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Field Investigation on Adaptive Thermal Comfort in Rural Dwellings: A Case Study in Linyi (China) during Summer

Hao Tang [1,2], Yali Gao [1,2], Shiteng Tan [1,2], Yuang Guo [1,2,*] and Weijun Gao [1,2,3]

[1] College of Architecture and Urban Planning, Qingdao University of Technology, Qingdao 266033, China; town946@sina.com (H.T.); wuyanxiaoxiao@outlook.com (Y.G.); tst1003671064@hotmail.com (S.T.); gaoweijun@me.com (W.G.)
[2] iSMART, Qingdao University of Technology, Qingdao 266033, China
[3] Department of Architecture, The University of Kitakyushu, Kitakyushu 808-0135, Japan
[*] Correspondence: guoyuang@qut.edu.cn; Tel.: +86-15902910901

Abstract: A large number of people in China still live in rural villages. The indoor environment of these rural dwellings directly affects the quality of life of the occupants. Nevertheless, constrained by the quality of dwelling construction, rural buildings have poorer indoor environments and, at the same time, have a higher operating energy consumption. However, inadequate attention has been given to the summer thermal environment in cold regions. This work has been carried out around the thermal environment of rural residences in cold regions during summer. Field measurements, questionnaires, and data analysis were used in this study. We recorded the indoor and outdoor thermal environment parameters on a typical summer day in the Linyi rural area. Moreover, the subjective sensations and thermal adaptive behaviors of the participants were recorded in detail with a questionnaire. Linear regression showed that the neutral temperature for residents in summer was 27.52 °C, with acceptable temperatures ranging from 25.14 °C to 29.9 °C. Age and gender differences were found to affect the occupants' sensation of thermal comfort and humidity, as well as their thermal adaptive behavior. In addition, a thermal adaptive model has been constructed in the study, which will further enrich the thermal adaptive investigation and provide a scientifically sound reference for the renovation and development of the local rural areas.

Keywords: thermal comfort; adaptive behavior; rural dwellings; cold regions; summer

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1. Introduction

1.1. Overview

Buildings and energy have been the focus of attention of various scholars. Improving the built environment and reducing energy use provide a common goal for global researchers. Chinese construction energy demand is still rising nowadays as a result of rapid urbanization and economic development [1]. Up to 2020, the overall energy consumption of the whole building process in China has already accounted for 45.5% of the national total energy consumption, of which 21.3% comes from the building operation phase [2]. Moreover, in many industrialized nations, between 30% and 60% of the energy required to power buildings is used to enhance the standard of the internal thermal environment [3]. It also indicates that the building operation stage has a huge potential for energy saving [4]. However, blindly reducing building energy consumption risks compromising the quality of the indoor thermal environment. Therefore, it is a pressing issue of how to lower building energy usage without sacrificing rural residents' quality of life.

With the upgrading of the economic level and the improvement of living conditions, residents have put forward higher requirements for the quality of life. Nowadays, guided by the concept of sustainable development, China has slowed down the pace of urbanization. Instead, it is focusing on the renewal and preservation of buildings. Attempts are made to improve the living standards of residents through residential renovation. Compared to urban regions, the construction system and building facilities of residential buildings in rural areas are relatively backward. For instance, most of the rural houses in northern China do not have thermal insulation measures [5], resulting in a subpar thermal environment with plenty of space for improvement. Furthermore, approximately 42% of China's total floor area is made up of rural residential areas [2], and 36.11% of the country's population still resides in rural areas [6]. Indoor residential environments have a direct influence on human health, especially considering that in developing countries [7]. For these reasons, it is necessary to consider the thermal environment of rural structures.

In contrast to the multi-story and high-rise residential patterns that exist in metropolitan areas, the general form of rural residential buildings is frequently decentralized, with one residence per household. As a result, even within the same location, there are significant differences between the thermal conditions of dwelling constructions in urban and rural areas. Coupled with the influence of living habits and other factors, the neutral temperature and thermal comfort range in rural locations vary from those in metropolitan areas, and rural inhabitants tend to be more resistant to cold and heat than their urban counterparts [8–11]. Long-term thermal acclimatization improves the acceptability of thermal comfort for residents to varying degrees, therefore climate-adapted design standards for rural residential buildings also need to be developed to achieve the organic unity of thermal comfort and building energy efficiency [12].

China covers a vast territory, spanning from north to south, with obvious variations in climate. According to the geographical and climatic characteristics of China, it can be divided into five types of architectural climate zones: serious cold zone, cold zone, hot summer and cold winter zone, hot summer and warm winter zone, and mild zone [13]. Although Linyi is located in a generally cold region, it experiences high temperatures during the summer. The local summer maximum temperature can reach 38 °C [14], and the hot weather usually lasts from May to the end of August. High temperatures can cause occupants to feel uncomfortable for an extended period of time [15], which is harmful to human health. Currently, research on the thermal environment of cold regions is mainly focused on winter, but few studies have addressed the thermal environment of the region in summer [16]. Studies have shown that the adaptive thermal comfort model was more suitable for rural housing than the rational thermal comfort model [17]. Thus, in order to fill the current research gaps and to develop the appropriate thermal comfort assessment criteria for the local conditions, field investigations of the summer thermal environment in such climates are urgently required.

1.2. Literature Review

Historically, there are two main types of thermal comfort models. One of those is the PMV steady-state model based on air-conditioned room environments by Danish scholar Fanger [18]. At present, there are several mainstream thermal comfort evaluation standards in the international arena: ASHRAE55 [19] and ISO7730 [20], which are based on the PMV model. However, although these international standards have reference value, they are unable to evaluate the thermal comfort of different populations around the world scientifically and accurately. Madhavi's [21] field study of a condominium in India found that the temperature range for thermal comfort for local residents was much higher than the scope of the Indian Standard, and the PMV was always found to be higher than the actual sensation vote. The other is the adaptive thermal comfort model proposed by scholars such as Humphreys [22,23], who compared the results of previous field surveys with laboratory results and found that human physiological adaptation to climate affects both survey and experimental results [24]. With the gradual increase in the understanding of thermal comfort, and after extensive field investigations, it has been found that there is a general deviation between PMV and actual mean thermal sensation vote (MTSV) [21,25,26]. For instance, Becker et al. [25] studied thermal comfort in residential buildings without air-conditioning systems in summer and winter in Israel and found that MTSV was higher than PMV. Al-ajmi et al. [26] discovered that PMV-derived neutral temperatures were underestimated by studying 25 air-conditioned houses within Kuwait. Currently, adaptive thermal comfort evaluation modeling has become a mainstream method for investigating thermal comfort as it predicts more accurately the occupants' subjective evaluation of the local thermal environment.

Faced with such a paradox, researchers worldwide have conducted numerous field studies and have gained a deeper and more profound realization of thermal comfort. From a field study of 30 dwellings located in the Dutch region, Ioannou et al. [27] discovered that while PMV predicted neutral temperature well, it did not precisely anticipate hot and cold sensations. Moreover, experimental data show that the occupants of houses with different thermal mass have different neutral temperatures even if their clothing and metabolism are similar. Jeong et al. [28] conducted a comparative study of residential thermal comfort in two different climate zones in Australia. It was found that the acceptable temperature ranges in both regions were wider than those specified by ASHRAE's adaptive comfort model. The results of the study also showed that 80% of the acceptable temperature range varies with climate change. Forcada et al. [29] investigated summer thermal sensations in older adults from nursing homes in a Mediterranean climate. Their experimental data showed that older adults had a summer comfort temperature of 24.4 °C, which was 0.9 °C higher than that of adults. This demonstrates that older people have better thermal tolerance. Sudarsanam et al. [30] carried out a field survey on summer thermal comfort in residential homes for the elderly in a warm and humid climate in India. The results of regression analysis showed that the summer thermal comfort range for local occupants was 28.5~31.5 °C, which is much higher than the international standards.

China has a complex climate and a variety of dwelling types. A great deal of field research has been conducted in China, but the bulk of this early work has been concentrated on modern buildings such as urban housing and public buildings [31–34]. Unlike the inhabitants in modern buildings, the occupancy habits and thermal experience of the inhabitants in traditional dwellings are significantly regionalized, which is an important factor affecting thermal comfort [35]. In addition to this, the thermal comfort demand of the occupants evolves with the seasons. The range of thermal comfort and thermal adaptation patterns of the population varies with the seasons [36]. Xu et al. [37] made site surveys for the Nanjing area and studied the thermal comfort and thermal adaptation behaviors of local people. The results showed that compared with modern dwellings, the residents of traditional dwellings were more tolerant of harsh environments, had a lower thermal sensitivity, and had a thermal neutral temperature of 28 °C in summer, which was higher than the ASHRAE standard. In a study of traditional dwellings in the ancient city of Guangfu, China, Wang et al. [38] observed that older traditional houses had poorer thermal environmental quality compared to newer traditional houses. Residents living in older dwellings had higher thermal neutral temperatures in summer and were more acclimatized thermally. Yang et al. [39] revealed that the upper limit of 80% acceptable temperatures was even as high as 34 °C during field investigations in the Turpan Basin. Thermal environment experiments were conducted by Lu on different types of buildings in the Hainan Province [40]. The results revealed that high humidity environments had no significant effect on human comfort, and that tropical islanders had better thermal tolerance, while cold tolerance was lower than expected. In a field study conducted in rural Sichuan, Li, Y. et al. [41] found that the thermal environments of rural buildings could not meet the thermal comfort range of older people in summer. Ji. L. et al. explored and validated the accuracy of a variety of thermal models and provided some recommendations for overheating buildings [42,43]. These works have contributed to the development of thermal comfort research.

Similar investigations are carried out in many other cases. So far, they have abundantly developed China's thermal comfort database, which establishes the foundations for architectural design, building energy efficiency, and thermal comfort research. Nevertheless, there are still some problems: (1) In a complex climatic environment, the rural inhabitants are constantly making new demands on the living environment, while the actual needs of the rural population are not currently understood. (2) Both international standards and the thermal comfort standards developed in China are difficult to apply to these specific rural areas. Existing thermal comfort models need to be supplemented and improved. (3) Insufficient attention has been paid to the summer thermal environment in cold regions, and there is a gap in research on the summer thermal environment in the context of cold regions.

Given the above, focusing on the Linyi area in the Shandong Province as an example, this paper investigates its summer thermal environment condition. Subsequently, a summer thermal adaptation model was re-established consistent with the local climate characteristics. This not only enriches and improves the thermal comfort database of rural areas in China, but also provides scientific data support for the construction of rural dwellings in Linyi.

In summary, the main objectives of the research in this paper are as follows:

- This study characterizes the thermal environments of rural dwellings in the cold regions of China and provides insights into the summer cooling practices of the local residents.
- Determine the neutral temperature and acceptable temperature range for the occupants of cold regions during the summertime, and investigate the characteristics of summer thermal adaptation among the various groups of dwellers.
- To establish an adaptive thermal comfort model that conforms to the local climate environment, hence enriching and supplementing China's thermal comfort database to offer a reference for indoor temperature settings.

2. Methodology

2.1. Climatic Characteristics

Linyi has a long history and is one of the important birthplaces of Chinese civilization. The Dongyi culture was nurtured in these lands and developed into the colorful, rich, and profound Yimeng culture. As shown in Figure 1, Linyi is located in the southeast of the Shandong Province, China, spanning latitudes 34°22′ to 36°13′ north and longitudes 117°24′ to 119°11′ east. With a resident population of about 11 million people and an area of about 17,200 square kilo meters, it is the most populous and largest city in Shandong province [44]. Linyi has a continental climate in the warm temperate monsoon zone, with an average annual temperature of 13.6 °C. The average temperature during the hottest month is 26.5 °C while that of the coldest month is −0.9 °C. From the climatic data of the last three years [45], the maximum temperature reaches 36 °C in May, 38 °C in June and August, and 36 °C in July. As far as the timing of the maximum temperatures is concerned, the hot days continued roughly from the beginning of May until the end of August. In winter, the lowest temperature in Linyi reaches −15 °C, and heating generally lasts from 10 November to 20 March the following year.

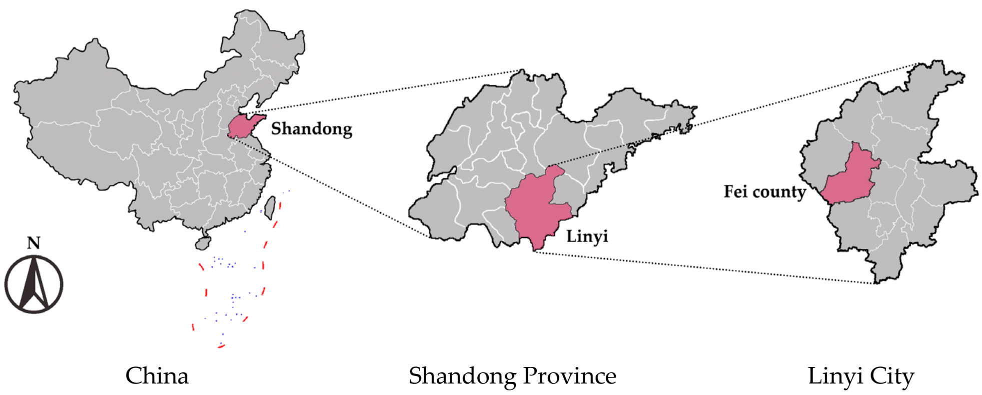


Figure 1. Geographic location of the experimental site.

2.2. Target Buildings

Previous studies have shown [46] that the most common form of residential houses in the rural areas of Linyi is courtyard style (Figure 2), which is confirmed by the combination of field visits and research. Every residential house has a large or small yard, and some of the residents also plant some greenery in the yard. This creates a certain area of shade during summer to reduce the temperature in the courtyard in the summer. The gate of the yard is usually located in the southeast corner and does not open directly into the courtyard. The lavatory is usually located in the southwest corner of the courtyard, the kitchen is in the east or west side, and the living room and bedrooms are located in the northernmost part of the courtyard. Local rural dwellings can be divided roughly into modern dwellings and traditional dwellings according to their construction age. The layout of these two types of houses is very similar, but the materials of the enclosure structure are totally different. Stone is abundant in Linyi, so it has become the main material for the enclosure of local houses. Many of the traditional dwellings were built of stone, and a few of them were built of raw clay. Stone buildings are the most distinctive and numerous traditional dwellings in the area. Consequently, after several visits and research, a residential house in Fei County, Linyi was finally selected as the test subject for this study. The house, which is constructed entirely of stone and has only one floor, was built in the 1990s. The external wall of the tested building had been renovated and it had been plastered with cement mortar on its internal and external surfaces. Compared to common concrete walls, such walls have a greater heat transfer coefficient and higher coefficient of heat accumulation.

Figure 2. Photos of the test house. (**a**) shows an overview of the village where the test house is located; (**b**) shows actual photographs of the test dwelling; (**c**) depicts the floor layout of the dwelling.

2.3. Onsite Measurement

The experimental instrument used in this experiment is a Thermo Recorder TR-72wf (TANDD, Tokyo, Japan), which mainly measures the temperature and humidity data indoors and outdoors. The black globe temperature (t_g) was derived from black globe thermometer measurements (AZ87786, M407972, Beijing, China), and the air flow rate was recorded by a hand-held anemometer (CEM DT-8880, CEMHuashengchang, Shenzhen, China). Table 1 describes the measuring range and accuracy of the instruments. The experiment lasted from 18 to 22 August 2023. The weather during the testing days was sunny. The bedroom and living room are the most frequently used areas in local houses, so the measurement points of this experiment are mainly arranged in these two areas. The distribution of measurement points is shown in Figure 2c, in which the bedroom on the west side and the living room on the north side are arranged. All of the above measurement points are arranged at a height of 1.5 m above the ground.

Table 1. Accuracy and measuring range of the instruments.

Test Parameters	Test Instrument	Range	Resolution	Accuracy	Accuracy Requirements in GBT50785 [47]
Air temperature	Thermo Recorder TR-72wf	0~55 °C	0.1 °C	±0.5 °C	±0.5 °C
Relative humidity	Thermo Recorder TR-72wf	10~95%	1%	±5%	±5%
Air velocity	CEM DT-8880	0.1~25 m/s	0.01 m/s	(0.03 ± 0.05 v) m/s	(0.05 ± 0.05 v) m/s
Black globe temperature	AZ87786	0~50 °C	±0.1 °C	±0.5 °C	±0.5 °C

2.4. Survey Questionnaire

Local villagers were clearly informed of the intention of this questionnaire survey prior to its completion. All interviews with the questionnaires were conducted voluntarily and knowingly by the villagers and were filled out anonymously. This questionnaire primarily included the following data:

- Basic information: containing age, gender, height, weight, income level, and current clothing status.
- Subjective perception: including thermal sensation, thermal preference, thermal acceptance, humidity sensation, and humidity preference.
- Adaptive Behaviors: thermal adaptative behaviors in daily life, and the common methods of cooling.

The questionnaire was in Chinese, but due to the fact that most of the local rural dwellers are elderly and have low literacy levels, many of them were illiterate and had difficulty filling out the questionnaire on their own initiative. Therefore, the questionnaire was mainly completed on behalf of the respondents. The respondents were asked individually about their actual feelings and situations, which were recorded by the researcher. The English version of the questionnaire is placed in the Appendix A, and the Chinese version utilizes the standard Chinese translation of the ASHRAE Thermal comfort scale. Vote scales are shown in Table 2. Thermal sensation was measured using ASHRAE's 7-degree scale, with −3 indicating cold, −2 cool, −1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, and 3 hot. For thermal preference and humidity preference, a 3-degree scale was used.

Table 2. Vote scales of subjective perception.

Scales	Thermal Sensation	Humidity Sensation	Thermal Preference	Humidity Preference	Thermal Acceptance
3	Hot	Very humid	–	–	Clearly acceptable
2	Warm	Humid	–	–	Acceptable
1	Slightly warm	Slightly humid	Warmer	More humid	Slightly acceptable
0	Neutral	Neutral	No change	No change	Neutral
−1	Slightly cool	Slightly dry	Cooler	Want dryer	Slightly unacceptable
−2	Cool	dry	–	–	Unacceptable
−3	Cold	Very dry	–	–	Clearly unacceptable

The daily survey was conducted from 8:00 a.m. to 6:00 p.m. In order to prevent too much disturbance to the households, we avoided the lunch time of the households at noon. The research finally obtained 178 questionnaires, of which 97 (about 54%) were from the elderly aged 60 and above, and 81 (about 46%) were from those aged below 60. Table 3 summarizes the basic information about the residents. The oldest person in the questionnaire was 94 years old and the youngest was 7 years old. A total of 101 male participants and 77 female participants were included in this study. All inhabitants had lived in the field for more than 10 years and were in good health.

Table 3. BMI of the inhabitants, and sample size by age and gender.

Gender	Sample	Age Range			BMI		
		Under 18	18~60	Over 60	Min	Max	Average
Female	77	7	27	43	14.67	32.00	22.50
Male	101	13	34	54	15.31	37.83	23.16

2.5. Calculation Method

2.5.1. Predictive Mean Vote (PMV) Index

PMV is a more objective indicator of human thermal comfort, which is widely used to evaluate indoor thermal comfort and has been codified in the international standard ISO7730 [20]. The index takes into account a combination of factors such as the degree of human activity, clothing insulation, air temperature, radiant temperature, air humidity, air flow rate [48], etc. It is the most comprehensive evaluation index yet, taking into account the multiple factors that influence human thermal comfort, and the calculation formula is as follows [49,50]:

$$\mathrm{PMV} = \left[0.303^{\mathrm{e}^{-0.036\mathrm{M}}} + 0.028\right]\mathrm{L} \tag{1}$$

where M is the total heat generated by human metabolism and L is the human heat load. In this study, the PMV index was calculated based on measured thermal environment parameters, estimated personal clothing, and metabolic rate.

2.5.2. Operative Temperature

In studies of indoor thermal comfort, the thermal conditions in a room are often expressed in terms of the operating temperature (T_{op}). It integrates the effects of air temperature and average radiation temperature on human thermal sensation. When the indoor air flow rate is less than 0.2 m/s, or the difference between t_{mr} (mean radiant temperature) and t_a (indoor air temperature) is less than 4 °C, T_{op} can be calculated according to the following formula:

$$T_{op} = \frac{t_{mr} + t_a}{2} \tag{2}$$

$$t_{mr} = \left[\left(t_g + 273 \right)^4 + \frac{1.1 \times 10^8 V^{0.6}}{\varepsilon D} \left(t_g - t_a \right) \right]^{0.25} - 273 \quad (3)$$

where t_g is black ball temperature, °C, V is air velocity, m/s, and D is black ball diameter, m.

2.5.3. Thermal Neutral and Acceptable Temperatures

In this paper, a linear regression method was adopted to calculate the thermo-neutral and acceptable temperatures. Thermal sensations obtained from field surveys were used as the dependent variable, and the corresponding indoor temperatures were used as the independent variables. According to the PMV-PPD equation proposed by Fanger [49], the thermal sensation voting value is ±0.5 when the thermal sensation satisfaction rate is 90%, and it is ±0.85 when the thermal sensation satisfaction rate is 80%. When the value of thermal sensation vote (TSV) is 0, the temperature corresponding to T_{op} is the neutral temperature, and when TSV is between −0.5 and 0.5, the respective temperature interval can be considered as the acceptable temperature. MTSV is the average value of TSV in a temperature band, which can more accurately reflect the relationship between TSV and T_{op}. Based on the distribution of the mean temperature, it is roughly divided into a temperature range of 0.5 °C. For instance, the 32~32.5 °C interval is centered at 32.25 °C. The MTSV value can then be taken as the average of the TSV in each of the divided temperature ranges. Similarly, the neutral temperature can be derived by making MTSV = 0. When MTSV is taken from −0.5 to 0.5, it can correspond to the acceptable temperature interval.

3. Results and Discussion

3.1. Environmental Parameters

3.1.1. Outdoor Temperature and Relative Humidity

The outdoor temperature and humidity throughout the measurement period are shown in Figure 3. During the period from the afternoon of the 18th to the morning of the 22nd, the maximum outdoor air temperature reached 35.7 °C, and the minimum temperature was 23.8 °C, with an average temperature of 29.1 °C. The highest temperature occurred on August 19 at about 3:30 p.m., while the lowest occurred on the 22nd at about 5:30 a.m. The highest relative humidity (RH) value of 90 percent occurred at about 3 a.m. on the 21st, and the lowest value of 35% occurred at about 2:30 p.m. on the 19th, with an average RH of the air of 66.1% during these days. The outdoor air temperature reaches its nadir roughly around 5:30 in the morning. It then starts to rise and continues until it reaches its peak at about 3:30 pm. Subsequently, the outdoor temperature gradually decreases until around 5:30 am the next day. The trend of RH change in the air is opposite to the change in air temperature; when the outdoor air temperature rises, the RH generally shows a downward trend, and vice versa. Generally, when temperatures are high, air moisture is relatively low.

As can be seen in Figure 4, approximately one-quarter of the time the indoor temperature is in the 26~28 range. Over 56% of the time, the air temperature is higher than 28 °C. RH 60~65% accounted for the highest percentage of about 29.2%, and more than 49.7% of the time, the RH of the outdoor air was greater than 60%.

3.1.2. Indoor Temperature and Relative Humidity

As shown in Figure 5a, indoor temperatures in residential homes generally increase with outdoor temperatures. However, both the maximum and minimum indoor temperatures in the bedroom and living room occur slightly later than outdoor temperatures. Compared to the bedrooms, the indoor temperatures in the living rooms fluctuated moderately. It ranged from 26.9 to 31.8 °C, with an average temperature of 29.1 °C. The indoor temperature in the bedroom, on the other hand, fluctuated between 26.0 °C and 35.7 °C, with an average of 29.6 °C. The maximum bedroom temperatures were the same as outside and significantly higher than in the living room. It is worth noting that the maximum temperature of the bedroom is significantly higher than that of the living room during the daytime, while the temperature and humidity are similar to that of the living room at night.

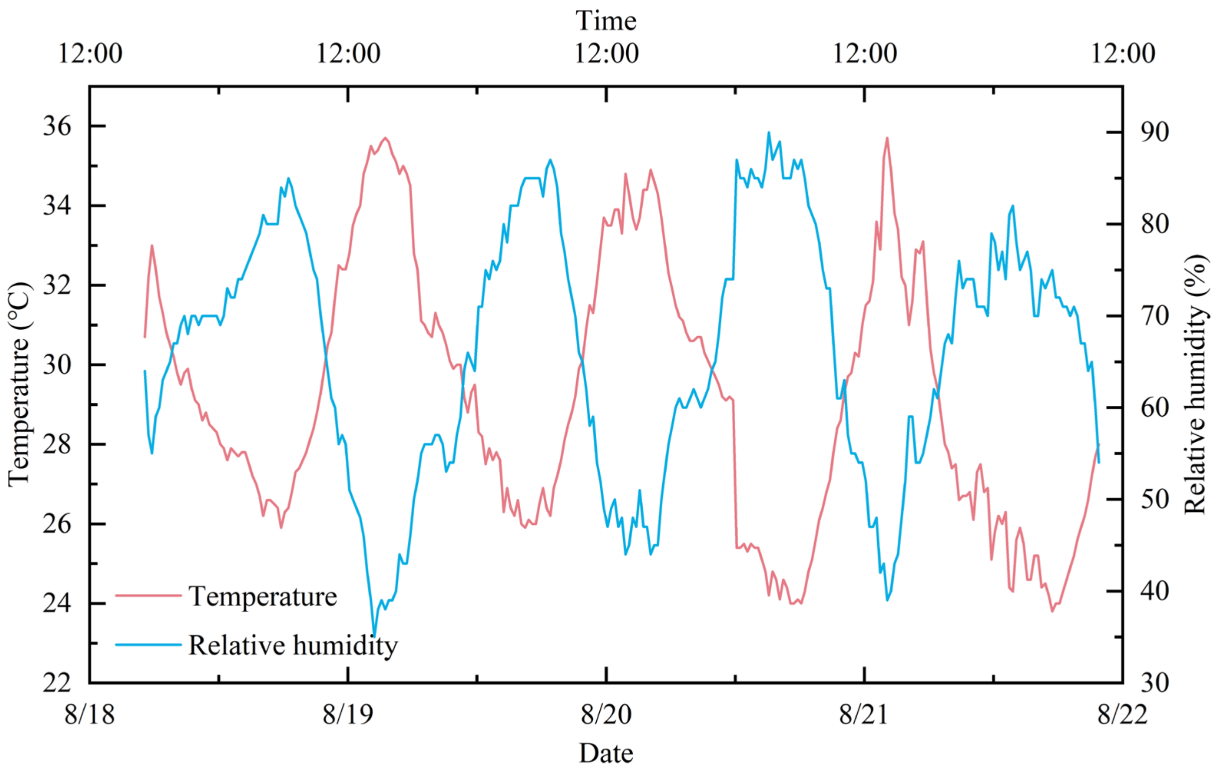


Figure 3. Outdoor temperature and relative humidity.

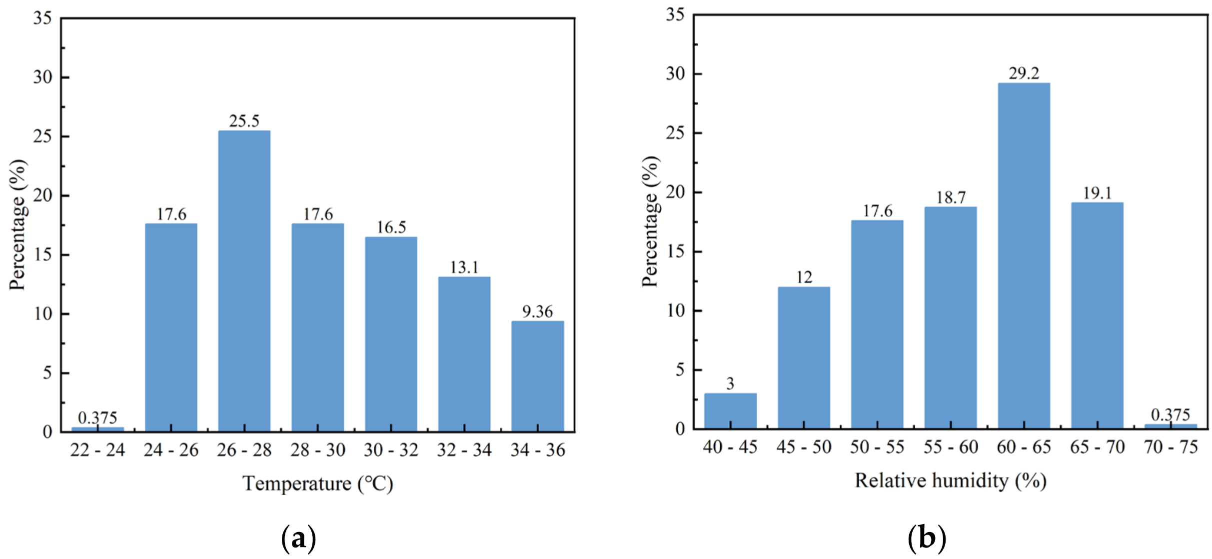
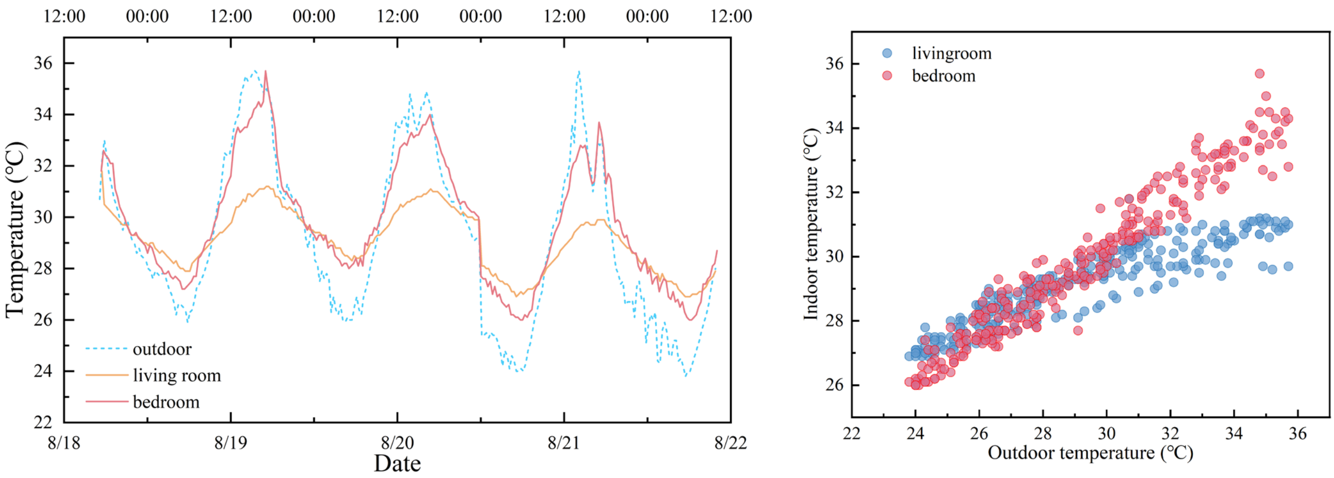
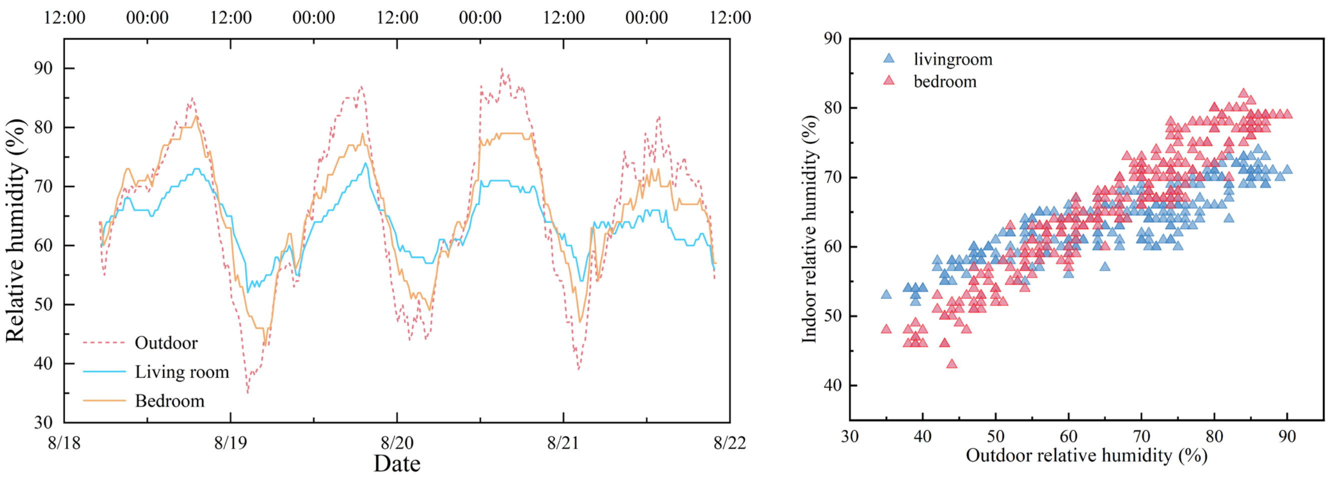


Figure 4. Percentage of outdoor temperature and relative humidity. (**a**) Temperature; (**b**) relative humidity.

Figure 5b reflects the trend of the indoor and outdoor RH. Similar to the temperature, the indoor RH variation in the living room follows the outdoor RH more smoothly than that in the bedroom. The fluctuations in the RH in both the rooms were less than the outdoors, and both the maximum and minimum values emerged slightly later than the outdoors. The fluctuation in the RH in the living room is still relatively small, fluctuating within the range of 52~73%, while the bedroom fluctuates between 43% and approximately 82%.



(**a**)



(**b**)

Figure 5. Indoor and outdoor temperature and relative humidity. (**a**) Temperature; (**b**) relative humidity.

Although the living room and the bedroom are constructed of identical materials, there is a notable discrepancy between the indoor temperature and RH variations in these two spaces. This is because the main orientation and window openings of the two rooms are different, and the exposed areas of them are varied. The main orientation of the living room is to the south, with window openings located on the north and south sides. Besides this, there are chambers on the east and west sides of the living room, which provide shelter. As a result, only the south wall and roof of the living room are exposed to direct solar radiation. In contrast, the bedroom, which has a predominantly westerly orientation, has window openings positioned on the east and west sides. Its east, west, and south walls, as well as its roof, are directly affected by solar radiation. This bedroom has a larger contact surface to the outside and more adequate heat transfer with the outside air. Consequently, its peak indoor temperatures and humidity levels are much closer to those outside, creating a marked distinction from the living room. At night, nevertheless, the fluctuations in temperature and humidity in the two rooms were very proximate, as they were no longer affected by solar radiation.

3.2. Results of the Questionnaire

3.2.1. Thermal Sensation

In order to understand the frequencies of the distribution at different temperature intervals for thermal sensations among the inhabitants, we divided the questionnaire corresponding to the temperature of the division. According to Cena et al. [51], young people can distinguish temperature differences of less than 1 °C, whereas older people can distinguish temperature differences of 2~3 °C. With a temperature interval of 2 °C, it was roughly divided into five temperature bands of 26~27 °C, 27~29 °C, 29~31 °C, 31~33 °C, and 33~35 °C. Since no temperatures below 26 °C occurred during the questionnaire completion process, the 25~27 °C interval was amended to 26~27 °C. As described in Figure 6, with the increase in temperature, there was a significant decrease in the proportion of those who chose comfort (TSV = 0). Concurrently, the proportion of those who felt hot (TSV > 0) was gradually increasing. For instance, within 26~27 °C, all the people felt that the temperature was moderate, and when the temperature was between 27~29 °C, the proportion of those who voted for two and three was 0%, and only 11% of the residents felt that the temperature was slightly warmer (TSV = 1). When the temperature exceeded 33 °C, the percentage of those who felt comfortable dropped to 22%, and 78% of the residents chose the hotter side (TSV > 0), with 43% choosing slightly warm and hot (TSV = 2 and TSV = 3).

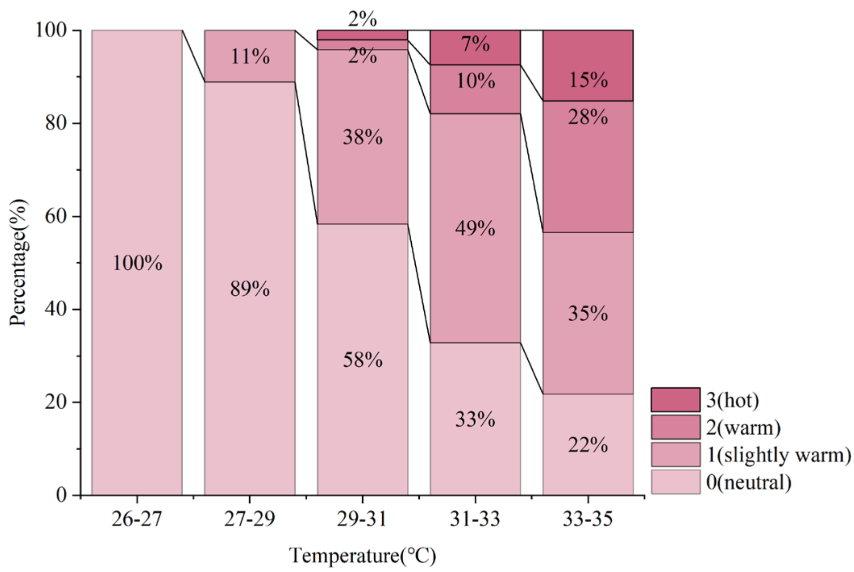


Figure 6. Frequency of thermal sensory distribution in different temperature intervals.

Figure 7 shows the frequency distribution of TSV for the different groups of people. Figure 7a reflects the difference in TSV between the elderly people over 60 years old and residents under 60 years old, while (b) illustrates the difference between genders. Given that the indoor and outdoor air temperatures were at high levels throughout the questionnaire-filling process, no resident felt cooler and all TSV were larger than zero. Approximately 42.7% of the occupants felt comfortable (TSV = 0) and 57.3% felt that the current thermal environment they were exposed to was on the hot side. Slightly warm (TSV = 1) was voted for by 30.9%, warm (TSV = 2) by 18.5%, and hot (TSV = 3) by only 7.9%. As shown in Figure 7a, about 54.6% of the residents over 60 years felt comfortable. This is significantly higher than the under 60 (28.4%) and overall. It is suggested that the local people over 60 years may have a better ability to tolerate heat than the younger residents. Figure 7b reflects the difference in thermal sensation between genders. The proportion of the female residents voting 0 and 1 was lower than that of the males and the overall level. Nevertheless, those choosing two and three were both higher than that of the males and the overall level. This shows that the local women may be considerably more thermal intolerant than the men.

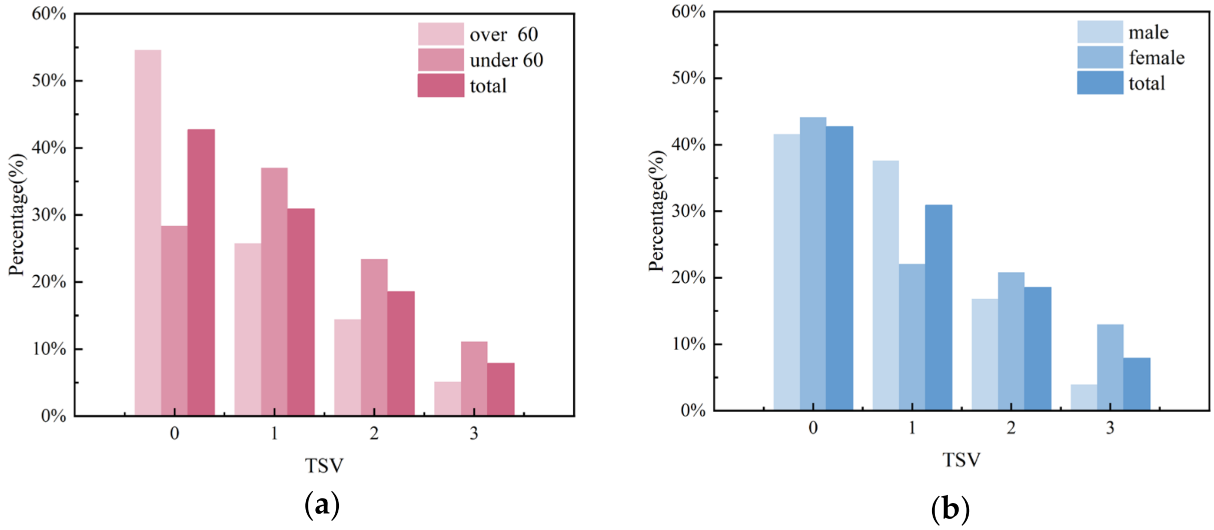


Figure 7. The frequency distribution of TSV for different groups. (**a**) Age; (**b**) gender.

3.2.2. Humidity Sensation

The humidity sensation vote (HSV) frequency distribution of different groups has been reflected in Figure 8. About 43.3% of the inhabitants felt that the RH of their environment was moderate, while around 36.0% felt dry and 20.79% felt humid. Similar to the thermal sensation, the humidity sensation is variable in different people. As shown in Figure 8a, the proportion of older people feeling moderately humid was higher than the overall and significantly higher than the younger residents, while the proportion of older people feeling either dry or humid was slightly lower than that of the younger residents. On the contrary, only 37.04% of the younger inhabitants felt that the humidity was moderate, 43.21% felt dry, while 19.75% felt humid. Figure 8b shows the gender difference in the percentage of HSV. A relatively higher proportion of the female residents than the males feel that the humidity is moderate. However, a higher proportion of the males than the females perceived the air to be dry. It indicates that the older age groups and female groups are more inclined to be comfortable with the current humidity of the environment.

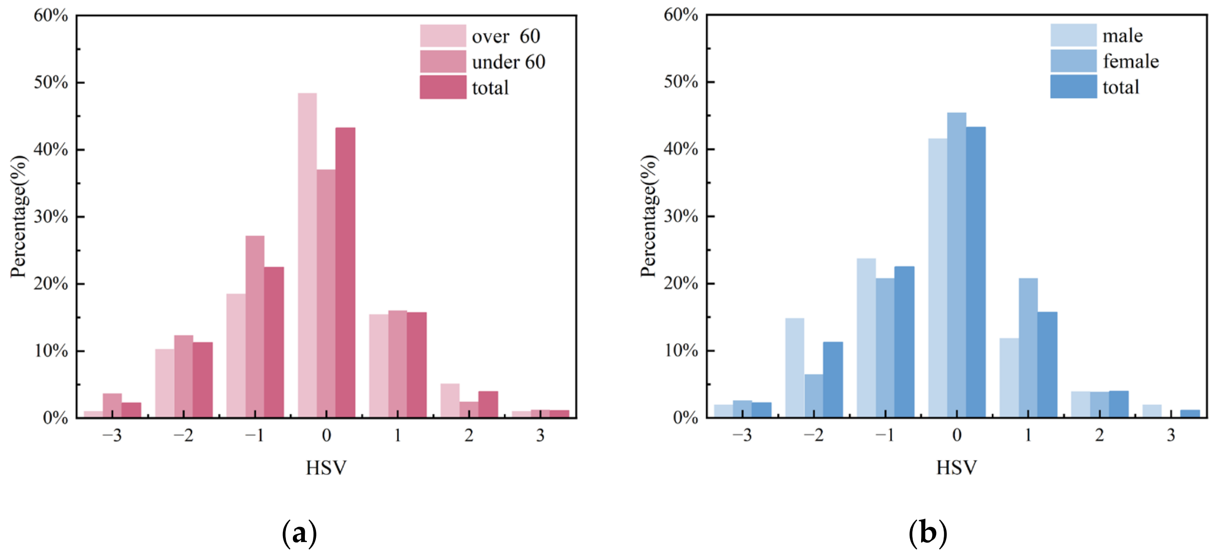
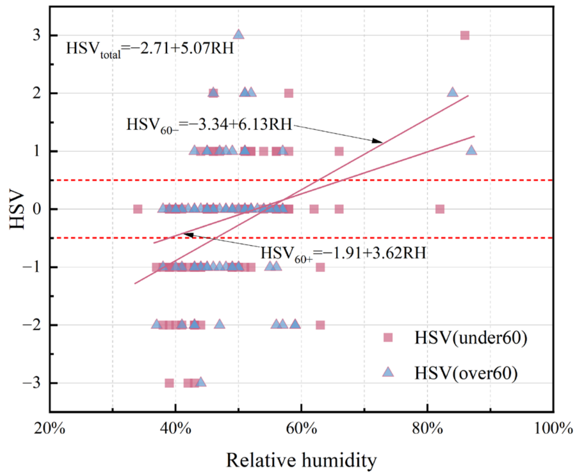


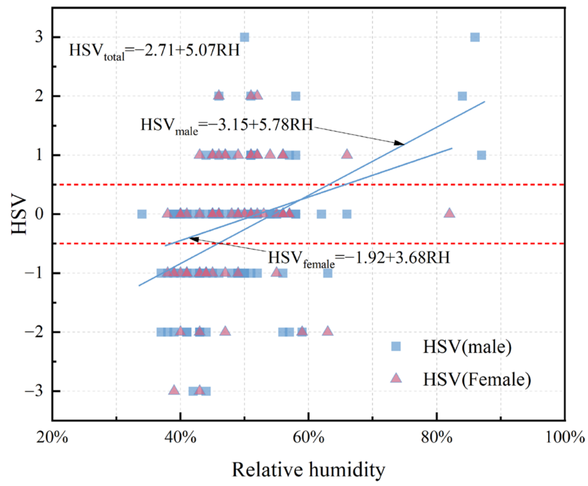
Figure 8. The frequency distribution of HSV for different groups. (**a**) Age; (**b**) gender.

Figure 9 illustrates the correspondence between HSV and the indoor air RH. The regression equation of HSV for the local residents can be obtained by linear regression:

$$HSV = -2.71 + 5.07RH \quad (4)$$



(**a**)



(**b**)

Figure 9. HSV and relative humidity. (**a**) Age; (**b**) gender.

As can be seen in Figure 9, the slopes for the residents over 60 years old are close to those for the female residents and are flatter than those for the younger and male residents. When the indoor humidity fluctuated, the HSV values of the elderly and the female population fluctuated insignificantly. This suggests that the older and female groups are less sensitive to changes in air humidity than the younger and male groups. It is generally accepted that an HSV in the range of −0.5 to 0.5 is deemed the most favorable range of RH for the local inhabitants. The regression curves in Figure 9 crossed two horizontal lines (±0.5) at different intersections. The comfort moisture range corresponding to the elderly and female population is wider for HSV ± 0.5. In other words, their comfort humidity scope is more extensive. The comfortable humidity ranges for different groups are shown in Table 4. Due to the physiological differences, the females are less sensitive to variations in RH, and their comfortable humidity ranges are slightly wider than those of the males. The decline in physiological functions, coupled with a weakened ability to perceive, results in the elderly being less sensitive to changes in humidity than the younger people, who have a wider range of comfortable relative humidity zones.

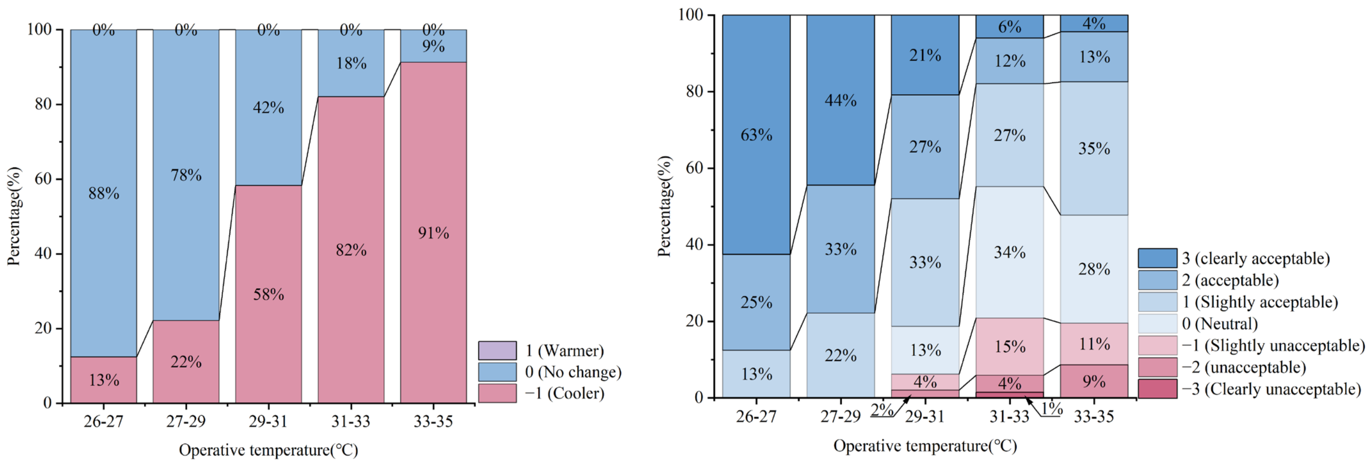
Table 4. Comfortable RH range for different groups.

Range	Total	Female	Male	Over 60	Under 60
CRH_{min} [1] (%)	43.63	38.59	45.85	38.95	46.33
CRH_{max} [2] (%)	63.37	65.76	63.15	66.57	62.64

Note: [1] lower limit of comfortable RH, [2] upper limit of comfortable RH.

3.2.3. Thermal Preference and Thermal Acceptance

Figure 10a characterizes the frequency distribution of thermal preferences within distinct temperature intervals. Given the sustained high temperatures during the research period, no resident expected it to be warmer. In the three-level scale of thermal preference, the only two cases that occurred were expecting it to be cooler (−1) and no adjustment (0). As the temperature range rises, the proportion choosing no adjustment drops significantly; by contrast, the proportion wishing to be cooler rises markedly. For example, within the 33~35 °C range, more than 90% of the participants expected the current temperature to be lower, although 9% of the participants believed that the current temperature did not need to be adjusted. In contrast, within the range between 26~27 °C, roughly 88% of the participants felt that the current temperature was fine and did not need to be adjusted, while 13% of them wanted the current temperature to be a bit lower.



(**a**) (**b**)

Figure 10. Percentage of thermal preference and thermal acceptance in different temperature zones. (**a**)Thermal preference; (**b**) thermal acceptance.

In Figure 10b, the acceptable percentage showed a decrease as the temperature range increased. There were no unacceptable cases when operating temperatures were less than 29 °C. Even in higher indoor temperature environments, such as 33~35 °C, the proportion of unacceptable is barely 20%, and still, around 52% of the residents tend to prefer acceptable. This phenomenon reveals that the local population shows a high tolerance to high temperatures and has developed a certain degree of adaptation to the local climate environment.

3.3. Neutral Temperature and Acceptable Temperature Range

3.3.1. Thermal Sensation Vote

The relationship between TSV and operative temperature is shown in Figure 11, and TSV has a tendency to increase with increasing operative temperature. Linear regression can be used to develop a model for the evaluation of summer thermal comfort in the Linyi area:

$$TSV = -6.12 + 0.22T_{op} \quad (5)$$

María et al. [52], in a study of thermal comfort in older adults in a Mediterranean climate, found that older adults were less sensitive to temperature changes and that their comfort zones were wider than those of adults. According to Figure 11a, in the present study, the slope of 0.2 for older people over 60 years old and 0.26 for younger residents demonstrates that local older people are also less sensitive to temperature changes than younger people. Gender differences also affect the TSV results as shown in Figure 11b. The TSV values of the males showed a flatter variation with temperature than the females. This is similar to the findings of Naja et al. [53] that the slope is less in the males than in the females. In this study, the slope was 0.22 for the population as a whole, 0.17 for the males, and 0.29 for the females. In other words, the local women are more sensitive to variations in temperature than the men.

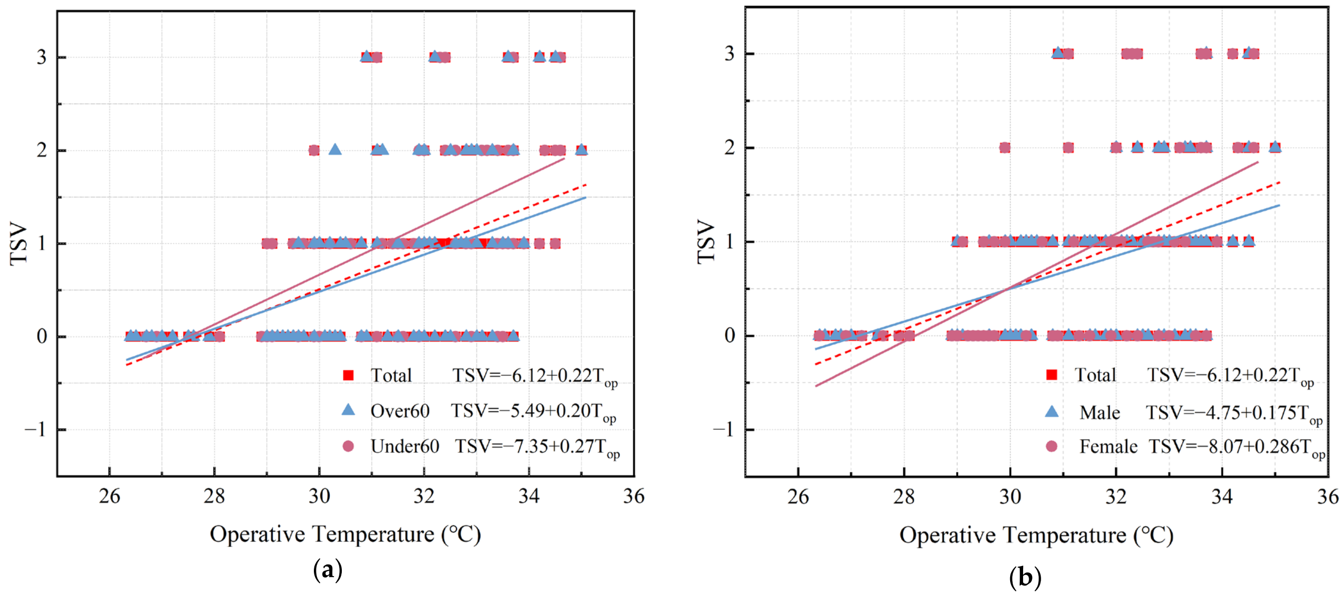


Figure 11. TSV and operative temperature. (**a**) Age; (**b**) gender.

3.3.2. Mean Thermal Sensation Vote

Using the center temperature of each temperature interval as the independent variable and MTSV as the dependent variable, the equation of the relationship between MTSV and T_{op} can be obtained by linear regression:

$$MTSV = -5.78 + 0.21T_{op}, \quad (6)$$

As shown in Figure 12, the overall trend of the MTSV is approximately the same as the results of the TSV, with a smaller slope for the males than for the females, and a smaller slope for the elderly than for the young. According to the linear regression formula, making MTSV = 0, it can be calculated that the neutral temperature of the rural residents in Linyi is 27.5 °C. The neutral temperature of the female occupants is 27.46 °C, while that of the male occupants is 27.65 °C. The neutral temperature of the elderly group is 28.2 °C, while that of the young people is 27.45 °C. The males and females had similar thermal neutral temperatures, whereas older people were 0.75 °C higher than younger people. Given MTSV = ±0.5, the acceptable temperatures for the various groups can be calculated as shown in Table 5.

The results of the experiment showed that among the local residents, the male group and the elderly group were more heat-resistant and they had a wider range of acceptable temperatures. A study of the occupations among the local population revealed that the majority of the population is predominantly home-based farmers. The elderly and male groups spent more time laboring in the field, consequently, they were exposed to high temperatures more frequently. Such experiences have enabled them to be more heat resistant and more adapted to hot environments and changes in temperature. As a result, they are also less sensitive to the variations in temperature and have a wider scope of acceptable temperatures.

Table 5. Neutral temperature and acceptable temperature range.

	Total	**Female**	**Male**	**Over 60**	**Under 60**
T_n (°C)	27.52	27.46	27.65	28.21	27.45
T_{amin} (°C)	25.14	25.53	24.71	25.58	25.18
T_{amax} (°C)	29.90	29.38	30.59	30.84	29.73

T_n: neutral temperature, T_{amin}: lower limit of acceptable temperature, and T_{amax}: upper limit of acceptable temperature.

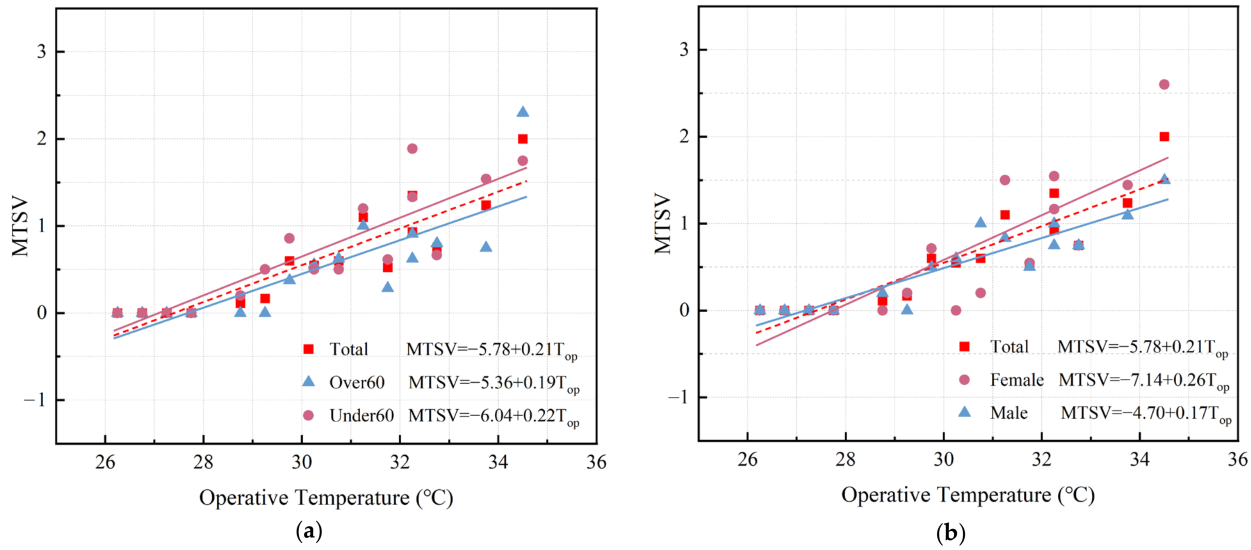


Figure 12. MTSV and operative temperature. (**a**) Age; (**b**) gender.

3.3.3. Comparison of MTSV and PMV

Based on the PMV calculation formula, the PMV values of inhabitants at different operative temperatures can be derived, and the correlation equation between PMV and operative temperature can be attained after linear regression:

$$PMV = -8.43 + 0.33T_{op}, \quad (7)$$

It can be observed in Figure 13 that the PMV predictions are distinctly higher than the MTSV, and most of the PMV scatter lies above the MTSV curve. It illustrates that PMV is unable to accurately predict the thermal comfort evaluation in the Linyi area, and its prediction results obviously overestimate the thermal sensation of the local residential population. In terms of slope, the PMV has a slope of 0.33 and its regression curve is also steeper than the MTSV (0.23). The variation in PMV values with operating temperature is more obvious. The neutral temperature predicted by the PMV is 25.5 °C, which is approximately 2.46 °C above the actual thermal neutral temperature; furthermore, the range of accepted temperatures predicted by the PMV is narrower than the actual level.

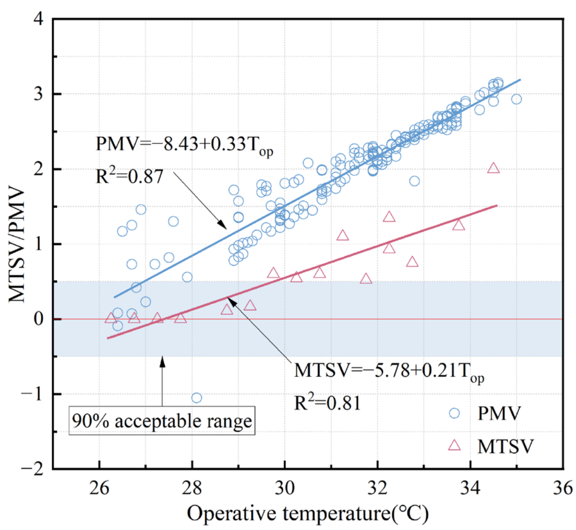


Figure 13. Comparison of MTSV and PMV.

To sum up, the PMV predictions deviate from the actual thermal sensations of the rural residents. This suggests that thermal adaptations did exist and that the PMV needs to be corrected.

3.3.4. Comparison with Previous Studies

Some of the summer thermal comfort evaluation models from other studies within China were selected for comparison with this paper, and the data statistics were counted in Table 6. Figure 14 shows the thermal comfort evaluation curves among various regions. The corresponding thermal comfort evaluation curves for Weihai and Xi'an in cold regions are close to this study. The neutral temperatures in all three regions of Weihai [54], Xi'an [55], and Linyi (this study) are relatively close to the acceptable temperature range. Their neutral temperature is near 27 °C, and the acceptable temperature scope is roughly between 24.5 and 29.5 °C.

Table 6. Comparison of selected Chinese summer thermal comfort studies.

Reference	Climate Zone	Area	MTSV Equation	T_n (°C)	T_{ace} (°C)
Xiong et al. [10]	HSCW [1]	Wuhan, R [4]	MTSV = 0.27T_{op} − 6.79	25.14	23.30~27.00
Zhang et al. [58]	HSWW [2]	Guangdong, R	MTSV = 0.232T_{op} − 5.579	24.05	under31.1
Yang et al. [39]	C [3]	Turpan, R	MTSV = 0.085T_{op} − 2.071	24.36	18.48~30.25
Yu et al. [56]	C	Tibetan, R	MTSV = 0.192T_{op} − 4.191	21.79	19.19~24.39
Liu et al. [54]	C	Weihai, R	MTSV = 0.236T_{op} − 6.363	26.94	24.82~29.06
Ge et al. [55]	C	Xi'an, R	MTSV = 0.213T_{op} − 5.642	26.38	24.04~28.71
This study	C	Linyi, R	MTSV = 0.211T_{op} − 5.781	27.52	25.14~29.90
Liu et al. [57]	C	Taiyuan, U [5]	MTSV = 0.329T_{op} − 9.056	27.50	25.98~29.02

Note: [1] hot summer and cold winter zone; [2] hot summer and warm winter zone; [3] cold zone; [4] rural; [5] urban; T_n is neutral temperature; T_{ace} is acceptable temperature.

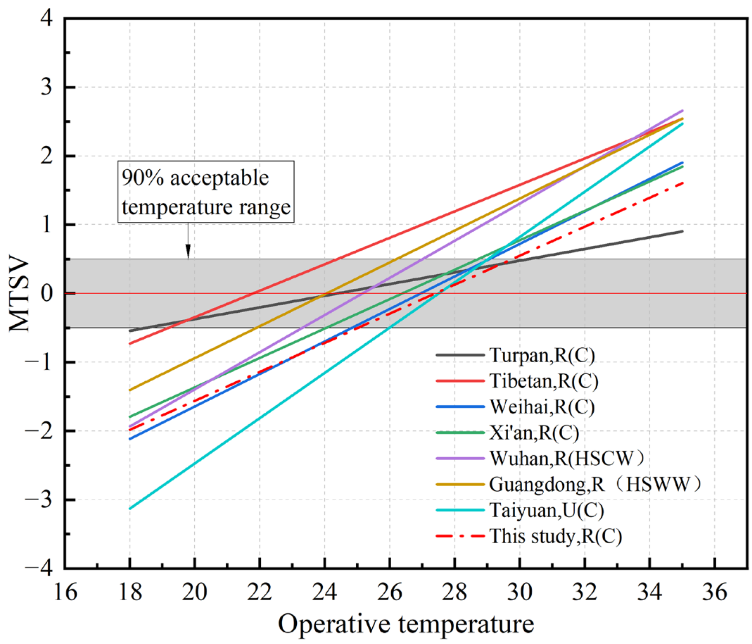


Figure 14. MTSV of different climate zones [10,39,54–58].

However, Turpan [39], which is also a cold region, as well as Tibetan [56] have significant discrepancies with this study. The summer thermal comfort rating curve for Turpan is the flattest of the selected studies. There is a widely acceptable temperature range of 18.48 to 30.25 °C for the local dwellers. Despite being in the same climate zone, Turpan is also quite distinct from the other cities. There is a huge gap between daytime and nighttime temperatures, with sustained high temperatures during the day and plummeting temperatures at night. This climatic feature reduces the thermal sensitivity of the inhabitants of Turpan. The slope of the Tibetan plateau area is similar to other studies, but its thermo-neutral temperature is significantly lower in the same climatic region (21.79 °C). This is owing to the fact that the area is at a higher altitude and has a cooler summer than the other areas.

The slope in Taiyuan [57] is significantly larger than in the other studies in colder zones, and the range of acceptable temperatures is the narrowest in these studies. Comparison with the studies in the other climatic regions shows that the neutral temperatures in Wuhan and Guangdong are slightly lower than those in the case of our study. These two regions are located in the south of China, where the hot weather lasts relatively long in summertime, whereas their neutral temperatures are lower instead. This may be due to the fact that the prolonged high temperatures have led to an increase in the use of air conditioners. Local residents spend more time in air-conditioned rooms. This has weakened their thermal tolerance to some extent.

3.4. Thermal Adaptive Model

3.4.1. Adaptive Thermal Comfort Model

Based on the adaptive thermal comfort theory, the indoor comfort temperature is intrinsically linked to the outdoor climate. Based on the regression of indoor comfort temperature and average outdoor temperature, the thermal adaptation model for summer in Linyi can be obtained (Figure 15). The following equation can be derived by linear regression:

$$T_n = 0.83T_{out} + 4.68 \quad (8)$$

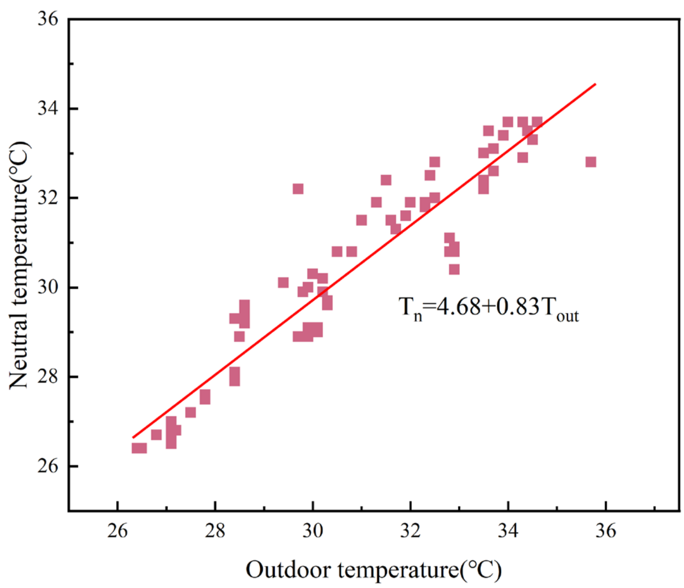


Figure 15. Thermal adaptive model of Linyi.

It can be seen that the indoor comfort temperature shows a significant increasing trend with the increase in the average outdoor temperature. Moreover, the slope of the thermal adaptation model in this study is steeper compared to the studies in the other regions. Yu et al. [59] studied the thermal adaptation of the elderly people in Shanghai and established a thermal adaptation model for different seasons of the local elderly people. The slope of their adaptive thermal comfort model was 0.418 in summer, 0.706 in winter, and 0.84 in the transition season.

With the slope of this model closer to one, the indoor comfort temperature approaches closer to the average outdoor temperature. Malik et al. [60] developed a thermal adaptive model for a naturally ventilated residential building in a region of India with a slope of 0.53. For the same working conditions, the thermal adaptative model developed by Chali et al. [61] for Ethiopian settlements has a slope of 0.55. As far as the current research status is concerned, thermal adaptative models in the Chinese region tend to have slopes that are larger than those in other countries. This is mainly explained by the fact that the Chinese residents have a better adaptation capacity to the climate. The use of air conditioning and heating equipment in dwelling construction is not yet as frequent as in developed countries. For instance, in the rural area of Linyi, air conditioning is basically not used for cooling due to economic constraints. Most of the residences are also under natural ventilation in summer, thus the indoor comfort temperature has a higher correlation with the outdoor temperature.

3.4.2. Comparison with Current Comfort Standard

Currently, the main international standards that use thermal adaptation models to determine indoor thermal comfort zones are EN15251-2007 [62] and ASHRAE 55-2023 [19]. Figures 16 and 17 represent the comparison of the thermal adaptation model of this study with these two standards. It can be visualized that the present study's thermal adaptive model slopes are significantly higher than the EN15251-2007 and the ASHRAE standard. In addition, most of the scattered points fall outside the thermal comfort zone. About 73.6% of these points fall completely outside the thermal comfort zone delineated by EN15251-2007. The ASHRAE standard sets a slightly wider range of outdoor temperatures than the EN15251-2007, from 10 to 33.5 °C. Yet only 21.5% of the points fall within the 90% comfort zone and 42.36% are within the 80% comfort range.

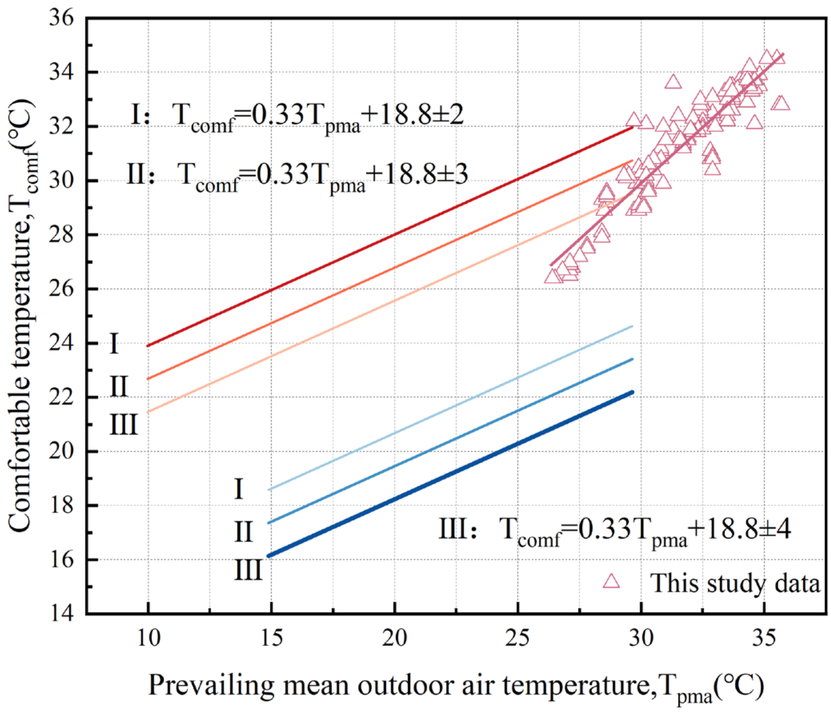


Figure 16. Comparisons with EN15251-2007.

China established evaluation standards for indoor thermal environments in civil buildings (GB/T 50785-2012 [47]) based on the domestic situation. Moreover, two different thermal adaptation regions are established according to the climate characteristics. In this paper, the thermal comfort region corresponding to the cold and severe cold zones was selected, as shown in Figure 18. The slopes in this study are similar to the upper and lower slopes in the criteria. However, the outdoor temperature range in this research is higher than the applicable range in the domestic standards. There are about 68% of the points that are outside the thermal comfort zone specified by the national standard. This indicates that the current Chinese standard underestimates the average outdoor temperature in cold zones.

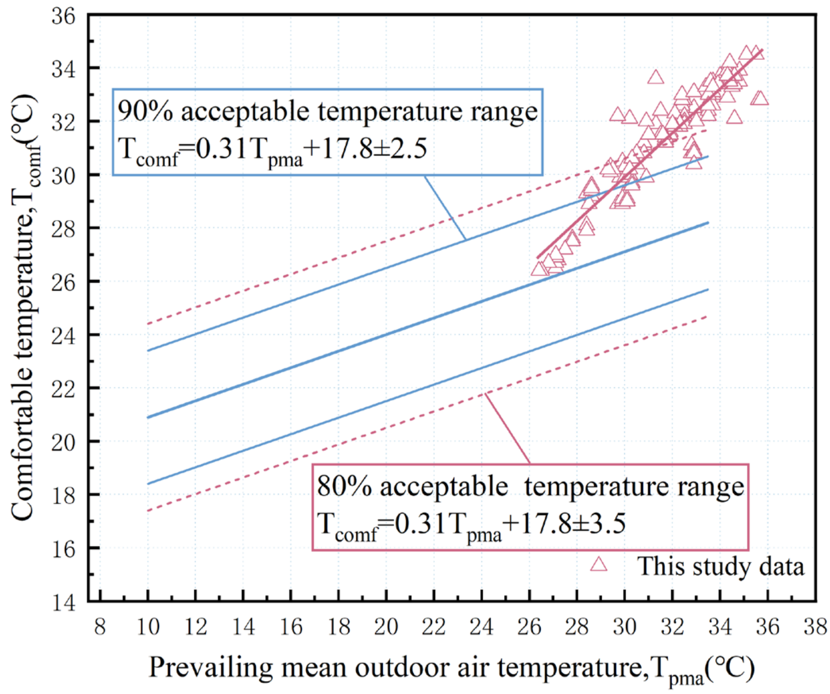


Figure 17. Comparisons with ASHRAE 55-2023.

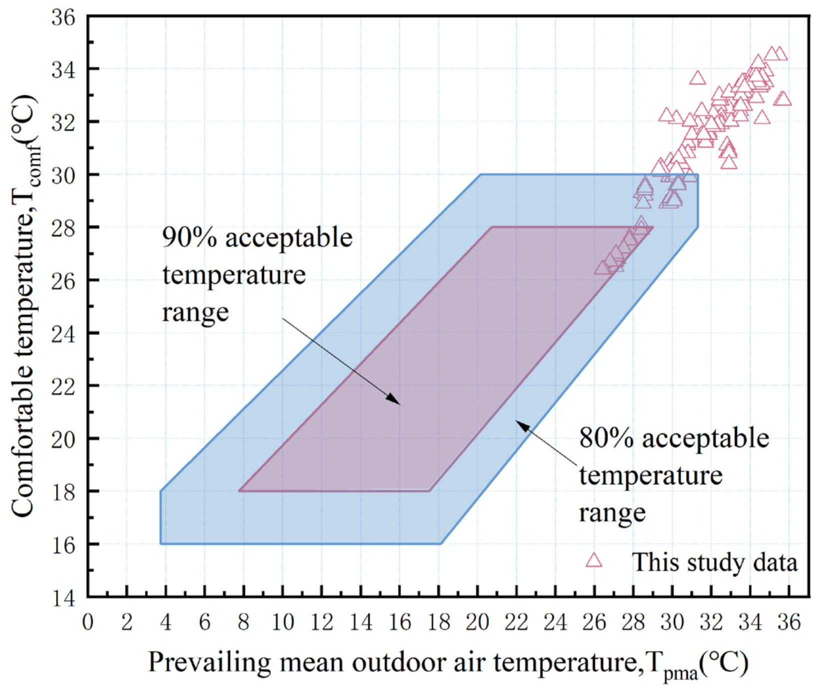


Figure 18. Comparisons with GB/T 50785.

Given the above, it demonstrates that EN15251, ASHRAE 55, and GB/T50785 are not well suited for summer thermal comfort assessment in the rural areas of Linyi.

3.5. Adaptive Strategies

3.5.1. Clothing Insulation

The thermal insulation of the clothing worn by the inhabitants is an important element that affects the thermal sensation. Increasing or decreasing clothing is a comparatively normal way of adjustment. A detailed record of what residents were wearing was kept during the survey. By finding the corresponding values in the ASHRAE 55-2023 standard, the thermal insulation of the inhabitants' garments was acquired after statistical calculations. Clothing thermal insulation against operative temperature is shown in Figure 19. As the temperature increased, the clothing thermal insulation of the residents decreased slightly. In previous studies, there was a high correlation between the clothing thermal insulation and the operative temperature, and the clothing thermal insulation value showed a clearly decreasing tendency with the increase in the operative temperature. Nonetheless, in this study, the correlation between operating temperature and garment thermal resistance was analyzed by SPSS, and the results of its analysis showed a significant p-value above 0.05, which indicates that there is no significant correlation between operative temperature and clothing thermal insulation. This implies that shifts in temperature during the summer likely will not provoke dress changes in the occupants. During the summer months, many residents need to work in their fields. For reasons such as solar protection, many villagers are accustomed to wearing long sleeves and long pants even if the outdoor temperature is extremely hot. This may explain the fact that there is no significant correlation between the residents' dress conditions and temperature.

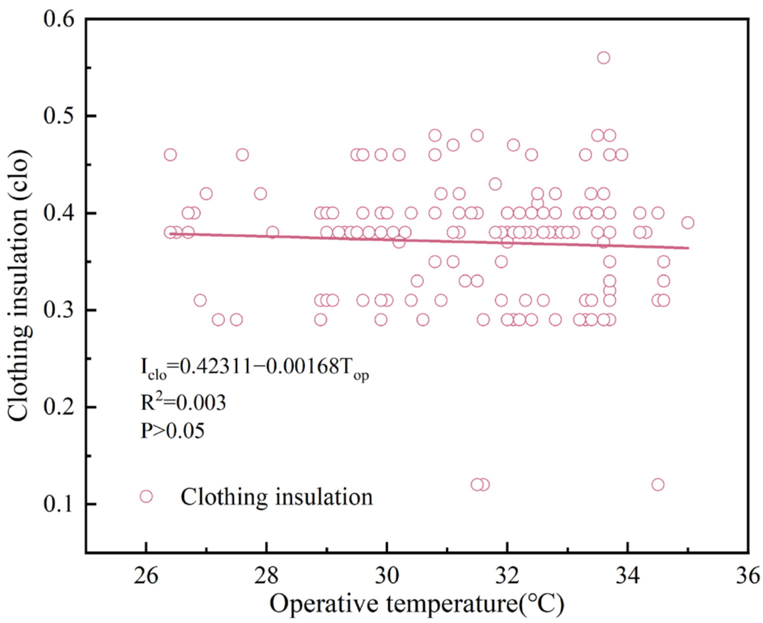


Figure 19. Relationship between clothing insulation and operative temperature.

However, there are some differences in the clothing habits by age and gender among the occupants. As shown in Figure 20, the older residents have higher mean values of thermal resistance of their garments than the younger ones, with most of the older people having their clothing thermal insulation clustered around 0.39 clo. The mean values of clothing thermal insulation for the local females were slightly higher than those of the males, mainly centered between 0.35 clo and 0.4 clo. The body's basal metabolic rate decreases with increasing age. Furthermore, men generally have a higher basal metabolic rate than women [63]. Therefore, the older people and female groups are inclined to wear more clothing.

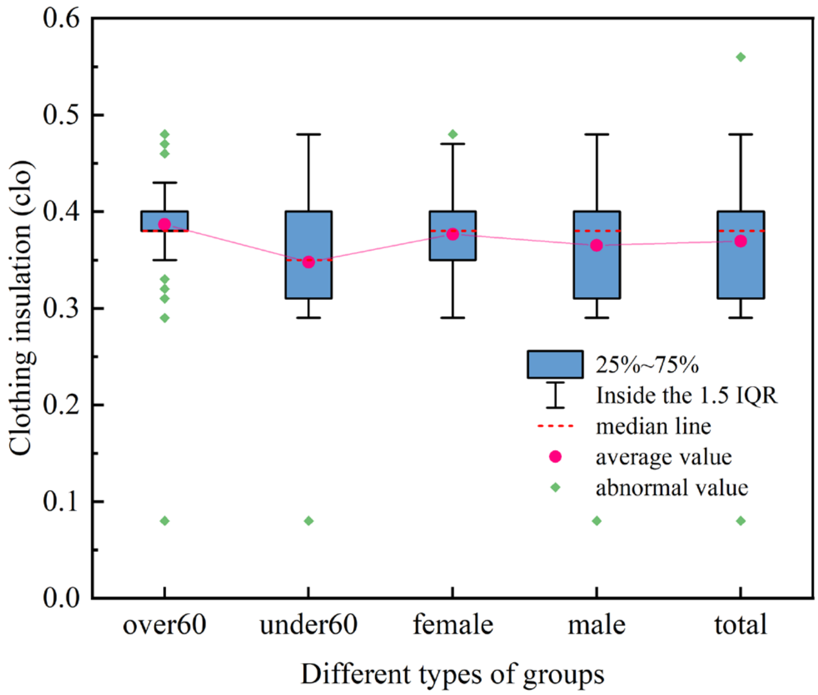


Figure 20. Clothing thermal insulation of different groups.

3.5.2. Metabolic Rate

The metabolic rate of the individual at different activities can be observed according to the ASHRAE 55-2023 standard. As reflected in Table 7, during the survey period, below were the main activities among the villagers: lying down (about 0.7 met), sitting still (about 1 met), standing (about 1.4 met), and walking (about 1.7 met). In addition, some of the participants were doing household work such as washing clothes, cleaning the house, etc. (about 2 met). As described in Table 7, approximately 66.3% of the residents were sitting, followed by walking (17.8%), and a few residents were standing and doing household chores when they filled out the questionnaire. The average metabolic rate of the population is about 1.2 met.

Table 7. Type of activity and metabolic rate of the population.

Activity	Sleeping	Seated	Standing	Walking about	Housework	Average
Metabolic rate (met)	0.7	1.0	1.4	1.7	2.0	1.2
Percentage (%)	1.12	66.29	8.43	17.98	6.18	

3.5.3. Thermal Adaptive Behaviors

Influenced by Linyi's summer climatic parameters, economic constraints, and chronic living habits, many adaptive thermal comfort strategies have been developed locally. For example, there are many local families with annual income levels below CNY 30,000 (about $4167), thereby air-conditioning is not equipped in many households. The results of the questionnaire show that the most common cooling device used by local residents is the electric fan. Around 80% of the dwellers preferred electric fans for cooling, followed by split air-conditioners, which accounted for only 18%, with merely 2% of the households using centralized air-conditioners. These two methods, together with cooling in the shade and opening doors and windows, constitute the predominant form of thermal regulation for the local population. It accounts for more than 83.2% of the total.

Figure 21 counts and shows the percentage of thermal adjustment methods for different groups. In the summer, the improvement of one's thermal sensation by reducing clothing accounted for only 1.35% of the total, which is not the first choice of local residents to cool down. This explains, to some extent, why there is no significant correlation between garment thermal resistance and temperature. Among older adults, turning on a fan (31.82%), cooling off in the shade (23.43%), and opening doors and windows (20.28%) were the three most prevalent ways, and these three categories accounted for 75.5% of the total. Some older people also choose to turn on the air conditioner (13.29%), but the proportion is significantly less than that of the younger people (22.41%). In addition to this, some elderly individuals will use their hand-held fans to cool down by flapping, which is hardly found among the young. Enhancing natural ventilation by opening windows and doors helps to reduce the buildings' energy use [64]. In general, seniors tend to prefer more economical cooling methods, reducing the need for costlier methods such as turning on the air conditioner. The three most common ways among the younger people compared to the older people are as follows: turning on fans (25.43%), turning on air conditioners (22.41%), and opening doors and windows (16.81%), but these three accounted for only 64.66%. Apart from that, the young people also like to cool off in the shade (11.64%). However, the young people are more varied in their choice of cooling methods than the older people; for example, some younger residents would also choose to take a bath, drink cold beverages, and lay down a cool mat, while almost none of the older residents take these methods. Gender differences in thermal regulation methods are minimal. It is noteworthy, however, that while the women are more likely than the men to open windows and doors and turn on the air conditioner to cool off, the male residents are more willing than the female residents to seek shade for cooling off.

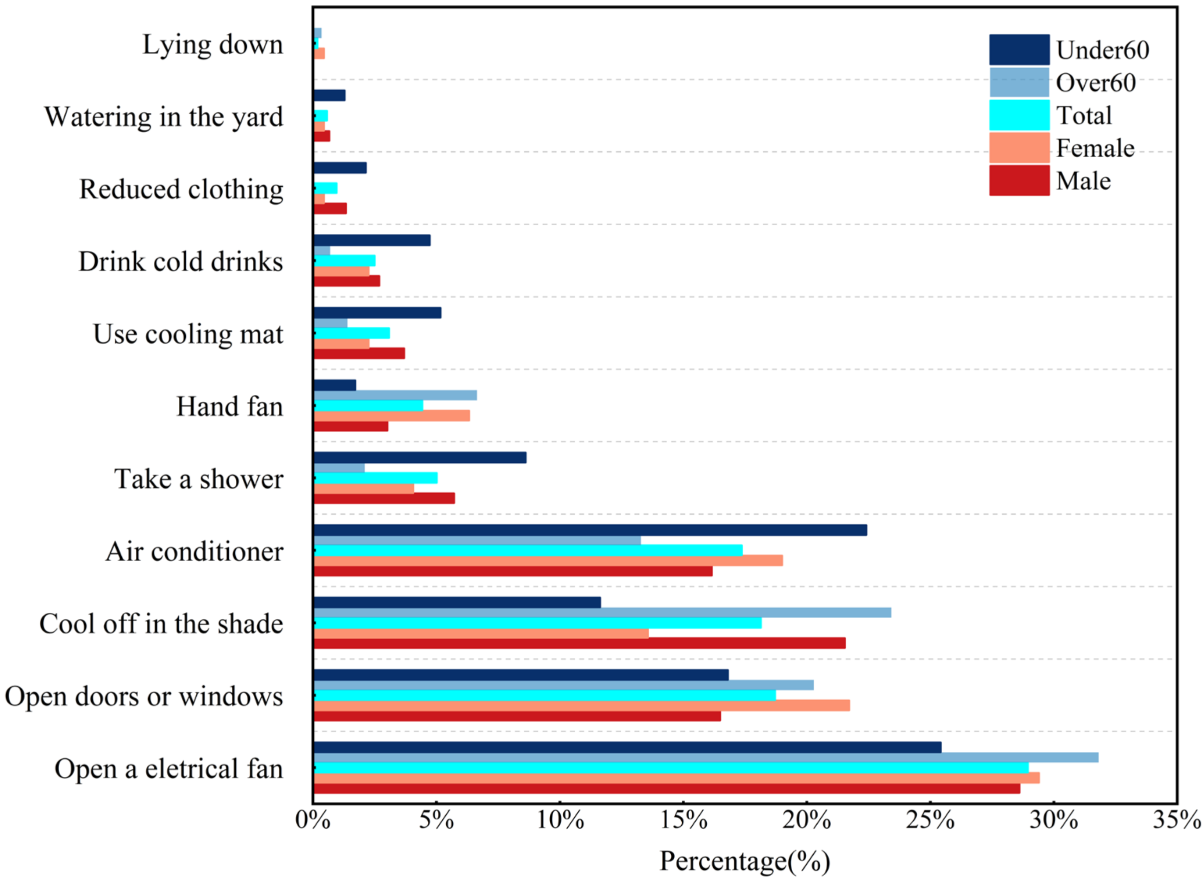


Figure 21. Thermal adaptive behaviors of the respondents.

3.6. Applications and Limitations

3.6.1. Application

In summary, the thermal neutral temperature and the acceptable temperature are obtained. At the same time, we established a thermal adaptation model for the Linyi area. Based on the average outside temperature, we were able to derive the neutral temperature. Complementing current thermal comfort studies, this provides data support for the delineation of thermal comfort ranges in the cold regions of China.

The paper compares in detail the differences in the subjective perception of the residents caused by gender and age. This can provide a reference for the design of local public buildings. For example, it can provide a basis for the temperature setting of nursing homes and hospital wards. Consider that elderly people are accustomed to spending their leisure time in the shade to keep cool. Therefore, it is recommended to plant vegetation in courtyards or provide shaded areas for residents to rest and cool off in appropriate locations within the community. This could potentially reduce the air conditioning usage among residents, leading to a decrease in the building's energy consumption.

3.6.2. Limitation

However, there are some limitations in this research. First, due to the field visit research process, most of the questionnaires relied on the researcher to fill them out on behalf of the respondents after asking them one by one. Coupled with the limitation of time and effort, the number of questionnaires finally recovered in this study was limited. Typical summer days were sampled for the survey in this paper, but the beginning and end of summer were not included. Weather conditions may differ from a typical day during transitional periods, such as the transition from spring to summer or summer to autumn. Furthermore, the thermal comfort predicted and assessed for the occupants in this paper is limited to local indoor environments. Many residents appreciate being outdoors (e.g., courtyards, alleyways, gates, etc.). These places also deeply affect human thermal comfort and need to be further studied.

4. Conclusions and Future Outlook

This paper focuses on summer thermal comfort and the thermal adaptation of the residents in the rural areas of Linyi and explores the indoor environment of the local stone buildings. It fills a gap in the study of summer thermal comfort in rural dwellings in cold regions. Meanwhile, the variation in thermal adaptation among distinct populations was analyzed and compared in detail. As a result, thermal adaptation models and thermal regulation methods for various residents were obtained. The analyses in the paper verified the applicability of the current standards for rural Linyi. These results contribute to the revision and supplementation of China's thermal comfort standards, and also provide case references for the subsequent studies of rural houses. The specific conclusions are as follows:

- From the measured data we found that the indoor thermal environment of rural dwellings in Linyi exceeded 30 °C for a long period of time. This is significantly exceeding the range of comfortable indoor temperatures stated in the standards. Long-term experience in such overheated environments has driven the local residents to develop thermal adaptations that enable them to exhibit good thermal tolerances.
- The elderly group and the female group are less sensitive to humidity changes indoors and have a wider range of comfortable humidity. For the older people, the ideal humidity range is around 38.95% to 66.57%, while the younger people should aim for 46.33% to 62.64%. The comfy humidity band for the females is around 38.59% to 65.76%, while for the males it is around 43.63% to 63.37%.
- The local men and residents over 60 years in Linyi have better thermal resistance. The older people had a neutral thermal temperature of 28.21 °C and a thermal comfort range of 25.58 °C to 30.84 °C. The residents under 60 years of age had a neutral thermal temperature of 27.45 °C and a thermal comfort range of about 25.18 °C to 29.73 °C.

There was no significant difference between the neutral temperatures of the males and females, which were 27.65 °C and 27.46 °C, respectively. However, the males have a wider acceptable temperature range of 24.71 °C to 30.59 °C, while the females are in the area of 25.53 °C to 29.38 °C.

- Both current Chinese and international thermal comfort evaluation criteria make it difficult to accurately assess the indoor thermal environment in the Linyi rural area. We re-established a thermal adaptation model that is consistent with the rural residents, and found that most of the scattered points fall outside the comfort range recommended by these standards. This suggests that the current standards are indeed inadequate and need to be revised through extensive field studies.
- The most common ways for the Linyi residents to stay cool are turning on electric fans, opening doors and windows, cooling off in the shade, and turning on the air conditioner. The young people have more varied ways of cooling down in summer. In addition to the most commonly used ways mentioned above, bathing, drinking cold drinks, and cooling mats can be one of the choices for the young persons. The seniors have fewer ways to cool down and are rarely willing to turn on the air conditioner to cool down.

In the future, we plan to conduct further research in the following directions: (1) The outdoor leisure space is an important area for rural residents, and the thermal environment of this place deserves attention. (2) In rural areas, the elderly population over 60 years old constitutes a significant proportion. We considered a more detailed division of older people into age groups and investigated the differences between the various age groups. (3) Further attention will be devoted to the methods of summer cooling in rural dwellings and their cooling efficiencies. And we will try to quantify their influences on human thermal adaptations.

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Appendix A

Linyi Summer Thermal Comfort Questionnaire

Date: ________________ **Time:** ______________________ **Weather:** sunny/cloudy/rain________

Air temperature: _______℃ **Relative humidity:** ___________%

PART 1: Basic information

1.Gender: female/male	**2.Age:** ______	**3.height:** ___cm	**4.Weight:** _____kg	**5. Household size**____
6. Careers: □farmer □workers □students □__________	**7. Annual household income?**________________			
8. How long have you lived here?	□ < 1 year □1-5years □6-10years □Over 10 years			

9. What are you wearing at this time?	
upper garment	□____
underwear	□____
skirts	□____
shoes	□____
socks	□____
9. What has been your main activity in the last 20 minutes?	
□____	

PART 2: Environmental perception

1. What do you feel about the current room temperature?						
□Cold	□Cool	□Slightly cool	□Neutral	□Slightly warm	□Warm	□Hot
2. What would you prefer the current room temperature to be?						
□Cooler	□No change	□Warmer				
3. How do you feel about the current indoor humidity?						
□Very dry	□Dry	□Slightly dry	□Neutral	□Slightly humid	□Humid	□Very humid
4. How would you prefer the current indoor humidity to be?						
□More humid	□No change	□Dryer				
5. Approximately how acceptable are you for the current indoor temperature?						
□Clearly unacceptable	□unacceptable	□Slightly unacceptable	□Neutral	□Slightly acceptable	□acceptable	□Clearly acceptable
6. How satisfied are you with your current overall indoor environment?						
□dissatisfied	□Rather dissatisfied	□Hard say	□relatively satisfied	□satisfied		

PART3: Adjustment of behavior

1. What do you normally do to cool down? (Please select the three most commonly used)			
□Reduced clothing	□Hand fan	□cooling met	□cool off in the shade
□Drink cold drinks	□Electrical fan	□Air conditioner	□Take a shower
□Open windows and doors	□Watering the yard	□Other ways (______________________)	
2. What is the most commonly used summer cooling device in your home?			
□Fan	□Separate air-conditioning	□central air conditioning	
□Other (________________________________)			

Thank you again for your cooperation and for your contribution to our research! We wish you a happy life!

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