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Usage Patterns of Air Conditioning System for Typical Types of Occupants and Their Interactive Features in Residential Buildings – A Case Study in Hangzhou, China

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Abstract: The usage pattern related to air conditioning (AC) can significantly influence the energy consumption of residential buildings in HSCW zone. A survey, consisting of the general information about the household and building characteristics, occupant behavior of controlling AC and occupants' reactions to others' requirements, has been carried out in Hangzhou in order to develop the database of AC usage patterns in this district, analyze the characteristics of AC usage of typical types of occupants (including children and teenagers, youth, middle age and elder) and their interactive features. The survey results indicate that in contrast to the children and teenagers, the elders prefer a relatively high outdoor temperature to start using AC, as well as the setting temperature. Meanwhile, the majority of them use the AC for a shorter time compared to other three types of occupants. At the same time, youth and middle-aged people would like to use AC for a long time and maintain a medium temperature and. Besides, these four typical occupants have a similar attitude on the operating of AC when there is someone else in the same space. Over 75% of respondents take others' feeling into consideration and share their opinions with their family members regarding turning on/off the AC and the setting temperature, which may change the operation patterns of AC.

Keywords: Usage Patterns of Air Conditioning System, Typical Types of Occupants, Interactive Features, China

1. Introduction

Building energy consumption can be influenced by a number of factors such as climate (outdoor air temperature, solar radiation, etc.), building characteristics (e.g. orientation, shape), building services and energy systems (e.g. space heating/cooling, hot water supply, etc.), building operation and maintenance, and so on [1]. Various studies have indicated vast disparity of energy use in similar or identical buildings, thereby suggesting that occupant behavior exerts a strong influence [2] [3]. Besides, large discrepancies are being observed between predicted and actual building performance, when occupant behavior is not taken into consideration [4]. The measured electricity demands are approximately 60% to 70% higher than predicted in both the schools and general offices, and over 85% higher than predicted in university campuses [5]. Adil et al. showed that the annual electricity consumption simulated using ENERWIN software would raise by 21% when the new data (mainly occupants' profile and electric equipment scheduling and operation) from the survey was used as opposed to the use of default data [6]. Therefore, some researchers argue that more responsive data related to occupant behavior should be used in order to achieve more accurate and consistent predictions.

Regarding the occupant behavior in residential buildings, some researchers reveal that the behavioral parameters related to air conditioning (AC) in HSCW Zone in China could have a significant influence on the energy consumption. Li showed that the different behaviors of controlling AC, including the habits of using AC, different AC setting temperature and switching mode, would greatly affect the energy consumption in residential building both in heating and cooling seasons [7]. [8] showed that the family's personnel structure, AC setting temperature and switching behavior significantly affect the energy consumption.

The HSCW Zone is located along Yangtze River, which is characterized by a sultry summer, damp and chilly winters, small diurnal temperature swings, large annual precipitation, and rather limited sunshine. Mainly because of economic and social reasons, there was neither heating nor cooling appliances in the past. With the economic development and rapidly rising standard of living, the demand for heating and cooling has increased, with residents often independently installing AC to supply heating and cooling [9]. On average, space heating and cooling energy consumption increased by nearly 70% per year from 1996 to 2008. Although the average heating energy consumption is still low at only 16.2 kWh/m^2/year [10], it is quite foreseeable that the consumption by AC will skyrocket in keeping with the residents' demand for a more comfortable living environment and periods of high temperature each summer. Hence, it is fundamental to fully understand the characteristics of occupant behavior related to AC system in summer and summarize the usage pattern, which is quite urgent and a basic step to develop the occupants' awareness and seek the energy saving potential of AC system.

However, few literatures focus on the behavioral pattern related to AC in this area, currently. Wang et al. concluded the main equipment and the corresponding energy-using behavior of AC in summer, revealing that most people choosing to open AC when they feel hot and close AC when they feel cold or leave the room. Meanwhile, a fixed AC temperature – dominate above 26°C- is preferred [11]. [12] indicated the AC usage model in the living room and bedroom respectively, based on continuous measurements of one family. Ren et al. develop an action-based quantitative stochastic model to predict AC usage in which typical patterns, including those driven by environmental triggers and event triggers, that affect AC usage are described mathematically as a series of conditional probabilities [13]. Most of literatures above mentioned only obtain the simple behavior pattern, such as opening the AC when people feel hot and closing AC when they feel cold, while no one can exactly gauge "hot-ness" or "cold-ness" and the proper usage time of AC. Others conclude the pattern by real-time monitoring the occupant behavior in several households, which may be too complicated to be widely surveyed, leading to the lack of universality.

In fact, the AC usage in residential buildings is found to be related to environment triggers (e.g. indoor temperature), event triggers (e.g. sleeping, eating, napping), individual triggers (e.g. age, profession, attitude) and some random triggers (including factors that cannot be identified or are minor) [13]. The reaction to other occupants' requirements has a significant influence on AC usage as well especially when more than one occupant stays in the same space. In order to study the characteristics of behavior related to AC of different types of occupants, as well as their interaction characteristics, a survey has been carried out in Hangzhou, based on the definitions for behavioral parameters for residential buildings [14] [15]. It is also the fundamental data which can be really useful for developing a database of usage profile of AC system in residential buildings in HSCW zone. Finally, the AC systems' usage patterns of typical occupants have been summarized in this paper, to provide a theoretical reference for the follow-up study of the residents' energy-using pattern.

2. Experiment Methodology

The survey was carried out simultaneously in Hangzhou, the provincial capital city of Zhejiang Province, in summer 2015. All the investigated families were located in different residential communities and selected by random sampling. The survey consisted of a paper questionnaire A sent to households to obtain the general information about the family and building characteristics, and a detailed questionnaire B to every family member to obtain detailed data on occupant behavior of AC which included questions on the use time of AC, AC setting temperature, switching mode and their reactions to others' requirements towards controlling AC.

The questionnaire A was sent to a total of 224 households and questionnaire B was delivered to 485 persons in the 224 families, and the response rate was 100% and 77.7% respectively. The fundamental information of families is shown in Table 1. The average number of owned AC is 2.8 per family and their mean power reaches 3117W/family. And above a quarter of them install AC in every room.

Table 1. *Fundamental information of investigated families.*

Information	Investigated results
Family structures	Two to five persons per family: approximately 91.0%
Gender ratio	Male: 52.8% Female: 47.2%
Residential type	Studio apartment: 5.4% Two-bedroom apartment: 38.6% Three-bedroom apartment: 40.4% Others: 15.6%
Building age	After 2000: 41.7% In 1991 -1999: 1.3% In 1981 -1990: 30.5% Before 1980: 17.1%
The average number of AC per family and their mean power	Average number of AC per family: 2.8 Mean power of AC: 3117W/family The AC installation rate in living rooms: 67% Mean power of AC in living rooms: 1010 W/family The AC installation rate in bedrooms (at least one bedroom): 91.9% Mean power of AC in bedrooms: 929W/family The rate of family with AC covering full space: 26.5%

3. Results and Analysis

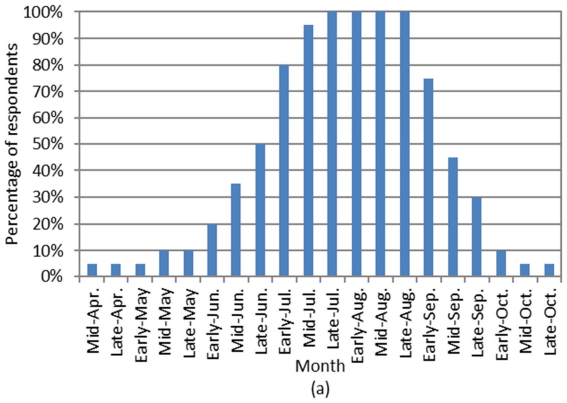
3.1. Age Demography

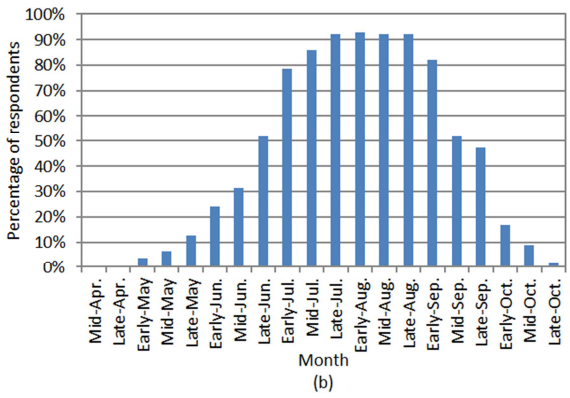
The usage of AC is closely related to occupants' age as they have different movements and activity patterns in the residence. For instance, the middle-aged persons between 31 and 60 years mainly work during the day while most of elders usually stay at home every day, leading to difference in the operation of AC. Hence, four typical types of human are identified in order to study their behavior patterns related to AC and interactive features. The survey shows that only 5% of them are children and teenagers (ages between 0 and 18), about 30% youth (ages between 19 and 30), the majority of about 53% are middle age (ages between 31 and 60), and 12% ages over 61 years old.

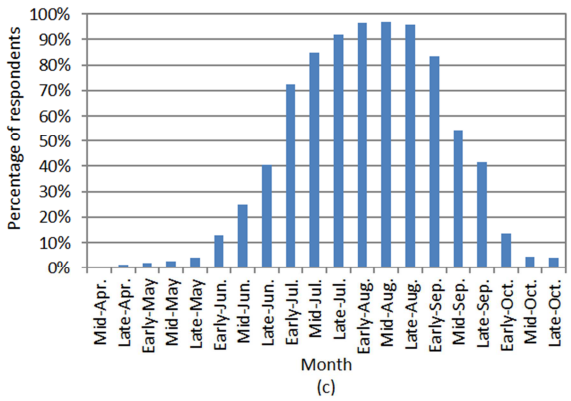
3.2. The Characteristics of AC Usage for Typical Types of Occupants

3.2.1. AC Schedules

Regarding the operation schedules in summer, the probabilities of using AC in different months by different persons are shown in Figure 1a-1d and vast disparity is observed. It is found that younger persons prefer to use AC in longer time, more than 50% children and teenagers may use AC from late June to early September, as well as youth and middle age. Most of elder choose to use AC during early July and early September, while very few of them may open AC in other months in order to save energy. It is also obvious that AC is frequently used in late July and whole August, as over 90% of these four typical human would open AC for a more comfortable living environment.







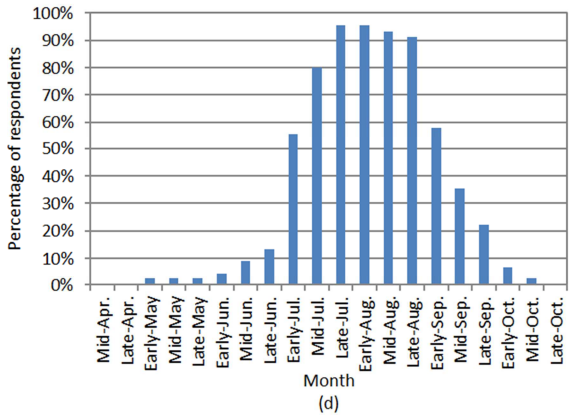


Figure 1. *The probability of using AC by typical human in summer. (a) Children and teenagers. (b) Youth. (c) Middle age. (d) Elder.*

Figure 2a-2d shows the hourly use in living room and bedroom on a typical weekday and weekend of four kinds of occupants. As the AC of all investigated families run in the mode of "only occupied space, only occupied time", the figure shows the strong spatial difference and timing difference of using AC. The peak usage period of AC in living room is at the daytime, which is opposite to that in bedroom, and the AC is less frequently used in living room under most circumstances. Compared with the operation schedules of the other three types of human, the figure shows that the hourly use of AC during weekdays and weekends is relatively similar for elder, mainly because they stay at home all days. Approximately 20% of them choose to open AC in living room at noon and at dusk, while above 40% use AC in bedroom from 22pm to 6am. The probability of using AC in bedroom also rises to a small peak in the afternoon.

Meanwhile, the use of AC for other typical occupants has a similar trend. As shown in Figure 2a, at weekday, the probability of using AC in living room reaches a peak from 18pm to 19am and keeps constant at nearly 15% in the rest of time, nearly 45% of middle age may open AC, and 30% children and teenagers, 30% youth as well. At weekends, the probability of AC usage would rise from 8am and start decreasing at 12am, then reaches a peak at dinner time as that at weekdays, which can be seen in Figure 2b. The AC in bedroom only runs more frequently in the evening at weekdays for children and teenagers, youth and middle age, while it has a small peak use in weekend afternoon (Figure

2d). Besides, the portion of middle-aged people is higher than other types in most cases towards using AC in summer.

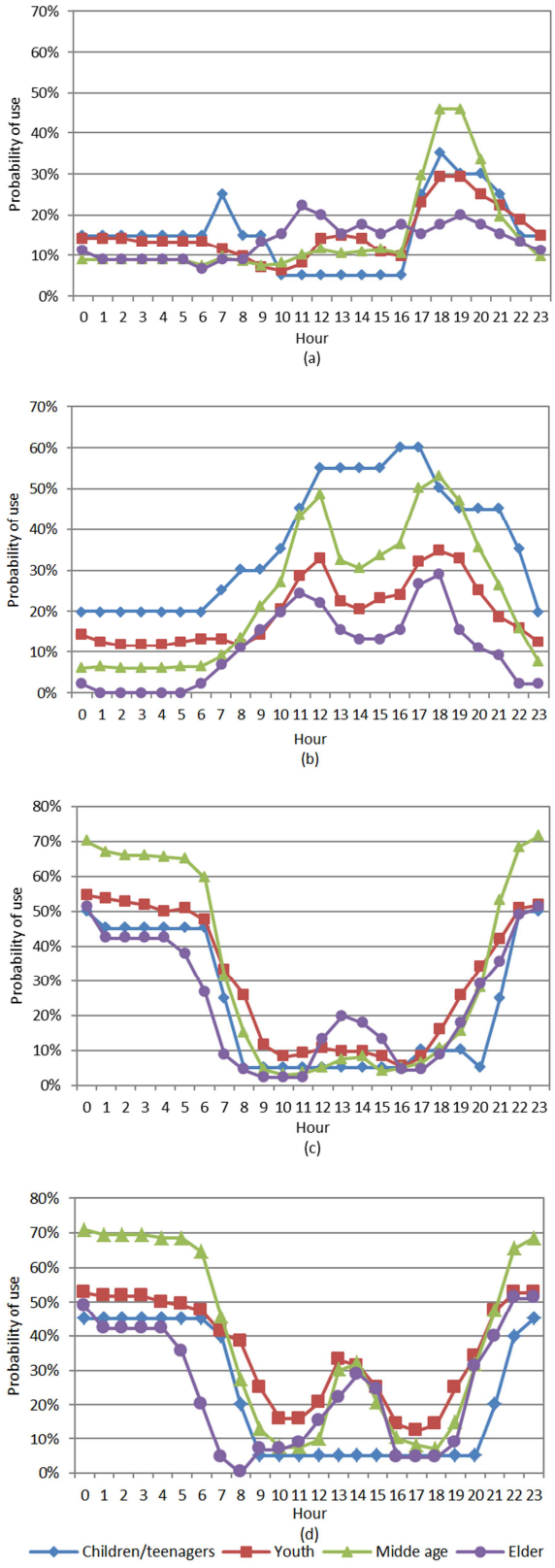


Figure 2. *(a) Probability of opening AC in living room on a typical weekday. (b) Probability of opening AC in living room on a typical weekend. (c) Probability of opening AC in bedroom on a typical weekday. (d) Probability of opening AC in bedroom on a typical weekend.*

3.2.2. Outdoor Temperature and Activity

The survey indicates that the AC usage is closely related to the outdoor temperature. Different typical occupants will start/stop using the AC for a different outdoor temperature range, shown in Figure 3a and Figure 3b respectively. The probability of starting using AC for a relatively low temperature by younger persons is higher than elders, approximately one third of children and teenagers start turning on the AC when outdoor temperature is below 30°C, while 13% of youth, 10% of middle age and none of elders choose to use AC under the same circumstances. However, a large proportion of all these occupants prefer starting using AC when outside temperature is among 30°C to 32°C. The Figure 3b shows that most occupants may stop using AC when outdoor temperature drops to below 30°C except elders, who may most likely to give up using AC when the temperature is still between 30°C and 32°C.

A questionnaire survey with 554 responses on AC-unit usage during the sleeping hours in Hong Kong revealed that 82.9% of the occupants use their ACs for over 5 hours during the sleeping period, while 82.5% of them reported using ACs during night time for more than 2 months annually [16]. Quite similar to the results in Hong Kong, most occupants response to use AC during the sleeping period, approximately 90% middle age and 80% children and teenagers, while few.

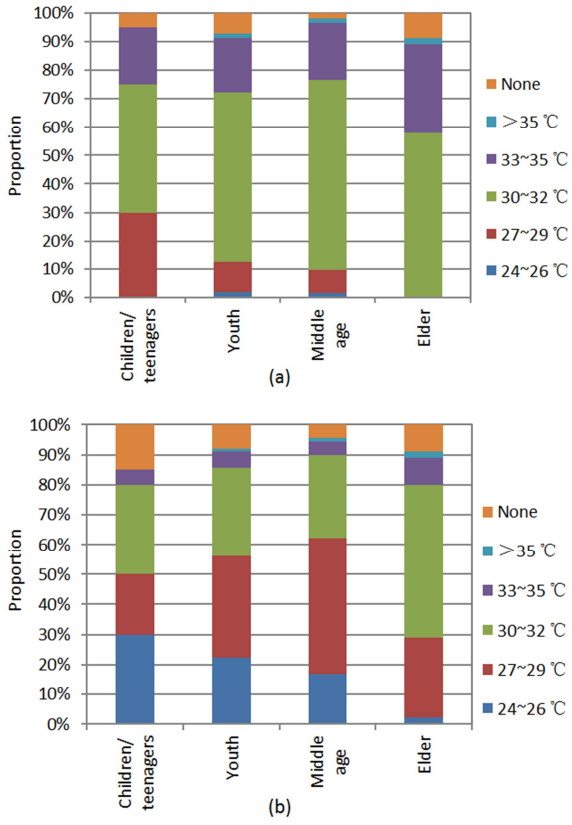


Figure 3. *(a) Percentage distribution of different outdoor temperature when starting using AC by different typical human; (b) Percentage distribution of different outdoor temperature when stopping using AC by different typical human.*

Would like to use AC during the day (Figure 4). Meanwhile, the probability of using AC by different occupants varies when they are doing different activities, according to the survey carried out in Hangzhou, as illustrated in Figure 5. Children and teenagers most likely turn on the AC when they are napping, sleeping, studying and watching TV. The portion of youth and middle age is relatively higher than others towards using AC related to every kind of activities. However, it is always less than half of elders choosing to open AC when they are eating, snapping, watching TV, etc., except sleeping.

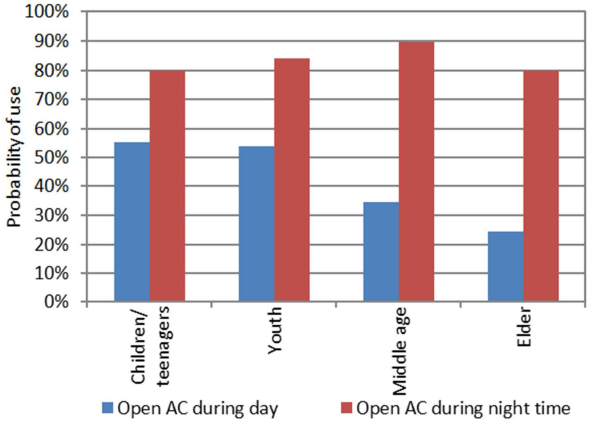


Figure 4. *The probability of using AC during the day and night time.*

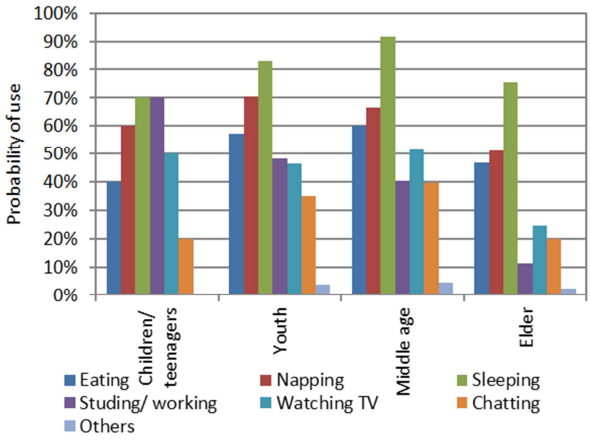


Figure 5. *The probability of using AC related to different activities.*

Before discussing the interactive features of occupant behaviour related to AC, the probability of operating AC is various when the occupant is alone, as shown in Figure 6. The AC would probably be used when child, teenager, youth or middle age is at home alone, while in contrast, it may be used by less than 40% elders. Besides, regarding turning on the AC once the occupant enters the room when there is no one else in the room, the older the occupant is, the less likely he or she would do it. Even though all types of occupant would like to open AC when he feels hot rather than as he enters a room. The results seems to be opposite about turning off the AC once the occupant leaves the room. Only 40% children and teenagers turn off it while above 70% elder do that in order to save energy.

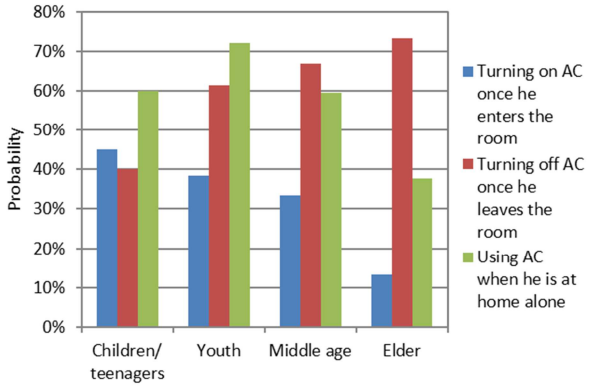


Figure 6. *Probability of operating AC when he is at home alone.*

3.2.3. Setting Point of AC

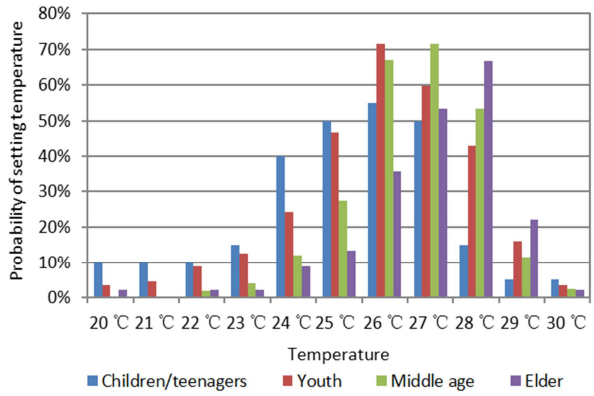


Figure 7. *Setting point of AC of different typical human.*

Figure 7 shows the setting temperature of AC currently used by respondents. It can be seen that most of the children and teenagers would prefer a relatively low indoor temperature setting between 24°C and 27°C, and the elders need a higher indoor temperature about 27°C and 28°C. The most likely temperature setting by children and teenagers, youth, middle age and elder is 26°C, 26°C, 27°C and 28°C, respectively. In addition, about 60% respondents keep the temperature constant when the AC is operating.

3.3. The Interactive Features of Typical Occupants

Actually, there is more than one occupant staying in the same room in most time, over 80% of them would take others' feeling about the indoor comfort into consideration (shown in Figure 8). Over 60% middle age thinks more about the children's feeling and approximately 45% consider the elders' comfort. Hence, there could be more than one interaction between different types of occupants which can significantly affect the operating of AC.

Figure 9 reveals the initiatives of controlling the AC of different types of occupants, when someone else is also in the same room. It indicates that over half of these four typical occupants wouldn't like to control the AC as long as someone else in the room too, especially the children/teenagers and elders. In another word, only a majority of youth and middle-aged people would like to

actively turn on/off the AC and change the setting temperature of AC by themselves, when some else are in the same room. Besides, when it comes to agreement on changing operation of AC, the responses of different occupants are relatively consistent, which can be seen in Figure 10. It shows that approximately 70% of them agree to turn on the AC if other occupants don't satisfy with the indoor environment, even though he feels comfortable. The similar tendency can be observed in changing the setting point of AC, while more youth and middle age may agree to change compared to other two types of occupant. However, some differences also occur in the consent of children and teenagers on turning off the AC. Only one third of them allow to stopping using AC when others want to.

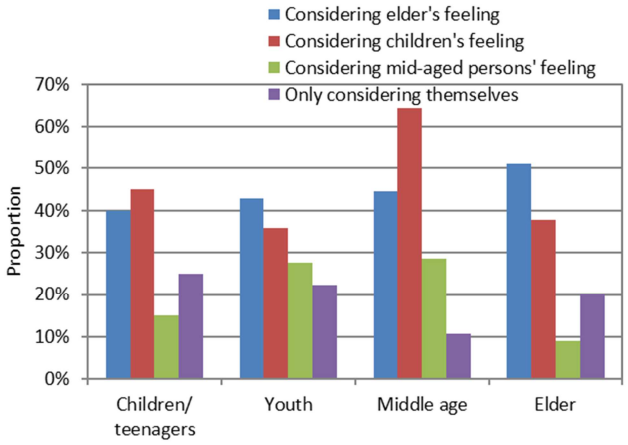


Figure 8. *The probability of taking other persons' feeling into consideration of different typical occupant.*

In another case, most of them would like to seek the agreement from others when he or she wants to change the status of AC because of discomfort, while others may feel satisfied at the same time. The average value of each typical occupant who changes operation of AC without asking is about 10% (Figure 11). The majority of them may turn on/off the AC or change the setting point after achieving anyone's agreement, and another part of them need the consent of most occupants in the same space.

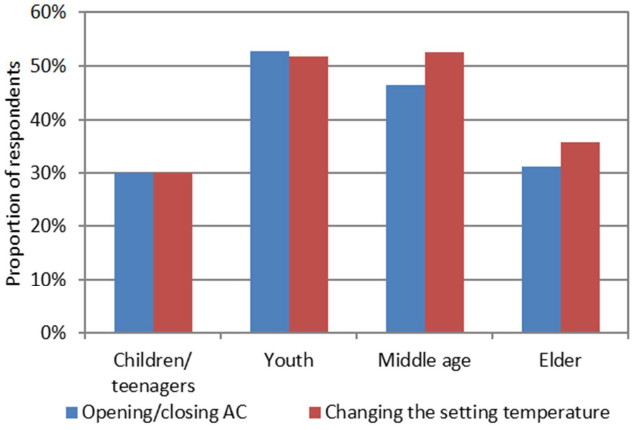


Figure 9. *The proportion of respondents about actively controlling AC by himself when someone else is in the same room.*

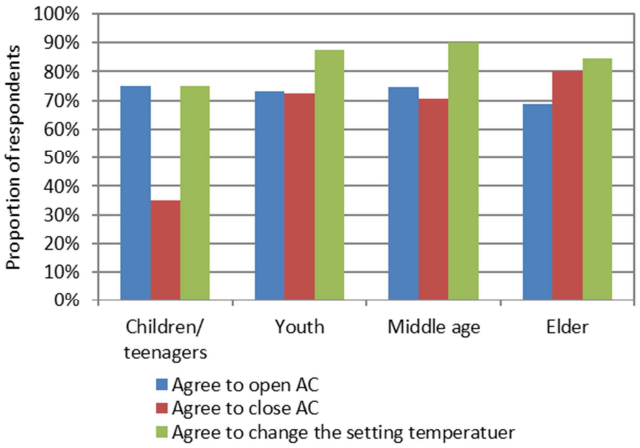


Figure 10. *The proportion of respondents about agreeing to open/close AC or change setting temperature when others feel uncomfortable, even though he feels comfortable at the same time.*

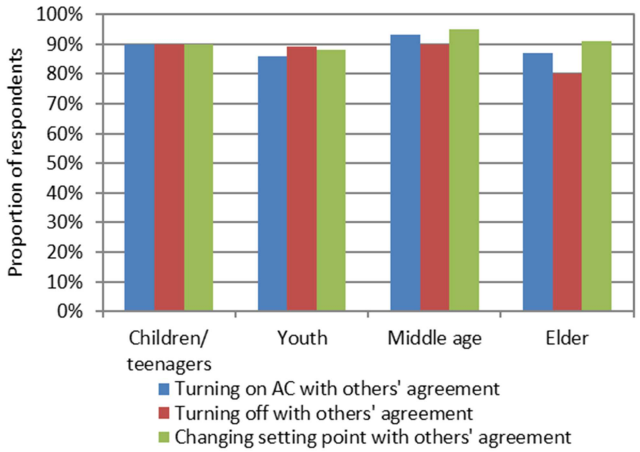


Figure 11. *The proportion of respondents whether he would operate the AC with others' agreement or not when he feels uncomfortable.*

3.4. Discussion

The survey results suggest that large differences occur in patterns related to AC of these tour typical occupants, as illustrated in Table 2. The outdoor temperature triggering them to start using AC in summer varies from 30.5°C to 32°C, while that prompting them to stop using AC is between 28°C and 30°C. Besides, more than 40% of children and teenagers would like to maintain an indoor temperature between 24°C and 27°C, leading to the average value is 25.5°C, which is lower than that of other types of occupants. This indicates that people might develop distinct individual temperature and thermal comfort preferences. In addition, majority of the youth would use their AC in living room and bedroom for a relatively long time, approximately 4h and 7h at weekdays respectively, as well as the middle age. The hours used at weekends can be even longer by youth and middle age. It is noteworthy that more than 80% of all occupant response to use AC during night time, while few of them use it during the day.

Regarding to the operation of AC, very few of them would like to turn on it once he enters the room, the highest proportion of respondents (45%) occurs in children and

teenagers (as shown in Fig. 6). In contrast, majority of them prefer to turn off the AC once he leaves the room, especially those elders. Besides, more than 60% of children-teenagers, youth and middle-aged occupants would use AC when he is in the room alone, and only 40% elder do the same thing.

Normally, over 75% of the respondents take others' feeling into consideration and share their views with their family members regarding turning on/off AC and AC temperature settings and take others' feeling into consideration when there is someone else in the same space (as illustrated in Table 3). Opposite to the diversity of using AC mentioned before, the reactions of these four typical occupants to others' requirements are quite similar. Less than half of them want to actively control the AC by themselves. In addition, more than 75% of them are in agreement with turning on and changing the setting point of AC when someone else doesn't satisfy with the indoor thermal environment even though he or she feels comfortable. A difference occurs in turning off AC under the same circumstance, only 40% of children and teenagers would agree to do so while over 70% of others do the same thing. Similarly, the majority of them seek the consent of others when he or she wants to change the status of AC. Therefore, the operation of AC may be different when different types of occupants stay in the same space, which needs to be noticed in the analysis of behaviour patterns and usage profile in the simulation.

4. Conclusion

224 households and 377 occupants in residential buildings in Hangzhou have been investigated about their usage of AC in summer. As people may develop distinct individual temperature and thermal comfort preference, 4 typical kinds of occupants are defined according to their age, which are children and teenagers (ages between 0 and 18), youth (ages between 19 and 30), middle age (ages between 31 and 60), and elder (over 61 years old). The survey results suggest that the majority of children and teenagers would prefer a relatively low setting temperature of AC at below 27°C. Meanwhile, approximately 70% of them start using AC when outdoor temperature reaches at 30°C. And a bit higher temperature is needed to trigger other three typical occupants to start using AC, especially those ages over 60 years, as illustrated in Table 2.

Table 2. *The characteristics of typical occupants' behavior related to AC.*

Category		Children and teenagers	Youth	Middle age	Elder
Average outdoor temperature (starting using AC)		30.5°C	31°C	31°C	32°C
Average outdoor temperature (stopping using AC)		28°C	28.5°C	28.5°C	30°C
Average AC setting temperature		25.5°C	26°C	26.5°C	27°C
Month (mostly used)		Early July – Early September	Middle July – Early September	Middle July – Early September	Middle July – Late August
Average opening hours	Living room – weekday	3.7h	3.7h	3.6h	3.3h
	Living room – weekend	8.9h	4.7h	5.8h	2.6h
	Bedroom – weekday	5.5h	7.2h	8.0h	5.7h
	Bedroom – weekend	5.4h	8.5h	9.3h	5.9h
Activity (above 50% of respondents)		Napping, sleeping, studying/working	Eating, napping, sleeping,	Eating, napping, sleeping, watching TV	Napping, sleeping

Table 3. *The interactive features of typical occupants.*

Category	Children and teenagers	Youth	Middle age	Elder
Considering others' feeling	75%	78%	90%	80%
Actively Turning on/off AC by himself when someone else in the same room	30%	50%	47%	31%
Actively Controlling setting point by himself when someone else in the same room	30%	53%	52%	36%
Agreeing to turn on AC when others feel uncomfortable	75%	73%	75%	69%
Agreeing to turn off AC when others feel uncomfortable	40%	70%	70%	80%
Agreeing to change setting point when others feel uncomfortable	75%	88%	90%	84%
Seeking others' agreement when he wants to turn on AC	90%	86%	93%	87%
Seeking others' agreement when he wants to turn off AC	90%	89%	90%	80%
Seeking others' agreement when he wants to change setting point	90%	88%	95%	91%

Regarding to the usage time of AC, youth and middle-aged occupants would like to use AC more frequently, leading to a longer time compared to others. It is quite worthy mentioned that the majority of elders use the AC at a high temperature and during a short time under any circumstances.

As a majority of respondents consider other occupants' feeling towards indoor thermal environment and over 75% of them reports to share their opinion with their family members regarding turning on/off the AC and controlling the setting temperature, the operation patterns of AC may change. Table 3 indicated that these four typical occupants have a similar attitude on the operating of AC when there is someone else in the same space. Most of them would consent to turn on/off the AC and change the setting point if others require to doing so as he or she dissatisfies with the temperature, even though themselves feel comfortable. On the other hand, over 80% of them would ask other's agreement on whether he or she could change the status of AC when he or she feels uncomfortable.

The survey is carried out in order to develop the database of the occupant behavior related to AC in HSCW zone which can be the basis of the study on the behavior patterns in

residential building. Then the summarized patterns can be used in simulation to improve the accuracy of energy consumption forecast in single building, as well as buildings in district.

However, the results in this paper are just the basic analysis of the survey. Later, correlation analysis between the occupant behavior related to AC and some environment triggers, event triggers, individual factors should be conducted to find the important factors. Then the typical families based on these typical individual and significant factors can be defined, as well as their behavior patterns of AC operation in summer and winter.

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