Study on Residents' Behavior of Using Air Conditioners in Bedrooms in Jiangsu, Zhejiang and Shanghai

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Abstract: Jiangsu, Zhejiang and Shanghai are characterized with the subtropical monsoon climate, which is sultry in summer and cold in winter. Most residents use air conditioners during summer and winter because of their uncomfortable environment. The bedroom is the venue where people spend the most time. In this paper, by monitoring the environment data in the bedroom, people's behavior of using air conditioners is inferred. Finally, it is found that there are three "intermittent" energy consumption modes for the bedroom air conditioner in this area: "Turn on before going to bed" and "Turn off before going to bed", "Turn off at regular time after going to bed" and "Turn off after getting up in the morning". The simulation result of actual behavioral energy consumption is more energy saving than predicted in the standard specification. The setting temperature of air conditioners is mostly higher than the standard 26°C in summer; mostly higher than 18°C in winter. There is an obvious difference between the resident tolerance temperature and the setting temperature. After the air conditioners is turned off, the indoor environment is still in a state that residents can tolerate for a period of time. Therefore, residents who turn off the air conditioners after getting up in the morning can consider turning off the air conditioners before getting up to further save energy.

***Keywords*:** building energy saving, bedroom, behavior of using air conditioners

Introduction

With the rapid development of China's urbanization process, the carbon emission in the whole process of construction is on the rise. According to the 2020 Research Report on China Building Energy Consumption, the total carbon emission of the whole process of Construction in China was 4.93 billion tons of CO_2, accounting for 51.3% of the national carbon emission in 2018[1]. Therefore, building energy conservation is an important way to achieve social sustainable development. Jiangsu, Zhejiang and Shanghai are closely integrated with one culture with GDP accounting for about 20% of the country. This region is hot in summer and cold in winter, with high humidity and less sunshine. With the development of economy, most residences are equipped with air-conditioning equipment to adjust the indoor environment to meet the requirements of human comfort. Studies have shown that air conditioners energy consumption in hot summer and cold winter climate zones of Jiangsu, Zhejiang and Shanghai accounts for 20%-30% of the total energy consumption of residential buildings [2-3], and air conditioners energy consumption is a relatively important item in the study of building energy conservation.

The traditional description of the use behavior of residential air conditioners remains unchanged. For example, the Code for Residential Design GB 50096-2011 [4] and the Standard for Energy-saving Design of Residential Buildings JGJ 134-2010 in hot summer and cold winter [5] define the operating parameters of air conditioners in a room as 26℃ in summer, 18℃ in winter and 1.0 times of air change/h. People's tolerance of indoor environment temperature and air conditioners setting temperature is the same. In addition, according to the standard, the calculation period of summer cooling lasts generally from early June to the end of August, and the calculation period of winter heating is from early December to the end of February, during which the air-conditioning equipment runs all day long. However, in fact, residents' regulation behavior of air conditioners is influenced by many factors with strong randomness and difference, which is one of the main factors leading to deviation between actual energy consumption of buildings and predicted energy consumption [6]. The difference in the use mode of air conditioners results in a 10-fold difference in the simulated energy consumption of different households [7]. Furthermore, some scholars have studied the influencing factors of differences in human behavior, and have proposed that residents' living habits, lifestyle, age, income and other factors have an impact on family energy use behavior [8−10]. The actual differences will affect the prediction and evaluation of building energy consumption and indoor environment in the stage of building design and operation, and affect the implementation of building energy saving measures. Therefore, it is necessary to study the energy consumption behavior of various typical families.

Domestic scholars have studied the air conditioners behavior of residential buildings in many regions [11−13], and the

results show that the use of air conditioners is closely related to seasons and room temperature, and the operating duration and energy consumption of air conditioners vary significantly among households. Ren[14] et al. investigated more than 20 houses in 8 cities in China, and divided the driving factors of air conditioners into three categories: environment, event (entering and leaving the room, sleeping and getting up), and random (energy price, family background, etc.). Referring to this classification method, the "environment" data was collected by household measurement, the "event" was queried, and the "random" factors were collected by questionnaire. The questionnaire information was summarized, and each household was numbered by initials and Arabic numerals: Suzhou was S, Taizhou was T, and Shanghai and Hangzhou were distinguished by H and H' respectively. In this paper, the elderly refer to retirees after the age of 60, and their annual household income can be divided into: lower than 80,000 yuan (low income), 80,000 to 150,000 yuan (lower middle income), 150,000 to 200,000 yuan (middle income), 200,000 to 300,000 yuan (upper middle income), and more than 300,000 yuan (high income). The main contents are shown in Table 1.

Table 1. Statistics by family members

No.	Member	Air-conditioning equipment for heating	Position	Area m^2	Profession	Educational Background	Annual Income	Testing Season
S1	Husband and wife (youth)	Split air conditioner	Household in middle place	18	white-collar worker	Higher Education	Middle level	Summer
S2	Husband and wife (middle-aged)	Split air conditioner	Household in middle place	12	Designer	Higher Education	Middle level	Summer
H1	young woman	Split air conditioner	Household in middle place	12	scientific research	Higher Education	Middle level	Summer
H2	Young man	Split air conditioner	Household in middle place	12	scientific research	Higher Education	Middle level	Winter
H'1	Senior	Split air conditioner	East	9	Null	Primary school	Below the average	Summer
T1	Children, Mother	Split air conditioner	East	10	Null	pre-school and higher education	Middle level	Winter
T2	Children, Husband	Split air conditioner	Detached	20	White COLLAR	Pre-school and higher education	Middle level	Winter
T3	Senior	Split air conditioner	East	10	Null	Primary school	Low lwevel	Winter

The bedrooms of 8 families are equipped with split air conditioners, and the distribution of family members and ages is in comprehensive range. Due to the limited number of instruments, household tests were carried out in summer and winter respectively.

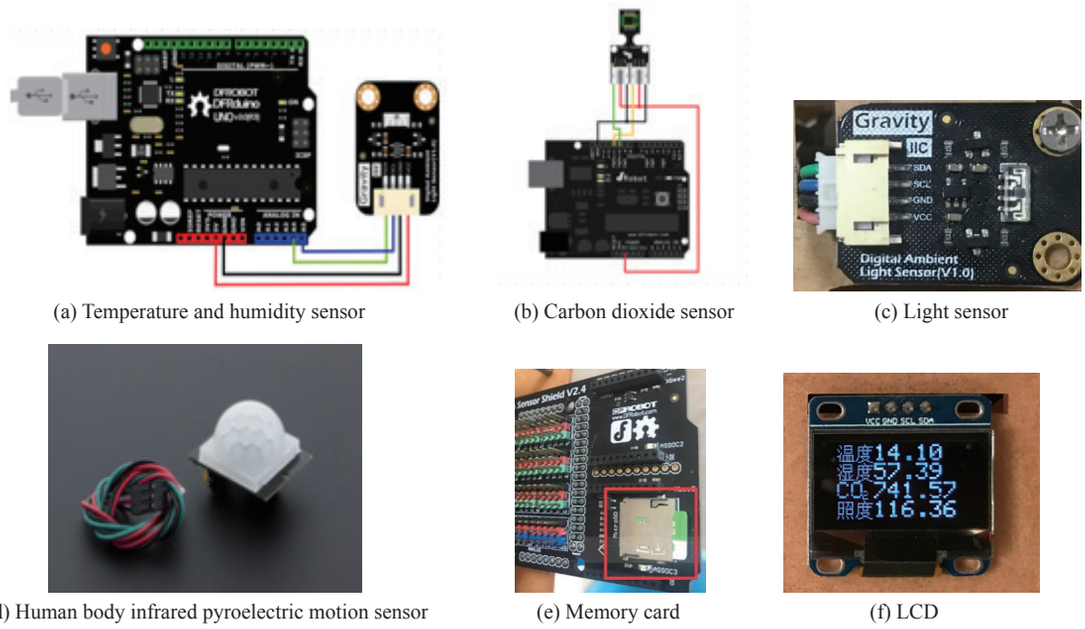
1. Research Methods

1.1 Indoor environmental monitoring

According to the correlation between energy-using behavior and environmental parameters, many scholars analyze people's behavior state at that time by long-term monitoring of indoor environment. For example, Jian Yiwen et al. [15] proposed that the change of CO_2 concentration in residential buildings can reflect the behavior of opening doors, closing doors and Windows. Mika Raatikainen et al. [16] inferred the situation of people in the room and whether the air conditioner was turned on according to changes in indoor and outdoor temperature and humidity, air pressure difference and CO_2 concentration. Zhou Hao [17] from Tianjin University made researches on a series of residents' energy consumption behaviors, such as on-off air conditioners, on-off lights, on-off Windows and attendance state, based on the indoor temperature and humidity, noise, illumination, CO_2 and formaldehyde concentration monitored. Therefore, this experiment is mainly to accurately collect indoor environmental parameters, and the construction and arrangement of data acquisition instruments become more important content.

With the rapid development of industry and information technology, automatic data collection and storage technology has been widely used in all aspects of society. Based on Aruduino platform, this paper developed a device that can collect real-time environmental data in residential buildings. Arduino is a simple and easy-to-use open source electronic prototype platform, including hardware (Arduino board) and software (Arduino IDE). By writing programs in Arduino IDE, the data feedback from each sensor is collected and saved to the memory card. With Arduino microcontroller as the core processor,

the system integrates temperature and humidity sensor, carbon dioxide sensor, illumination sensor, human infrared pyroelectric motion sensor, memory card and LIQUID crystal display. The main accessories are shown in Figure 1.



(a) Temperature and humidity sensor (b) Carbon dioxide sensor (c) Light sensor

(d) Human body infrared pyroelectric motion sensor (e) Memory card (f) LCD

Figure 1. Main parts of the instrument

The accuracy of the data collected by each sensor reaches two decimal points, and the data is processed by Arduino and recorded in the memory card in real time. The recording step length is 1 minute. The human infrared pyroelectric sensor is effective for active people, with bad effect for stationary people. The memory card is removed every other month and the data is copied to the computer. Meanwhile, check whether the data collection of the instrument is normal.

1.2 Identification of air conditioner usage behavior

In light of the changes in the collected environmental data, human behavior is deduced backwards, as shown in Figure 2 below. According to the increase of illumination value from 0LX to 75LX at Ta time, it can be inferred that when people enter the room at night, they first turn on the light, and then turn on the air conditioner at Tb time due to the rising temperature. From the gradual increase of CO_2 concentration, it can be inferred that the doors and Windows are closed, and finally the room temperature is stable at 28.0~28.5℃. After the air conditioner is turned off at Tc time, the temperature gradually rises. From the illumination value at Td time to 0LX, it can be seen that the lamps are closed and ready to sleep. After the inquiry, the door is "into the room after a period of time, off before falling asleep" air conditioners use mode. The difference between winter and summer mainly lies in the opposite trend of temperature change. The room temperature rises after heating equipment is turned on and decreases after heating equipment is turned off.

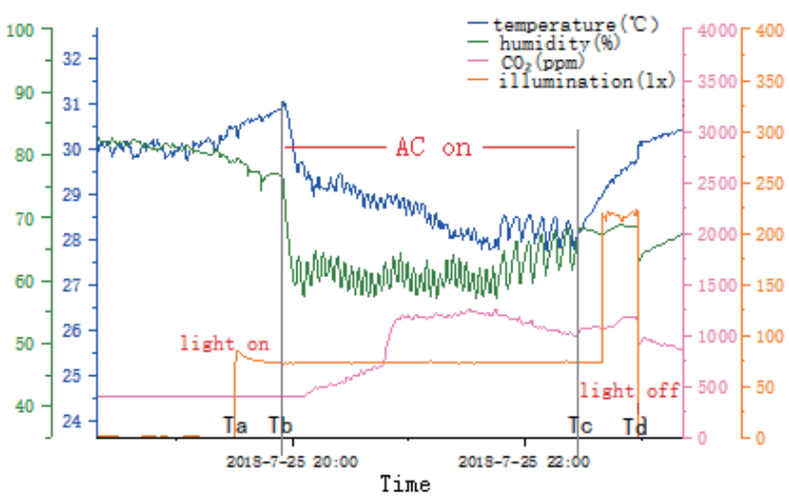


Figure 2. Curve section of turning on and off air-conditioning equipment in summer

1.3 Data processing

The amount of data collected this time is in large quantity, and the data should be cleaned first after the completion. There are many uncontrollable things in the house: such as sudden power failure, blocking the instrument affecting the illumination acquisition, and accidentally touching the instrument causing displacement. Some sensors also produce data noise: zero drift phenomenon occurs when CO_2 is collected, and CO_2 or illuminance value occasionally shows a large jump. Therefore, it is necessary to preprocess the data before data analysis in order to get accurate behavior information.

Data cleaning is mainly for scientific and standardized processing of missing, outlier and wrong data, so that the obtained sample information is more reliable and complete. According to the characteristics of the data in this test, some simple and suitable data processing methods are selected.

1.3.1 Processing of missing data

Two methods can be used to deal with missing data: ignoring tuples and linear interpolation. If more than four consecutive tuples are not collected, you cannot fill in the missing values and directly choose to ignore these tuples. Linear interpolation is used to process the sample points missing within 3 consecutive times. For example, if there are 5 consecutive parame-ters (x_i, x_i+1, x_i+2, x_i+3, x_i+4), among which, x_i+1, x_i+2, x_i+3 are the missing data, they can be filled in the following ways:

$$x_{i+1}= (x_{i+4} – x_i)/4+ x_i \quad (1)$$

$$x_{i+2}= [(x_{i+4} – x_i)/4]\times 2+ x_i \quad (2)$$

$$x_{i+3}= [(x_{i+4} – x_i)/4]\times 3+ x_i \quad (3)$$

(1) Global outlier

Global outliers are data points that deviate greatly from the normal value. The specific causes of data outliers need to be identified first. If it is caused by an instrument error, these points can be deleted first, and then the data interpolation method above can be used to supplement the deleted points. For example, the CO_2 sensor has an outlier of abnormal size due to data jump caused by mechanical vibration or electrical interference. Figure 3 shows an abnormally large jump in CO_2 concentration in a short period of time. These mutation points clearly deviate from the trend of stage changes in environmental parameters, and such CO_2 concentration mutation has nothing to do with residents' behaviors.

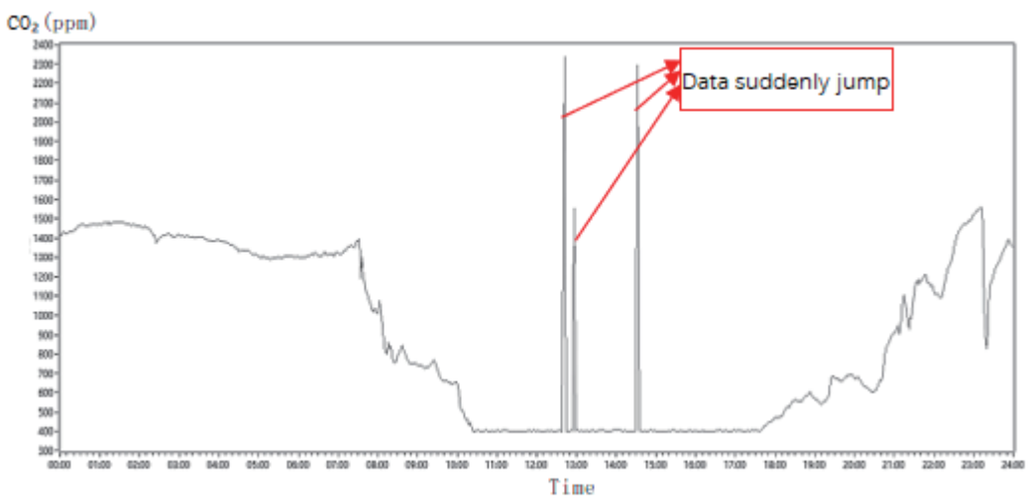


Figure 3. Change of CO_2 concentration in a given day

In addition, Transistor parameters are affected by temperature and power supply voltage instability, when the amplifier circuit input signal is zero, after the amplifier amplification, in the output end of the formation of a larger voltage, resulting in the generation of zero drift phenomenon. The data will fluctuate greatly, making the trend of change in a short period of time extremely irregular. It is difficult to define the time and amount of zero drift, but it does not affect the change trend of the collected data. Since this phenomenon basically occurs in the collection of CO_2, CO_2 in this paper is mainly related to people in the room and the switch window, so try to describe these two situations from the trend judgment, without considering the

accuracy of the specific value.

(2) Situation (condition) outlier

Outliers usually occur under certain conditions, but not under other conditions. For example, in the collection of illumination, the data collected under a specific environment and behavior deviates significantly from other concentration points. Taking FIG. 4 as an example, the illuminance value decreased significantly in a short period of time at night, but did not fall to 0lx, indicating that the illuminance meter was sheltered rather than caused by the action of turning off the light.

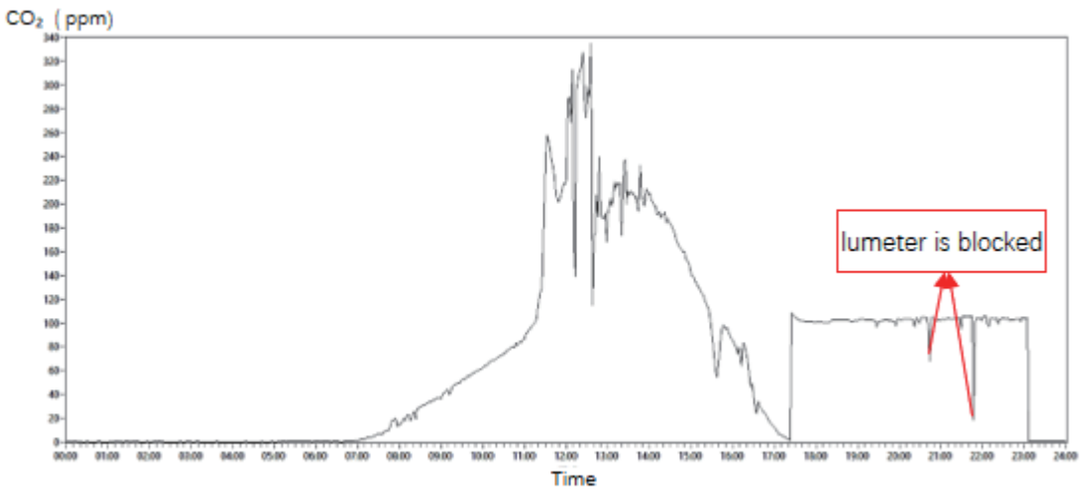


Figure 4. Change of illuminance value on a given day

1.3.2 Mathematical method for judgement of outlier data

Classical outlier detection methods are often divided into four categories based on statistics, clustering, classification and proximity[18]. This paper mainly adopts outlier detection methods based on clustering and proximity. The detection method based on clustering mainly inspects the relationship between objects and clusters. When an object deviates from any cluster or belongs to a small cluster, it can be treated as an outlier. Generally, k-means clustering method is adopted. Assum-ing that there is a set of sample points $D=\{P_1, P_2,\cdots, P_N\}$, it is randomly divided into K independent clusters to form a new set $C=\{C_1, C_2, \cdots, C_K\}$, and the center point of each cluster C_j is calculated according to the following formula:

$$m_j = \frac{1}{|C_j|}\sum_{p\in C_j} p \tag{4}$$

Then the distance between each sample point Pj and the central point mj of each cluster was calculated and divided into the nearest cluster, thus generating a new set C'. Iterative process should be conducted until the new cluster is the same as the previous one. The distance calculation formula is as follows:

$$SEE = \sum_{j=1}^{k}\sum_{p\in C_j} |p-m|^2 \tag{5}$$

Generally, the data amount of outlier cluster is in a small range with apparant deviation value from the normal value, which should be deleted during statistics. However, there will also be a class of data in the normal range, but because the interference deviates from the law of surrounding data, outlier detection method based on proximity is adopted. Proximity based outlier detection includes three methods: distance, network and density. According to the continuity of data collection in time, distance based outlier detection is selected here. Providing that the sample set $D=\{P_1, P_2,\cdots, P_N\}$,the distance threshold r is given.Besides, for any point P_j, the number of other samples in the neighborhood R is counted. Then a frac-tional threshold π is set. When the proportion of the sample number in the neighborhood to the total sample number is lower than π, point P_j can be regarded as an outlier, and the expression is as follows:

$$\frac{\left|\left\{r \middle| dist(r,r') \le r\right\}\right|}{|D|} \le \pi \tag{6}$$

This paper adopts the method of intuitive judgment according to the curve combined with mathematical classification judgment, which can well deal with the whole and local deviating data, and finally get a relatively smooth data chart, which is conducive to the statistics of residents' behaviors.

2. Analysis of statistical results

Bedrooms are normally used for sleeping at night or taking naps during the day. This time, S1, S2, H1, H2, H'1, T1, T2 and T3 are mainly classified by different behavior patterns of air conditioners. In addition, S1, S2 and T2 families with working people were divided into working days and rest days. H1, T1 and T3 are ones without residents in working; H1 and H2 are post-doctors in school, with relatively free time, and are divided into separate categories. The periods not listed in the table below all mean that the air conditioner is not turned on or off during that period.

2.1 Usage mode of air conditioners in specific periods before sleeping

The young man in H2 is a postdoctoral fellow in school. Because his activities on campus are limited and his time is relatively free, his time in the school is not strictly divided into working days and rest days.

Table 2. Distribution of H2 air conditioner startup time

Time / No.	Season	07:00 ~ 08:00	08:00 ~ 13:00	13:00 ~ 14:00	14:00 ~ 15:00	15:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 07:00
H2	Winter	64%	0%	8%	7%	0%	7%	14%	0%

Table 3. Distribution of shutdown time of H2 air-conditioning equipment

Time / No	Season	08:00 ~ 09:00	09:00 ~ 15:00	15:00 ~ 16:00	16:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 00:00	00:00 ~ 01:00
H2	Winter	64%	0%	8%	0%	7%	0%	7%	14%

As can be seen from the above table, their usage habits are divided into turning on air conditioners for a period of time when they take a shower at night, take a nap and get up in the morning, especially when they get up in the morning, accounting for 64%.

2.2 Switch off mode of air conditioner during sleeping

The air conditioners in H'1, T2 and T3 are turned on before going to bed and turned off during sleeping. After asking the residents of these three households, they believe that sleeping with air conditioners on is easy to catch cold in summer and dry in winter, which is easy to cause discomfort and disease.

(1) In the first three households, T2 is a family with working staff, which is divided into working days and rest days for discussion.

Table 4. Distribution of startup time of T2 air-conditioning equipment(working days)

Time / No.	Season	00:00 ~ 18:00	18:00 ~ 19:00	19:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 00:00
T2	Winter	0%	0%	0%	60%	40%	0%

Table 5. Distribution of shutdown time of T2 air-conditioning equipment (working days)

Time / No	Season	12:00 ~ 00:00	00:00 ~ 01:00	01:00 ~ 02:00	02:00 ~ 12:00
T2	Winter	0%	20%	80%	0%

As can be seen from the above two tables, the air conditioners is turned on between 20:00 and 22:00 in the evening on weekdays. The family entered the bedroom earlier in the evening,with main reasons that there were children in the home who would go to bed earlier. Switch off devices between 00:00 and 02:00, when most people are already asleep.

Table 6. Distribution of startup time of T2 air-conditioning equipment (days off))

Time / No	Season	00:00 ~ 09:00	09:00 ~ 10:00	10:00 ~ 12:00	12:00 ~ 13:00	13:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 00:00
T2	Winter	0%	20%	0%	10%	0%	50%	20%	0%

Table 7. Distribution of shutdown time of T2 air-conditioning equipment (days off)

No \ Time	Season	02:00 ~ 10:00	10:00 ~ 11:00	11:00 ~ 14:00	14:00 ~ 15:00	15:00 ~ 00:00	00:00 ~ 01:00	01:00 ~ 02:00
T2	Winter	0%	20%	0%	10%	0%	20%	50%

As can be seen from the above tables, air-conditioning equipment is turned on and off during waking up in the morning, taking a lunch break at noon and sleeping in the bedroom at night on rest days, and the rest time in the evening is similar to that on weekdays.

(2) H'1, T3 refer to families withe veterans. The seniors are generally characterized with a calm mind withe a regular life. They like to get up early for exercise and take a walk after dinner.

Table 8. Distribution of startup time of H'1 and T3 air-conditioning equipment

No. \ Time	Season	00:00 ~ 12:00	12:00 ~ 13:00	13:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 00:00
H'1	Summer	0%	31%	0%	63%	6%	0%
T3	Winter	0%	50%	0%	50%	0%	0%

Table 9. Distribution of shutdown time of H'1 and T3 air-conditioning equipment

No. \ Time	Season	12:00 ~ 13:00	13:00 ~ 14:00	14:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 00:00	00:00 ~ 01:00	01:00 ~ 02:00
H'1	Summer	15%	16%	0%	31%	32%	6%	0%	0%
T3	Winter	0%	50%	0%	0%	0%	0%	0%	50%

It can be seen from the above table that the seniors generally develop the habit of taking a nap during the day and entering the bedroom from 20:00 to 21:00 at night. Studies have pointed out that in the same intensity of noise environment, the seniors are more likely to develop emotional irritability than people of other ages [19], so they hope to have a quiet environment after falling asleep, especially at night.

2.3 Switch-off mode the air conditioner when getting up

The air conditioners in S1, S2, T1 and H1 are in operation mode after sleeping and getting up. The two office workers, S1 and S2, used air-conditioning equipment in summer and were divided into working days and rest days for discussion.

(1) The usage of air-conditioning equipment by S1 and S2 office workers on working days is shown in the table below.

Table 10. Distribution of startup of S1 and S2 air conditioners (working days)

No. \ Time	Season	12:00 ~ 17:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 00:00	00:00 ~ 01:00	01:00 ~ 12:00
S1	Summer	0%	16%	43%	25%	8%	8%	0%
S2	Summer	0%	0%	0%	0%	50%	50%	0%

As can be seen from Table 10 above, S1 household proves the fact that normally the bedroom air conditioner after 20:00 in the evening was normally used, while S2 uses it after 23:00 in the evening. The main reason is that S2 works in a design institute and often works overtime at night.

Table 11. Distribution of shutdown time of S1 and S2 air conditioners (working days)

No. \ Time	Season	00:00 ~ 06:00	06:00 ~ 07:00	07:00 ~ 08:00	08:00 ~ 09:00	09:00 ~ 10:00	10:00 ~ 00:00
S1	Summer	0%	0%	39%	54%	7%	0%
S2	Summer	0%	50%	50%	0%	0%	0%

It can be seen from Table 11 above that the two families basically left their bedrooms before 09:00 in the morning, and S1 had a Chinese New Year holiday during the test period, so air-conditioning equipment was used from 09:00 to 10:00.

See the table below for the usage of air-conditioning equipment for S1 and S2.

Table 12. S1 Distribution of operation time of air Conditioner (days off)

No. \ Time	Season	00:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 00:00
S1	Summer	0%	50%	50%

Table 13. S1 Distribution of shutdown time of air conditioner (days off)

No. \ Time	Season	00:00 ~ 08:00	08:00 ~ 09:00	09:00 ~ 10:00	10:00 ~ 11:00	11:00 ~ 00:00
S1	Summer	0%	50%	25%	25%	0%

Use of air conditioners on rest days of S1 is closer to that on working days, and it mainly lies in the fact that people in S1 failed to have the habit of taking a lunch break during the day. The use of air-conditioning equipment during the rest day test was not monitored in S2.

(2) T1 is the family whose mother takes care of children at home, and the usage pattern is shown in the table below.

Table 14. Distribution of startup time of T1 air conditioner

No. \ Time	Season	12:00 ~ 13:00	13:00 ~ 14:00	14:00 ~ 18:00	18:00 ~ 19:00	19:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 01:00	01:00 ~ 02:00
T1	Winter	29%	14%	0%	14%	29%	10%	0%	4%

Table 15. Distribution of shutdown time of T1 air conditioners

No. \ Time	Season	04:00 ~ 07:00	07:00 ~ 08:00	08:00 ~ 09:00	09:00 ~ 10:00	10:00 ~ 15:00	15:00 ~ 16:00	16:00 ~ 03:00	03:00 ~ 04:00
T1	Winter	0%	14%	25%	14%	0%	43%	0%	4%

As can be seen from Table 14 and 15 above, this family is characterized with the habit of lunch break and the family members go to bedroom early in the evening. In addition, the family members used the heating equipment at 01:00 ~ 04:00, the reason is that bed-wetting was caused by the child, this kind of accidental incident can be ignored.

(3) Post-doctoral

H1 Young women are post-docs at school, because their activities are limited and during the summer vacation. Combined with the statistical results of test data, weekdays and rest days are discussed without distinction.

Table 16. Distribution of startup time of H1 air conditioner

No. \ Time	06:00 ~ 07:00	07:00 ~ 12:00	13:00 ~ 14:00	14:00 ~ 15:00	15:00 ~ 16:00	16:00 ~ 19:00	19:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 00:00
H1	2%	0%	5%	5%	0%	0%	20%	15%	13%

Table 17. H1 Distribution of shutdown time of air conditioner

No. \ Time	Season	00:00 ~ 01:00	01:00 ~ 02:00	02:00 ~ 03:00	03:00 ~ 04:00	04:00 ~ 05:00	05:00 ~ 06:00	06:00 ~ 07:00	07:00 ~ 08:00
H1	Summer	0%	2%	5%	0%	0%	0%	0%	3%

No. \ Time	Season	08:00 ~ 09:00	09:00 ~ 10:00	10:00 ~ 11:00	11:00 ~ 12:00	12:00 ~ 13:00	13:00 ~ 14:00	14:00 ~ 15:00	15:00 ~ 16:00
H1	Summer	0%	6%	16%	24%	10%	8%	3%	0%

No. \ Time	Season	16:00 ~ 17:00	17:00 ~ 18:00	18:00 ~ 19:00	19:00 ~ 20:00	20:00 ~ 21:00	21:00 ~ 22:00	22:00 ~ 23:00	23:00 ~ 00:00
H1	Summer	5%	8%	5%	0%	0%	5%	0%	0%

It can be seen from the above tables that the household usually spends a long time in the bedroom. According to the later investigation, it can be known that the household has the habit of reading in the bedroom. Normally, the households accessed

in the bedroom in the evening after 19:00 to turn on the air conditioners until the next day at noon.

2.4 Rule analysis

The bedroom is basically used for daytime nap and night sleep and for private space. The people are those of a certain generation or generation and children. One out of eight households uses air conditioners at a certain time before going to bed, such as taking a shower or getting up. Households 3 "turn on the air conditioner before sleeping and turn off the air conditioner when sleeping"; Household 4 "turn on the air conditioner before going to bed and turn off the air conditioner when getting up". The weekday bar chart is distinguished from other figures by dotted boxes, as shown in figure 5-7 below.

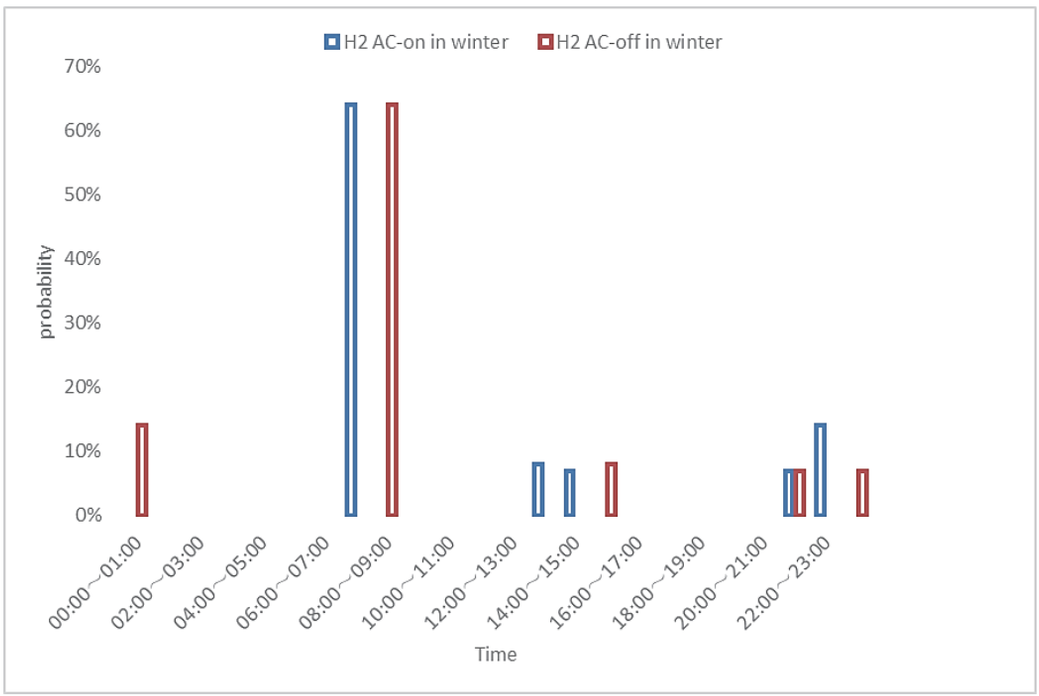


Figure 5. Action probability distribution of air conditioner for "specific period of use before bed"

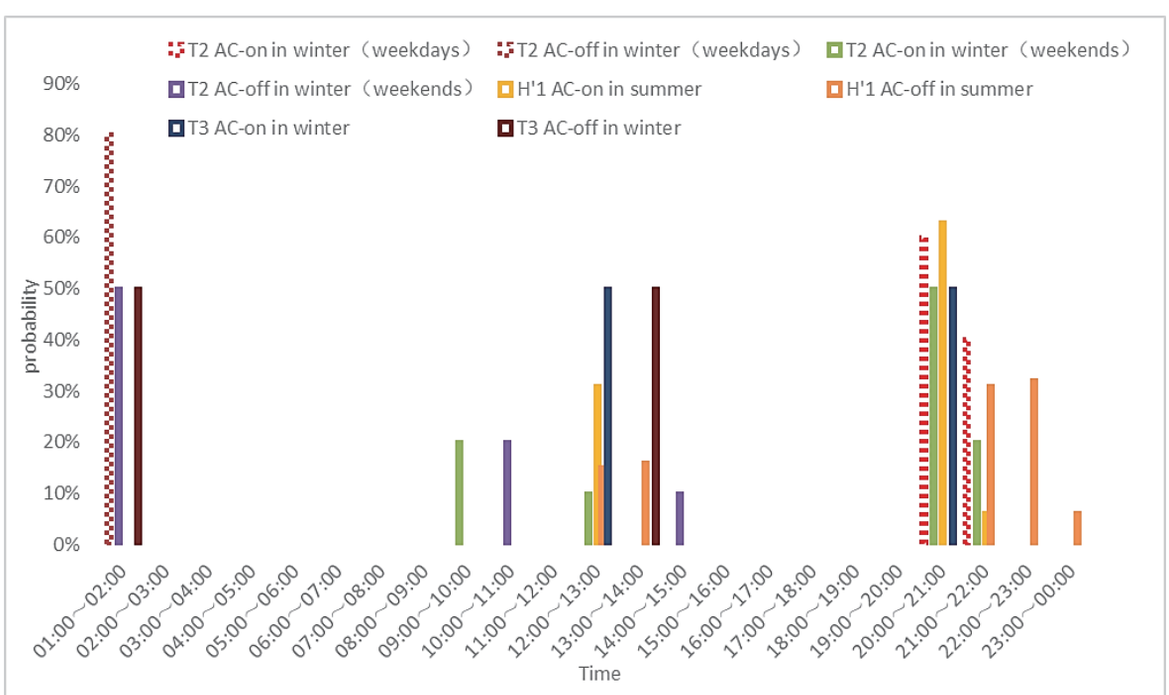


Figure 6. Probability distribution of turning on air conditioners before sleeping and turning off air conditioners during sleeping

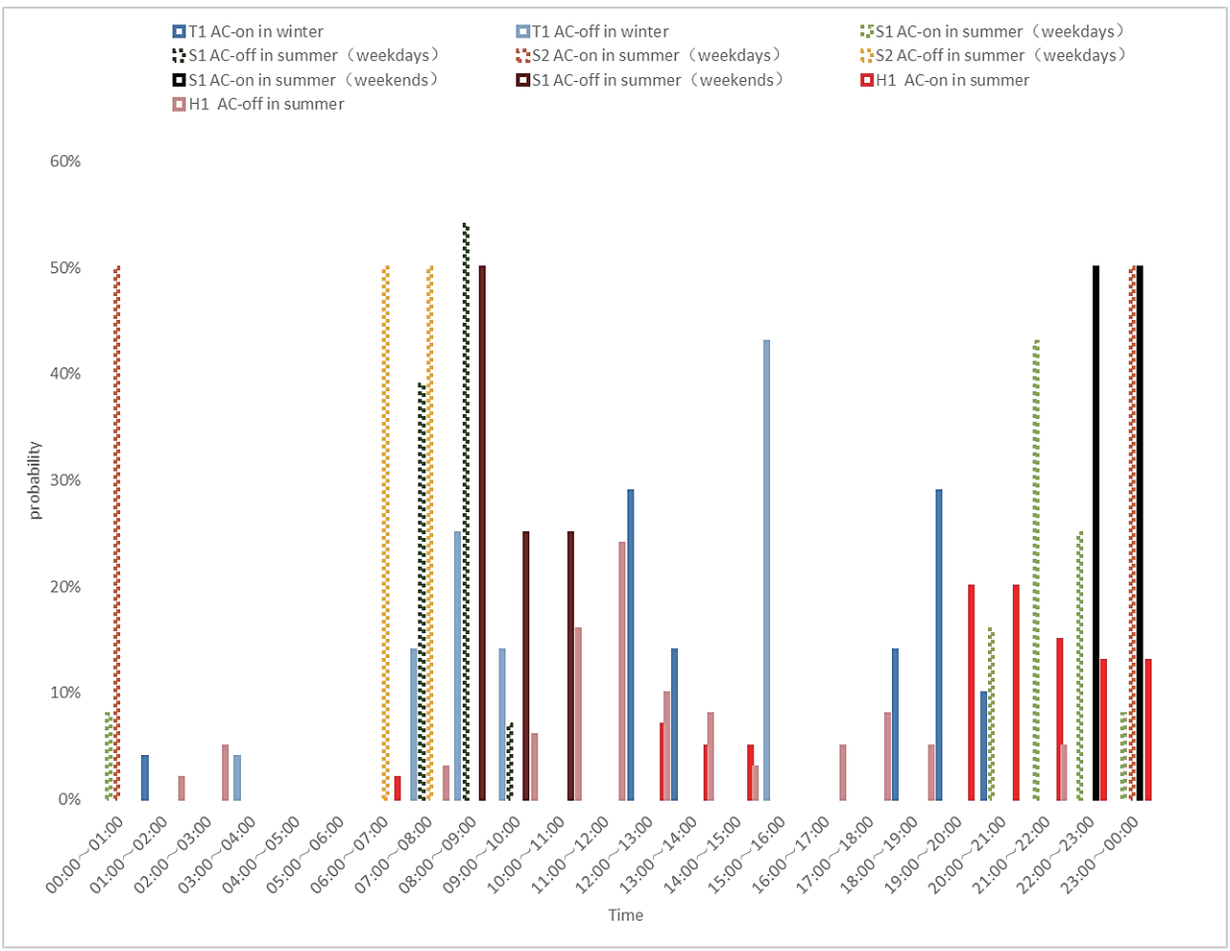


Figure 7. Action probability distribution of turning on air conditioner " before sleeping and off when getting up"

Based on figure 5 to 7 above, it can be seen from the operation period: the air conditioners is turned on from 12:00 to 13:00 and turned off from 13:00 to 14:00 during nap time; In the evening, the air conditioner is mainly turned on between 21:00 and 22:00, and the time for turning off the air conditioner is scattered, with 21:00 to 23:00 before going to bed. There are also 00:00 ~ 02:00 time off after falling asleep; On weekdays, people usually wake up from 06:00 to 08:00, and on holidays or when they do not work, they usually wake up about an hour later. In terms of behavior, most of the elderly have the habit of napping and tend to "turn off the air conditioner when sleeping"; Office workers tend to use their bedrooms regularly on days off, while families without the habit of napping are similar to those on weekdays.

3. Tolerance temperature and set temperature

From the perspective of setting parameters of software energy consumption simulation, the running time and set temperature of heating and air-conditioning equipment affected by human behavior have a great impact on energy consumption. Therefore, the set temperature of heating and air conditioners is statistically analyzed below. At the same time, the tolerance temperature of each type of family to the environment before turning on the device was calculated to understand the difference of their living habits.

Tolerance temperature Take the data one minute before the device is turned on, and set the temperature take the average value after the device is stabilized. If the bed temperature is set low in summer, adjust it after falling asleep, and take the average temperature that reaches the temperature after falling asleep as the setting temperature. The test results were classified according to test areas in the home, and the use of heating and air-conditioning equipment of different types of families was counted, as shown in Table 18 and 19.

Table 18. Statistics of indoor temperature tolerance of residents

Specific user	No.	Season	Residents tolerate temperature in the indoor environment(℃)					
			Mean	Median	Mode	Maximum value	Minimum value	Standard deviation
Young female	H1	Summer	32.93	32.92	33.51	34.34	30.96	0.84
Young male	H2	Winter	14.40	14.43	14.36	15.42	12.84	0.68
Seniors	H'1	Summer	35.74	35.82	35.42	38.47	32.93	1.31
Seniors	T3	Winter	8.94	8.92	8.92	10.80	8.54	0.51
Couples(Youth)	S1	Summer	30.47	30.65	30.74	30.98	29.42	0.40
Couples(Middle -aged)	S2	Summer	32.10	32.08	31.60	32.71	31.41	0.55
Children,Mother	T1	Winter	6.25	6.20	6.12	7.00	5.68	0.41
Children,Couples	T2	Winter	8.95	8.41	8.08	10.91	8.03	0.92

Table 19. Statistics of setting temperature of residential air-conditioning equipment

Specific user	No.	Summer	Set ting temperature of air conditioner(℃)					
			Mean	Median	Mode	Maximum value	Minimum value	Standard deviation
Young female	H1	Summer	28.67	28.65	28.62	30.83	26.98	0.68
Young male	H2	Winter	16.70	16.78	17.66	17.69	14.82	0.62
Seniors	H'1	Summer	27.41	27.29	27.04	29.07	26.34	0.51
Seniors	T3	Winter	20.15	20.23	19.57	21.39	17.06	0.75
Couples(Youth	S1	Summer	27.49	27.88	28.54	28.72	25.25	0.97
Couples(Middle -aged)	S2	Summer	30.59	30.39	30.28	31.70	29.14	0.69
Children,Mother	T1	Winter	19.61	19.66	19.38	21.76	12.12	0.84
Children,Mother	T2	Winter	18.78	19.30	16.28	21.91	14.10	1.90

(1) Temperature tolerance

People's tolerance to the environment is sequenced in a descending manner. The tolerance to temperature in summer is sequenced in a descending manner. The sequence in winter is sequenced in a ascending manner.

Table 20. Ranking of tolerable temperature in residential indoor environment

Summer					Winter				
Specific user	No.	Temperature (℃)	Educational background	Income	Specific user	No.	Temperature (℃)	Educational background	Income
Seniors	H'1	35.82	Primary school	Low level	Children,mother	T1	6.20	Secondary schooling	Middle level
Female youth	H1	32.92	Higher education	Middle level	Seniors	T3	8.92	Primary school	Low level
Couples (middle aged)	S2	32.08	Secondary schooling	Middle level	Children,couples	T2	8.32	Secondary schooling	Middle level
Couples(youth)	S1	30.65	Higher education	Middle level	Male youth	H2	14.43	Higher Education	Middle level

As can be seen from the above Table, the difference between the maximum and minimum allowable temperature in summer in the test samples is 5.17℃, and the minimum is 30.65℃, which exceeds 26℃ in the standard. The difference between the maximum and minimum tolerance temperature in winter is 8.23℃, and the maximum is 14.43℃, lower than 18℃ in the standard. The rest are not significantly correlated with gender, age, educational background, income level, etc. The main reason is that human behavior is complicated and random, and regularity may not be reflected if the sample size is too small.

(2) Setting teperature

The following Table mainly classifies the statistics by season, and also ranks the median set temperature in summer from high to low. Winter ranked from lowest to highest.

Table 21. Ranking of indoor setting temperature

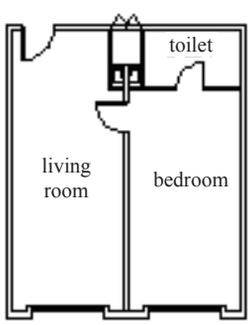
Specific user	No.	Educational	Income	Season	Setting Temperture(℃)
Couples Middle aged)	S2	Higher education	Middle level	Summer	30.39
Young female	H1	Higher education	Middle level		28.65
Couple(Youth)	S1	Higher education	Middle level		27.88
Seniors	H'1	Primary	Below average		27.29
Young male	H2	Higher education	Middle level	Winter	16.78
Children,couples	T2	Pr-school, Higher education	Middle level		19.30
Children,mother	T1	Pr-school, Higher education	Middle level		19.61
Seniors	T3	Primary	Low level		20.23

Based on the above table, the following conclusions can be drawn. 1. Compared with the standard set temperature of 26℃ in summer and 18℃ in winter, the actual set temperature of rooms in summer is generally higher than 26℃ and that in winter is generally higher than 18℃. 2. There is a large difference in the set temperature of each family. It can be seen from the graph that the temperature is linearly dispersed and not centrally distributed. 3. The bedroom temperature is on the high side in summer, in line with the visual impression that people in summer are afraid of catching cold when they sleep. 4. Due to the small sample size, there is no obvious correlation with gender, age, education and income level.

4. Case simulation results

Based on questionnaire and the practical test,S1 household with relatively longer operation duration of air -conditioner was selected from 8 households as the energy consumption simulation case. The DesignBuilder energy simulation software is used to create different building models that are set according to standard specifications and real-world energy behavior patterns.

the floor position of the house. The result differences in energy consumption simulation were made.The floor plan is displayed as follows.Model is built based on the position of the house.



Layout plan

After the model is established, the theoretical energy consumption value is calculated according to the input parameters specified in the standard. Then, parameters related to the energy consumption behavior in the model are modified. Some parameters unrelated to the behavior are set to the same value as those in the standard.

Some theories show that there are two kinds of thresholds, subjective threshold and objective threshold respectively. When the stimulus intensity is lower than objective threshold, people can not feel the stimulus; when the stimulus intensity is greater than the objective threshold and less greater than the subjective threshold, the stimulus will continue to be processed until "subliminal perception" is generated[20]. When the accumulation of subliminal perception exceeds the subjective threshold, people can feel the presence of the stimulus and then adjust the device, so this process is described as behavioral delay or "inertia". According to the above theory, the average value of the median of the tolerated temperature and the set

temperature is taken from the actual behavior mode as the theoretical indoor set temperature of residents. The specific setting method is shown in Table 22 below.

Table 22. Parameter settings for bedroom S1

Bedroom S1 — Jiangsu Province Standard for Thermal Environment and Energy Saving Design of Residential Buildings DGJ32/J 71-2014		
Material value — by passive building envelope of more than 6 storeys (Series 1)		
Heat transfer coefficient of envelope ($W/m^2 \cdot K$) : K roof =0.6; K external wall =1.0; K raised floor =1.0; K partition wall and floor =1.8; K door =1.4; K outer window =2.4; Outer window glass SC=0.62.		
Software Parameter Setting	Standard operating mode	Actual operating mode
Operation mode of air conditioners for heating	All day	Interval (Start when sleeping)
Tolerance temperature	Summer 26℃	Summer 30.47℃
Setting temperature	Summer 26℃	Summer 27.49℃
Duration	July 16th to August 5th	

Table 23. Daily table of operation of S1 actual air conditioner

Utilization rate of air-conditioning equipment in summer(%)											
Until 01:00	Until 02:00	Until 03:00	Until 04:00	Until 05:00	Until 06:00	Until 07:00	Until 08:00	Until 09:00	Until 10:00	Until 11:00	Until 12:00
90.10	93.75	93.75	93.75	93.75	93.75	93.75	87.08	30.94	13.65	12.30	0
Until 13:00	Until 14:00	Until 15:00	Until 16:00	Until 17:00	Until 18:00	Until 19:00	Until 20:00	Until 21:00	Until 22:00	Until 23:00	Until 24:00
0	0	0	0	0	0	0	0	4.58	34.58	59.06	80.42

Figure 8 shows the simulation results of energy consumption of S1 bedroom air conditioners in summer. The standard energy consumption is 6.22 times of the actual energy consumption.

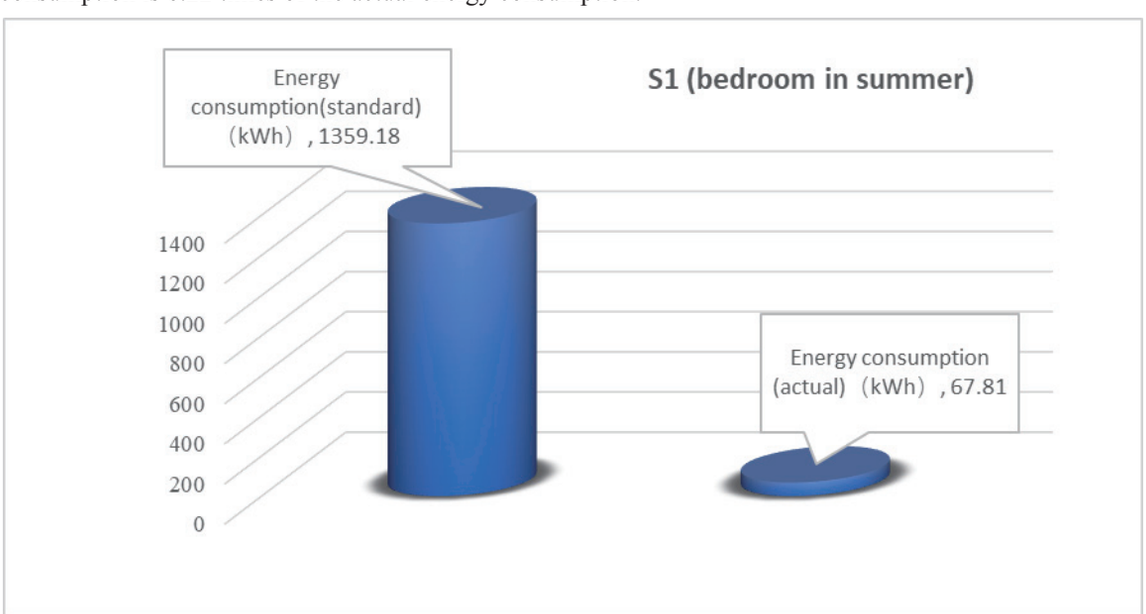


Figure 8. Comparison of energy consumption in S1 bedroom in summer

Most households in Jiangsu, Households in Zhejiang and Shanghai use split air conditioners in "intermittent" mode, and the actual energy consumption of air conditioners is higher than the standard prediction.

5. Conclusion

Main purpose of this paper is to collect data on the household environment and explore data on the actual use of energy and actions. At the same time, the main factors of forming such behavior characteristics are studied, and the shortcomings of existing standards and energy consumption simulation software are found, so that in the future, the design, research and engineering applications can be more close to the actual life.

(1) The usage behavior of air-conditioning equipment can be identified through indoor temperature and humidity changes based on CO_2 concentration changes; The adjustment action of the luminaire can be identified based on the change of indoor illumination level. In this paper, all the environmental sensors are integrated into a set of equipment with small volume, light weight and little impact on residents' life, and the time synchronization of data acquisition is realized. The proposed method is feasible and can be used in behavior research.

(2) Different from the continuous operation of heating and air-conditioning equipment in the standard heating season and cooling season, the split air conditioners in residents' bedrooms in Jiangsu, Zhejiang and Shanghai is mainly used in "inter-mittent" mode. There are three modes for air conditioners in bedroom such as "turn on before sleep or before falling asleep", "time off after in sleep", "turn off after getting up in the morning". According to the measured results of 8 households, the tolerance temperature of air-conditioning equipment in summer is higher than the standard 26℃, and the range of each household is from 30.65℃ to 35.82℃. In winter, the temperature ranges from 6.20℃ to 14.43 ℃. air conditioners setting temperature is mostly higher than 26℃ in summer, the highest is 30.39 ℃; In winter, most of them are above 18℃, and the highest is 20.23℃. The difference of values between different households is due to the difference of residents' energy use behavior, indicating that the standard values involved in the current code do not conform to the current general behavior pattern.

(3) The energy consumption of randomly selected households was simulated, and the actual energy consumption of house-holds with "intermittent energy consumption" behavior was lower than the energy consumption result simulated according to the standard. According to the difference between "tolerance temperature" and "set temperature", the indoor environment of households with "intermittent" use of heating and air-conditioning equipment is still in a state that residents can tolerate for a period of time after the equipment is turned off. Therefore, residents can consider turning off the equipment before leaving the room to further save energy.

(4) By analysis on the influencing factors of the use of air conditioners in each bedroom, it is found that the seniors generally develop the habit of napping; The use of air conditioners during working days can be affected by occupation; In addition to indoor temperature and humidity, living habits also affect the behavior of air conditioners. It is expected that subsequent researchers can continue to increase the number of monitored households, expand the research sample, and summarize the complete household energy behavior rules.

References

[1] The Research Report of China Building Energy Consumption2020[J]. *Building Energy Efficiency*, 2021, 49(02):1-6.

[2] Liang Pan. Energy saving potential and economic analysis of green technology in residential building in hot summer and cold winter area[D]. Huazhong University of Science and Technology,2015.

[3] Zhao Bingwen, Yang Ting, Qi Lijuan, et al.Measurement and analysis of residential air conditioners energy consumption in Hangzhou[J]. *Building Energy Efficiency*, 2019, 47(7):6.

[4] Ministry of Housing and Urban-Rural Development of the People's Republic of China. GB 50096-2011 Code for Residential Design. 2011.

[5] Ministry of Housing and Urban-Rural Development of the People's Republic of China. JGJ 134-2010. Energy Saving Design of Residential Buildings in Hot summer and cold winter area. 2010.

[6] Yan Da, Chen Youming, Pan Yiqun, et al. Research status and development of building energy simulation in China [J]. *Building Science*, 2018, 34(10):130-138.

[7] Zhou X, Yan D, Feng X, et al. Influence of household air-conditioning use modes on the energy performance of residential district cooling systems[J]. *Building Simulation*, 2016, 9(4):429-441.

[8] Carlsson-Kanyama A, Engstrom R, Kok R. Indirect and Direct Energy Requirements of City Households in Sweden Modeling[J]. *Journal of Industrial Ecology*, 2005, 9(1-2):221-235.

[9] Jamasb T, Meier H. Household Energy Expenditure and Income Groups: Evidence from Great Britain[J]. *Working Papers*, 2010.

[10] Chen J, Wang X, Steemers K. A statistical analysis of a residential energy consumption survey study in Hangzhou, China[J]. *Energy & Buildings*, 2013, 66:193-202.

[11] Zhou Xiang, Mou Di, Zheng Shun, et al. Simulation of use behavior of air conditionerand energy consumption in summer in Shanghai[J]. *Building Technology Development*, 2016, (6):4.
[12] Zhao Bingwen, Yang Ting, Qi Lijuan, et al.Measurement of energy consumption of air conditioner and analysis in Hangzhou[J]. *Building Energy Efficiency*, 2019, 47(7):6.
[13] Du Chenqiu, Yu Wei, Li Baizhan, Ma Yanjiong, Ming Ru, Yao Runming. Evaluation of characteristics of use of air conditioners of residents in Chongqing[J]. *Building Science*, 2020, 36(10):8.
[14] Ren X, Da Y, Wang C. Air-conditioning Usage Conditional Probability Model for Residential Buildings [J]. *Building & Environment*, 2014, 81(nov.):172-182.
[15] Jian Yiwen, Liu Jian, LI Qingrui, et al. Experimental study on the relationship between indoor CO_2 concentration and human behavior in residential buildings[J]. *Journal of HV&AC*, 2012, 42(9):114-114.
[16] Raatikainen M, Skn J P, Johansson M, et al. Effects of Weather Conditions and DifferentialAir Pressure on Indoor Air Quality[C]// WASET 2012 DUBAI, UAE. 2012.
[17] Zhou Hao. Research on recognition method of human behavior based on indoor environment monitoring data[D]. Tianjin University, 2016.
[18] Meilin, Zhang Fengli, Gao Qiang.Review of outliers detection technology [J/OL]. Application Research of Computers:1-9[2020-11-11]. https://doi.org/10.19734/j.issn.1001-3695.2019.09.0513.
[19] Raatikainen M, Skn J P, Johansson M, et al. Effects of Weather Conditions and DifferentialAir Pressure on Indoor Air Quality[C]// WASET 2012 DUBAI, UAE. 2012.
[20] Reing E M, Merikle P M.Using direct and indirect measures to study perception without awareness[J]. *Perception & Psychophysics*, 1988, 44(6):563.