire survey, interviews and field measurements. For example, Kempton et al. [6] studied the operation of RACs to understand how energy consumption and peak power demand were influenced by the needs, perceptions, and behaviors of users through field measurements and interviews. It was found that many non-economic factors would influence the use of RAC. These included health, thermal comfort, safety, waste, folk physiological theories, and folk theories about how RACs function, etc. Yoshino et al. [7] reported a survey on the actual conditions of residential indoor environment in three cities in China to evaluate thermal comfort and the possibility of energy conservation for space cooling by using questionnaire and field measurements. Lin and Deng [8] investigated the outdoor

* Corresponding author. Tel.: +852 27665859; fax: +852 27657198.
*E-mail address:* besmd@polyu.edu.hk (S. Deng).

0378-7788/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2006.04.004

ventilation rate in high-rise residences employing RACs through field measurements and laboratory experiments. Li et al. [9] carried out a study on residential energy consumption through administering questionnaire to 50 households in Shanghai, China and found that there existed a close link between the building type and the residential energy consumption. Through site measurements, interviews and observations, Lutzenhiser [10] surveyed the use of RACs in 279 California apartments and observed that most users opted for a manual, rather than automatic control strategy. It was found that the choices of control strategies were sometimes guided by the theories of RAC operation and control that were not in agreement with engineering accounts of the machine's design. However, in these studies, the focuses were only on the control strategies and energy use of RACs, whereas the investigations on indoor thermal environment and IAQ both in individual bedrooms and at nighttime (sleeping period) were not carried out.

This paper reports on a questionnaire survey on the sleeping thermal environments and bedroom air conditioning in high-rise residences in Hong Kong. The survey was to gather relevant background information in order to develop strategies for bedroom air conditioning in the subtropics. The methodologies used in the questionnaire survey are firstly introduced. This is followed by reporting the results of the survey. Finally, the misunderstandings in the use of RACs are discussed.

## 2. Methodologies

A questionnaire survey to investigate the sleeping habits of local people, user behaviors in using bedroom air conditioning, and the current situation of the use of bedroom air conditioning in residential buildings in Hong Kong was carried out. The following were investigated:

- Use patterns and types of bedroom air conditioning systems used;
- Use of bedding and sleepwear;
- Sleeping thermal environments during nighttime with RACs turned on;
- Ventilation strategies in bedrooms;
- Other issues such as the effects of the noise from operating RACs on sleeping quality.

A questionnaire with 20 questions was sent out in three different ways. The first was to distribute the questionnaire to friends, relatives, and classmates of questionnaires' administrators. The second was through an on-line questionnaire survey and the last through target visiting. More than 400 questionnaires were distributed by the first way and 183 respondents replied the on-line questionnaire by email. Most of the data collected by these two ways were from the respondents with the age range of 18–50. In order to minimize bias, target visiting was conducted to obtain data from teenagers and elders. Therefore, one target visiting was carried out, through which 102 questionnaires from elders aged between 50 and 82 years old were collected. Another target visiting was undertaken during a scout training course, through which 71 responses from teenagers aged between 11 and 17 years old were collected.

The questionnaire survey was carried out between September 2002 and May 2003 and the response rate of the survey was 92.3%. A statistical package for social science (SPSS) was used to analyse the data collected from the questionnaire survey.

## 3. Results

A total of 554 valid questionnaires were returned and the data collected from these questionnaires were analysed using SPSS. Fig. 1 shows the breakdown of respondents' age groups. 55.8% of the respondents were male while the other 44.2% female.

### 3.1. Use patterns and types of bedroom air conditioning systems used

As shown in Fig. 2, 68% of the respondents would leave their RACs on throughout the duration of their sleep. The rest would however use their RACs only for certain hours during sleep. Fig. 3 shows the percentage breakdown of the number of months when occupants would use their RACs in bedrooms for sleeping in a year. It may be seen that 82.5% of the respondents reported using their RACs during nighttime for more than 2 months annually.

Furthermore, 75% of the respondents used WRACs while the other 25% used split type room air conditioners (SRACs). Other air conditioning systems such as a variable refrigerant volume (VRV) system, a central residential air conditioning system, etc., were not common.

### 3.2. Indoor thermal environments

The survey showed that in shared bedrooms, most of the respondents would have the same opinion as their roommates on whether turning RACs on (72%) and on indoor air temperature settings (76%). Fig. 4 shows the percentage breakdown of the indoor air temperature settings at nighttime currently used by respondents for bedroom air conditioning in Hong Kong. It can be seen that most of the respondents (>80%) would prefer a relatively low indoor air temperature setting at below 24 °C.

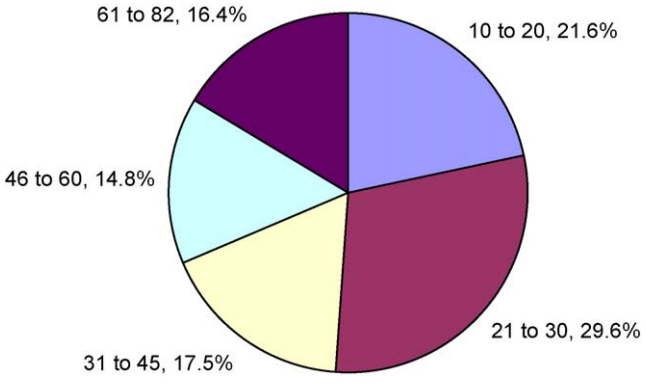


Fig. 1. Percentage breakdown of respondents' age group.

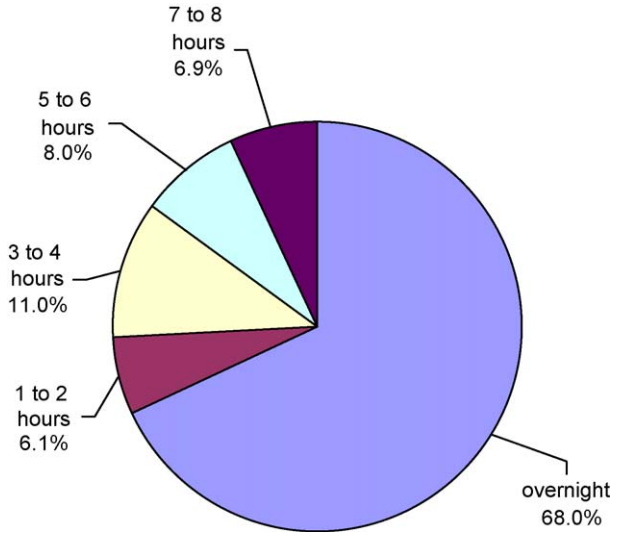


Fig. 2. Percentage breakdown of the number of hours with RACs turned on while sleeping at night by respondents.

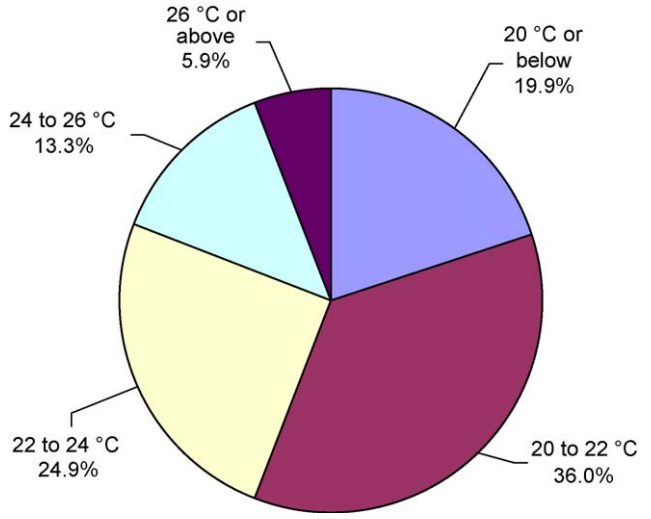


Fig. 4. Percentage breakdown of the indoor air temperature settings by respondents.

Approximately a quarter of respondents experienced waking up during sleep sometimes because of a high indoor air temperature while another quarter woke up sometimes because of a low indoor air temperature. About 10% of the respondents experienced waking up when indoor air temperature fluctuated. These suggested that approximately 60% of the respondents had experience of waking up during sleep because they felt either cold or warm, i.e. thermally discomfort, even if their bedroom RACs were turned on.

### 3.3. Use of bedding and sleepwear

When the respondents were asleep and their RACs turned on, 47% of the respondents wear sleepwear (full-slip) and 45% wear briefs/panties and half-slips. Half of the respondents covered themselves with quilts, 40% with blankets and the remaining 10% just did not use any bedding. This indicated that most of the respondents would wear some sleepwear and use some bedding during their sleep with RACs turned on.

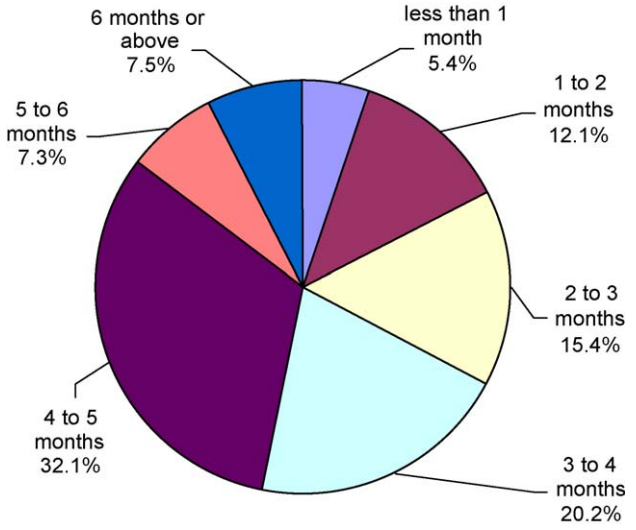


Fig. 3. Percentage breakdown of the number of months with RACs turned on while sleeping in a year by respondents.

### 3.4. Ventilation and indoor air quality

The majority of the respondents could feel the airflow from RACs when they lied down on bed, but 32% of them did not like the airflow. Over 70% of the respondents felt stuffy because of poor IAQ. However, only 32% experienced waking up during sleep because of poor IAQ.

Regarding the ventilation control for RACs, 66% of the respondents did not know that there was a ventilation switch (bar) in a WRAC (as shown in Fig. 8). Over half of the respondents did not know the actual function of the ventilation switch even if they knew its existence in a WRAC. Many misunderstood that the purpose of the ventilation switch in a WRAC was for ventilation only when the WRAC ran at ventilation mode. These respondents did not know that a certain amount of indoor air could be exhausted to outdoors and therefore inducing the same amount of outdoor air to indoors when the WRAC ran at cooling mode. As shown in Fig. 5, 68% of the respondents did not use any ventilation control intentionally during their sleep with RACs turned on (this 68% of respondents might probably also include those who did use certain ventilation control without being aware of that they actually did).

### 3.5. Other issues

Regarding the effect of the noise from operating RACs on sleeping quality, nearly 70% of respondents felt that the noise level from other sources such as traffic was higher than that from the RACs in their bedrooms. The majority felt that the noise level from a RAC had little influence on their sleeping quality.

On the other hand, the survey results suggested that the percentage breakdown on the preferred indoor air temperature

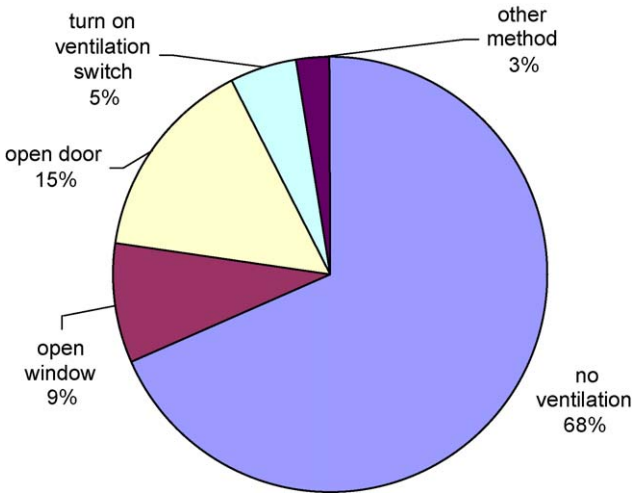


Fig. 5. Percentage breakdown of ventilation control strategies used by respondents.

settings by both male and female was almost the same. Furthermore, the survey results also indicated that older people would prefer a relatively higher indoor air temperature.

Generally speaking, as shown in Fig. 6, 93% of the respondents indicated that using RACs could help improve their sleeping quality.

## 4. Discussions

The survey results suggested that the majority of the respondents would use their RACs at night when sleeping for more than 2 months in a year. This may be ascribed to the hot and humid climate and the comparatively small diurnal variations in ambient air temperature in subtropical Hong Kong.

Although the survey results suggested that over 70% of the respondents shared the views with their family members regarding turning on RACs and indoor air temperature settings, a wide range of the adaptation to summer heat (the preferred indoor air temperatures ranging from below 20 °C to over 26 °C) became obvious, as illustrated in Fig. 4. This suggested that people might develop distinct individual temperature and

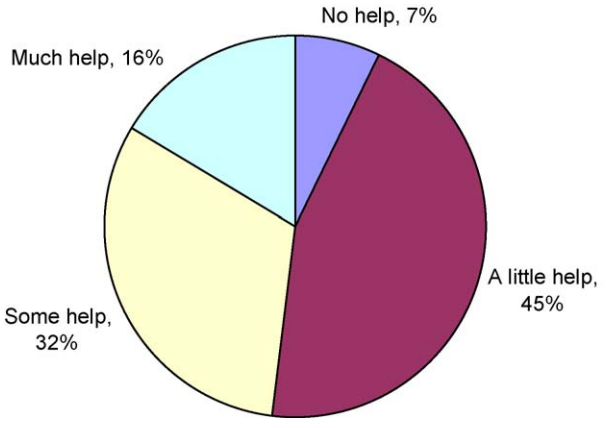


Fig. 6. Percentage breakdown of the views of respondents on the usefulness of using RAC to improve sleeping quality.


Fig. 7. The remote controller of a typical SRAC showing indoor air temperature setting.

thermal comfort preferences. However, over 60% of the respondents would like to maintain an indoor air temperature between 20 and 24 °C, and about 20% of the respondents would prefer even a lower indoor air temperature at below 20 °C.

Normally, in the cases when SRACs are used, the respondents would be able to know the actual indoor air temperature settings from the remote controllers for SRACs, as shown in Fig. 7. However, in the cases when WRACs are used, no remote controllers are available and the thermostat knob in a WRAC (as shown in Fig. 8) is not labeled with actual temperature. Typically the thermostat knob in a WRAC is marked with an arbitrary 1–9 scale, with "1" indicating "Warmer" and "9" "Cooler" or simply an arrow indicating "Cooler" as in the WRAC shown in Fig. 8. Therefore, users might not know the actual indoor air temperatures maintained in their bedrooms. Generally speaking, the survey results implied that most respondents would prefer a lower indoor air temperature than the suggested design indoor air temperature (24–26 °C). This can be further supported by the results of field monitoring of overnight mean indoor air temperature in 10 bedrooms, averaged at 23.3 °C [11]. This may be partly due to the relatively higher thermal insulation values of sleepwear and bedding used by the respondents during sleep.

The survey results also showed that nearly half of the respondents would wear full-slip sleepwear and 90% of the respondents would cover themselves with quilts or blankets during sleep with RACs turned on. A question may therefore arise: why should a relatively low bedroom air temperature be

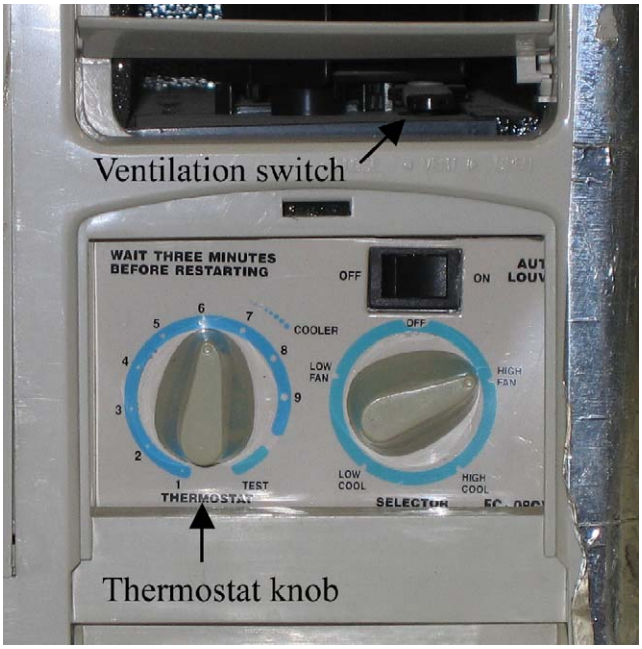


Fig. 8. The thermostat knob and ventilation switch in a typical WRAC.

maintained, while people are covered with a rather thick quilt at the same time? A lower indoor air temperature means more energy consumption for RACs. As shown in a previous study, indoor air temperature setting would significantly affect the yearly total energy use for RACs. Supposing that the indoor air temperature setting is increased from 23 to 25 °C, the yearly total cooling energy for sleeping (only considering nighttime operating period) in a typical bedroom in Hong Kong could be reduced by around 35% [12]. Moreover, a low air temperature means cold stress to human, which has more negative effects on the sleep quality than heat stress [13]. This may be supported by the survey results that a quarter of respondents experienced waking up during sleep sometimes because of the low indoor air temperature. On the other hand, the fact that around 60% of the respondents had experience of waking up during sleep because of thermal discomfort even if their bedroom RACs were turned on may suggest an opportunity for fundamentally re-designing of RACs' control.

The survey results suggested that over 70% of the respondents felt stuffy because of poor IAQ when their RACs were turned on, and that poor IAQ even caused 32% of the respondents to wake up during sleep. This implied that the current situation of IAQ in bedrooms might not be acceptable for most of the surveyed respondents and the ventilation was not adequate to maintain an acceptable IAQ in most of the bedrooms in Hong Kong. This may be partly ascribed to the fact that the air-tightness of residential buildings is high hence building air leakage (infiltration) levels are low. A previous related field study on outdoor ventilation rates in bedrooms using RACs showed that the mean outdoor air flow rates were 1.8 L/s in rooms equipped with SRACs and 2.7 L/s in rooms with WRACs, respectively [8]. On the other hand, the survey results also showed that nearly 70% of the respondents did not use any ventilation control methods (including those who used without being aware of that they actually did) during sleep with RACs turned on. Poor ventilation would therefore result in poor IAQ and make the occupants feel stuffy, hence affecting their sleeping quality. This may also suggest there is an urgent need to review and ultimately redesign the ventilation controls for RACs.

On the other hand, approximately two-third of the respondents did not know that there is a ventilation switch (bar) in a WRAC (as shown in Fig. 8) and over half of the respondents did not know the function of a ventilation switch even if they knew its existence in a WRAC. This finding is consistent with the results in a previous study [6], where three-quarters of the surveyed residents did not use their thermostats in WRACs to control cooling, instead, they switched RACs on and off manually. Many were not aware that there was a thermostat in a RAC and even tended to think of the thermostat as an air flow controller, rather than a temperature controller. These surprising mismatches between the control devices provided on WRACs and the ways most people actually use them indicated an urgent need for user education. Furthermore, many people did not have experience with air conditioning, and their confusions over the functions of the components on a control panel of a WRAC were probably very common. In some cases, differences in use can be traced to residents' understanding of how RACs should be controlled—ideas often at odds with formal engineering understandings of air conditioning control and function. But even in cases where RACs were used in an intended fashion, residents' understandings may also differ from the formal account [10]. Therefore, a brief but clear user's manual for RACs would be elementary to help users understand and control these units.

## 5. Conclusions

The majority of the respondents often used their RACs at night when sleep for more than 2 months in a year. WRACs were more commonly (75%) employed in bedrooms in high-rise residences in Hong Kong. Other air conditioning systems such as VRV system, central residential air conditioning systems, etc. were rarely used.

The survey results suggested that over 80% of the respondents would prefer a relatively low indoor air temperature at below 24 °C. On the other hand, 92% of the respondents would wear sleepwear and 90% would cover themselves with quilts or blankets during sleep with the RACs turned on. The survey also suggested that approximately 60% of the respondents experienced waking up during sleep because of thermal discomfort, even if the RACs in their bedrooms were on.

The current IAQ situation in bedrooms in Hong Kong might not be acceptable for most of the surveyed. Over 70% of the respondents felt stuffy because of poor IAQ with the RACs turned on at night. This may be ascribed to the fact that nearly 70% of the respondents did not use any ventilation strategies during sleep when using the RACs. Therefore, it is necessary to use certain effective ventilation methods (e.g. mechanical ventilation) in order to improve IAQ in bedrooms at nights.

Around two-third of the respondents did not know that there was a ventilation switch (bar) in a WRAC and over half of the

respondents did not know the function of such a ventilation switch even if they knew its existence in a WRAC. This lack of knowledge of the ventilation control devices provided on WRACs indicated an urgent need for user education.

## Acknowledgments

The authors acknowledge the funding from The Hong Kong Polytechnic University to support this project. They would also like to thank Mr. Yeung Yip Kan, Mr. Li Chun Ho, Miss Ching Ka Wai, Mr. Wong Ka Shing and Mr. Wong Chung Kin for their help in collecting the data of the questionnaire survey.

## References

[1] Department of Energy, The USA Annual Energy Review 1989. DOE/EIA-0384(89), Energy information administration, Department of Energy, Washington, DC, 1990, pp. 43, 46.
[2] C. Lam, C.M. Hui, Outdoor design conditions for HVAC system design and energy estimation for buildings in Hong Kong, Energy and Buildings 22 (1995) 25–43.
[3] J.C. Lam, An analysis of residential sector energy use in Hong Kong, Energy 21 (1996) 1–8.
[4] C. Seligman, J.M. Darley, L.J. Becker, Behavioral approaches to residential energy conservation, Energy and Buildings 1 (1978) 325–337.
[5] H.A. McLain, D. Goldenberg, M.A. Karnitz, S.D. Anderson, S.Y. Ohr, Benefits of Replacing Residential Air Conditioning Systems, ORNL/CON-113, Oak Ridge National Laboratory, 1985.
[6] W. Kempton, D. Feuermann, A.E. McGarity, I always turn it on super: user decisions about when and how to operate room air conditioners, Energy and Buildings 18 (1992) 177–191.
[7] H. Yoshino, S. Guan, Y.F. Lun, T. Shigeno, Y. Yashino, Q. Zhang, Indoor thermal environment of urban residential buildings in China—summer investigation in three cities, in: Proceedings of the 2nd International Workshop on Energy and Environment of Residential Buildings in China, Tongji University, Shanghai, China, October 14–15, (2002), pp. 68–75.
[8] Z.P. Lin, S.M. Deng, The outdoor air ventilation rate in high-rise residences employing room air conditioners, Building and Environment 38 (2003) 1389–1399.
[9] Z. Li, H. Yoshino, R. Shi, C. Zhang, A questionnaire survey on residential energy consumption in Shanghai, in: Proceedings of the 2nd International Workshop on Energy and Environment of Residential Buildings in China, Tongji University, Shanghai, China, October 14–15, (2002), pp. 46–51.
[10] L. Lutzenhiser, A question of control: alternative patterns of room air-conditioner use, Energy and Buildings 18 (1992) 193–200.
[11] Z.P. Lin, Strategies for bedroom air conditioning in the subtropics. PhD Thesis, The Hong Kong Polytechnic University, 2005, pp. 55–56.
[12] Z.P. Lin, S.M. Deng, A study on the characteristics of nighttime bedroom cooling load in tropics and subtropics, Building and Environment 39 (2004) 1101–1114.
[13] E.H. Haskell, J.W. Palca, J.M. Walker, R.J. Berger, H.C. Heller, The effects of high and low ambient temperatures on human sleep stages, Electroencephalography and Clinical Neurophysiology 51 (1981) 494–501.