buildings

MDPI

Article

Field Investigation on the Thermal Environment and Comfort of People Exercising in a Fitness Center

Haiying Wang *, Yongwang Hao, Huxiang Lin, Rongfu Hou and Kefei Gong

School of Environmental and Municipal Engineering, Qingdao University of Technology, Qingdao 266520, China
* Correspondence: wanghaiying@qut.edu.cn

Abstract: A favorable thermal environment in fitness centers is important to attract more members and is beneficial to the health of exercising people. The purpose of this study was to research the actual thermal environment of a typical fitness center in different seasons and the thermal requirement of exercising people. A field investigation covering winter, spring, and summer was conducted. The environmental parameters were measured. Subjective questionnaires involving individual information, clothing insulation, thermal sensation, etc., were collected. Participants' heart rates were tested to estimate their metabolic rate (MR). A total of 740 valid questionnaires were collected. The results showed that a scissors gap existed between the predictive mean vote (PMV) and the thermal sensation vote (TSV) for the exercising people. For the higher MR group, there was a separation between the TSV and thermal preference vote, e.g., most participants would not prefer to cooler or warmer thermal environment when they felt hot or cold. The CO_2 concentration changed greatly among seasons and the distribution in the fitness center was not uniform. With mechanical ventilation, the CO_2 concentration in summer was the lowest. In other seasons it became much higher due to limited natural ventilation. However, subjective response to indoor air quality showed no significant difference among seasons. The participants felt more satisfied to the overall thermal environment in the transition season. The results can be referenced in the thermal environment management in fitness centers during seasonal changes.

Keywords: thermal environment; indoor air quality; thermal comfort; field investigation; exercising

check for updates

Citation: Wang, H.; Hao, Y.; Lin, H.; Hou, R.; Gong, K. Field Investigation on the Thermal Environment and Comfort of People Exercising in a Fitness Center. *Buildings* **2024**, *14*, 3296. https://doi.org/10.3390/buildings14103296

Academic Editor: Ricardo M. S. F. Almeida

Received: 19 September 2024
Revised: 11 October 2024
Accepted: 16 October 2024
Published: 18 October 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

With enhanced awareness of self-fitness, fitness centers or gyms are developing rapidly in China. According to statistics, the number of fitness centers in China had exceeded 44,300 by 2020, and the number of members exceeded 70 million, which accounted for more than 5% of the total population [1]. The inside service and facilities of fitness centers are important to attract more members, while healthy and comfortable thermal environment may play a more important role to make people satisfied. People take various activities in fitness centers, and their metabolic rate (MR) changes accordingly, which is much higher than normal activities in daily life. Researchers have studied people's physiological and subjective response to the thermal environment both in climate chambers and in the field when performing higher MR activities.

Studies conducted in climate chambers are mainly focused on exercising people with confined MR. Yang et al. found that with increased MR in treadmill exercises, the associated environmental neutral temperature was reduced [2]. They also reported that the PMV–PPD model was unable to predict human thermal sensation or acceptability correctly at slightly higher MR. Wang et al. found that the PMV model overestimated the thermal sensation of the subjects taking moderate activities, and the subjects' thermal sensation was related to sweat activity [3]. Their study showed that the sweat process led to a decrease in neutral skin temperature when MR increased. Wang et al. also explored the changes in body heat loss and its effect on the thermal sensation of these subjects, and found that when the ratio

of latent heat loss increased; people's mean thermal sensation vote (TSV) would increase too [4]. Tsuzuki et al. showed that exercise can increase the mean skin temperature and thermal sensation of the elderly people under condition of 23 °C and 27 °C [5]. Generally, the elderly subjects felt the experimental conditions were warmer than predicted by PMV. Zhai et al. found that the PMV model overestimated the cooling requirements of people during exercise [6]. They indicated that subjects expected more air flow rather than lower temperature during exercise. Their study also showed that exercising people had higher skin wetness and core temperature. These studies in climate chambers found that the PMV model was not accurate in predicting the thermal sensation of exercising people, and with higher MR, people's thermal requirement of the environment would be different.

There were some field studies carried out in sports training halls and gyms. Ji et al. conducted experiments in a university badminton hall and found that the temperature and relative humidity (RH) had significant effects on the thermal sensation of exercising people [7]. They found that PMV increased linearly with the increase in temperature, humidity, and MR, while it decreased with the increase in wind speed. Zhang et al. also conducted a series of experiments in a badminton hall [8]. They found that exercising caused airflow disturbance around the human body, which enhanced the heat transfer between the human body and the surrounding environment, and resulted in changes in thermal sensation. Huang et al. conducted a field investigation of athletes during a basketball game in a naturally ventilated gym [9]. The results showed that the physiological parameters and thermal sensation of athletes changed greatly during exercise. Fletcher et al. showed that neither PMV nor the modified PMV could accurately assess the thermal comfort of people engaged in non-sedentary activities, suggesting that the PMV index was limited to activities with a MR less than 2 met [10]. Revel et al. studied the thermal comfort of people in sports stadiums with the aim of improving the comfort of people and the efficiency of energy control systems for energy use in sports stadiums [11]. Ji et al. concluded that for exercising people, the appropriate environment temperature could be higher than the conventional air conditioning temperature predicted by the PMV model, which was important for energy saving in the air conditioning system [12]. Fantozzi et al. stated that the physiological components were particularly important in evaluating thermal environment of physical activity spaces because of high a MR [13]. Bao et al. found that indoor air quality affected the subjective response of exercising people, and suitable temperature and RH, CO_2 concentration, and other low concentrations of pollutants were the guarantee of good fitness effects [14]. Lu et al. conducted a study in a fitness center, and found that the indoor air quality in these places was poor, with high CO_2 concentrations exceeding the requirement of standards [15]. Exercising in such an environment would have a negative impact on the health of exercising people. Wang et al. suggested displacement ventilation to achieve better indoor temperature and velocity distribution in the personalized activity area in gyms [16]. Alessia et al. demonstrated that, with the exception of a few environments affected by structural limits, the real-time visualization and monitoring of CO_2 concentrations allows for effective air exchanges to be implemented [17]. Pan et al. developed clustering algorithms to determine the carbon dioxide concentration limit, thus enabling real-time air volume adjustment. An ERV-based carbon dioxide concentration limit reduced the energy consumption of ventilation facilities by 11% [18].

Most of these field studies were conducted in large halls for the training of badminton, basketball, etc. The effects of temperature, RH, air movements on the thermal comfort of exercising people were discussed. However, due to the difference in thermal environment control and the type of exercising, the thermal comfort range is still unclear. For fitness gyms, more attention was paid to indoor air quality. In addition, these studies mainly focused on summer conditions. Few studies were conducted during winter and transition seasons.

A few field studies were conducted in factories to find the thermal requirements of laboring people with higher MR. Pinto et al. investigated the existing environment of the

steel by-product manufacturing industry, and conducted subjective surveys of workers [19]. The data showed that the correlation between workers' thermal sensation and PMV was 81%. Therefore, he suggested that the PMV model was applicable to predict the thermal sensation and preference of these workers. Shaharon et al. conducted survey for 99 workers in summer and found that lower room temperature was more appreciated [20]. Their results showed that to create an optimal comfortable workplace, the temperature should be maintained from 20 °C to 26 °C and the relative humidity be maintained in the range of 40% to 60%. Wang et al. conducted a field study in a rubber factory and found that the PMV model overestimated the thermal sensation of workers in summer [21]. The workers adapted to higher temperature in summer well even with confined behavior adjustment. These field studies showed that the applicability of PMV was not certain for workers in factories. Additionally, with higher MR, workers expected lower temperature environment in summer, and they can also be adaptive to an unfavorable thermal environment.

In general, most climate chamber and field studies on the thermal comfort of people with higher MR showed that the PMV model was not accurate, and the thermal requirement of these people was different. The indoor air quality could be very different depending on the ventilation methods, and subjects' response to indoor air quality can be different.

When people exercise in fitness centers, they perform various activities. They may percept the thermal environment differently because of different MR levels. In addition, Wang et al. found that emotional state could have some influence on subjects' perception of the thermal environment [22]. Under a positive emotional state, people were more receptive to the thermal environment, and evaluated the thermal environment better than those under a negative emotional state. This psychological factor may affect people's sensation of the thermal environment when they perform physical activities actively or passively. The psychological expectations of people who were in field training, factories, and exercising in chambers may be different from those who exercise freely in fitness centers.

Therefore, a field investigation in a typical fitness center was conducted to test its thermal environment conditions, and analyzed the thermal comfort of the users. This survey covered winter, summer, and the transitional season to achieve a full understanding of the thermal environment during different seasons.

2. Methods

A typical fitness center in Qingdao, Shandong Province of China was selected to conduct the field investigation. This center is one of the chain stores of a large fitness company, which has developed more than 400 stores in the country. Figure 1 shows the inside view and the layout of the fitness center. There are various fitness facilities including treadmills, weight lifting and stretching machines, aerobic exercise rooms, spinning rooms, swimming pools, private coaching rooms, etc. The swimming pool and private coaching areas were not investigated in this study. The fitness center has an air-conditioning system in summer and a floor heating system in winter. The heating season in winter starts from 15 November to 5 April of the next year, and the cooling season in summer is from 15 June to 15 September. The field investigation was from December to August covering three representative seasons of winter, spring (transition season), and summer.

2.1. Measurement of Environmental Parameters

The environmental parameters measured in the field study included outdoor temperature and RH, indoor temperature and RH, black globe temperature, air velocity, and CO_2 concentration. Considering the large area of fitness center, a total of 10 measuring points were set to measure indoor environmental parameters. The location of the measuring points numbered from 1 to 10 are shown in Figure 1. Each indoor measuring point was at the height of 1.1 m above the ground. The outdoor sensors were placed above ground and were hidden from direct sunlight. The investigation time was from 16:00 to 20:00 when there were more people in the fitness center. Therefore, the outdoor and indoor environmental parameters were also measured during this time. Investigators visited the

center regularly and would first ask each people if he/she was willing to participate in the survey, then measure his/her hear rate (HR), and collect questionnaires upon their consent.

The measuring equipment for the field study is shown in Table 1.

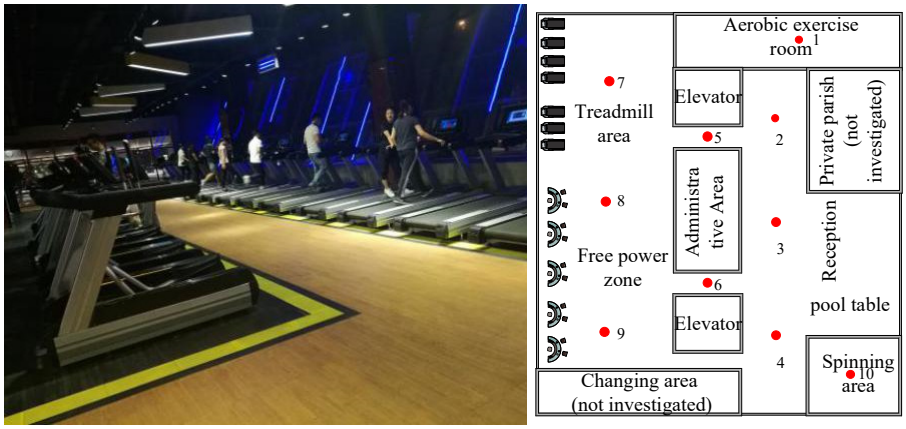


Figure 1. Inside view and layout of fitness center (the red dots show the location of ten measuring points).

Table 1. Details of equipment used in investigation.

Equipment	Type	Parameters	Range	Accuracy
Temperature and RH loggers	WSZY-1A (Tianjian Huayi Technology Development Co., Ltd., Beijing, China)	Air temperature RH	−40~100 °C 0~100%	± 0.5 °C ±3%
Anemometer	Kanomax 6004 (Kanomax Group, Osaka, Japan)	Air velocity	0.1~20.0 m/s	±0.05 m/s
Black globe temperature loggers	JTR04 (Xinye Environment Protection Co., Ltd., Qingdao, China)	Black globe temperature	5~120 °C	±0.5 °C
CO_2 concentration meter	TEL7001 (General Electric Company, Boston, MA, USA)	Carbon dioxide	0~10,000 ppm	±50 ppm

2.2. Design of Questionnaires

Participants' personal information and their response to the thermal environment were collected in questionnaires. The questionnaire was conducted via an application on smart phones, and most of the respondents could complete the questionnaire within 1 min.

Individual information in questionnaires included: gender, age, weight, height, occupation, exercising frequency, current clothing, exercise duration, and exercise type. The thermal response to the thermal environment included: (1) thermal sensation; (2) thermal preference; (3) thermal comfort; (4) overall thermal environment satisfaction; (5) odor sensation; (6) air quality satisfaction; and (7) sweat feeling.

The ASHRAE (the America Society of Heating, Ventilating and Air-condition Engineering) seven-point scale was used for the thermal sensation and thermal preference vote [23], and a five-point scale was used for the thermal comfort vote [24] and satisfaction vote, etc. The scales of thermal response and their meaning are shown in Table 2.

Table 2. Meaning of thermal response.

Scales	Thermal Sensation	Thermal Preference	Thermal Comfort	Overall Thermal Environment Satisfaction	Air Quality Satisfaction	Smell Sensation	Sweat Feeling
−3	Cold	Colder					
−2	Cool	Cooler					
−1	Slightly cool	Slightly cooler					
0	Neutral	No change	Comfortable	Very satisfied	Very satisfied	No peculiar smell	No sweating at all, dry skin
1	Slightly Warm	Warmer	Slightly uncomfortable	Satisfied	Satisfied	Slight peculiar smell	No sweating, slightly damp skin
2	Warm	Hotter	Uncomfortable	Slightly unsatisfied	Slightly unsatisfied	Medium peculiar smell	Sweating Slightly, damp skin
3	Hot	Much hotter	Much uncomfortable	Unsatisfied	Unsatisfied	Strong peculiar smell	Sweating, visible drops on skin
4	-	-	Intolerable	Very unsatisfied	Very unsatisfied	Intolerable peculiar smell	Sweating a lot, with falling drops

2.3. Equations Used in Analysis

2.3.1. HR and MR

In this study, the subjects' HR was tested to estimate their MR. The HR was measured using an electronic blood pressure meter (Omron HEM-629, OMRON Corporation, Kyoto, Japan). The MR was estimated according to the standard of ISO 8996 [25]. Details of the calculations are shown in Tables 3 and 4. Figure 2 is the field pictures of measuring the HR.

Table 3. MR estimation based on HR for females.

Age (Years Old)	Weight (kg)				
	50	60	70	80	90
20	2.9 × HR-150	3.4 × HR-181	3.8 × HR-210	4.2 × HR-237	4.5 × HR-263
30	2.8 × HR-143	3.3 × HR-173	3.7 × HR-201	4.0 × HR-228	4.4 × HR-254
40	27 × HR-136	3.1 × HR-165	3.5 × HR-192	3.9 × HR-218	4.3 × HR-244
50	2.6 × HR-127	3.0 × HR-155	3.4 × HR-182	3.7 × HR-207	4.1 × HR-232
60	2.5 × HR-117	2.9 × HR-145	3.2 × HR-170	3.6 × HR-195	3.9 × HR-219

MR in W/m^2, HR in bpm.

Table 4. MR estimation based on HR for males.

Age (Years Old)	Weight (kg)				
	50	60	70	80	90
20	3.7 × HR-201	4.2 × HR-238	4.7 × HR-273	5.2 × HR-307	5.6 × HR-339
30	3.6 × HR-197	4.1 × HR-233	4.6 × HR-268	5.1 × HR-301	5.5 × HR-333
40	3.5 × HR-192	4.0 × HR-228	4.5 × HR-262	5.0 × HR-295	5.4 × HR-326
50	3.4 × HR-186	4.0 × HR-222	4.4 × HR-256	4.9 × HR-288	5.3 × HR-319
60	3.4 × HR-180	3.9 × HR-215	4.5 × HR-249	4.8 × HR-280	5.2 × HR-311

MR in W/m^2, HR in bpm.

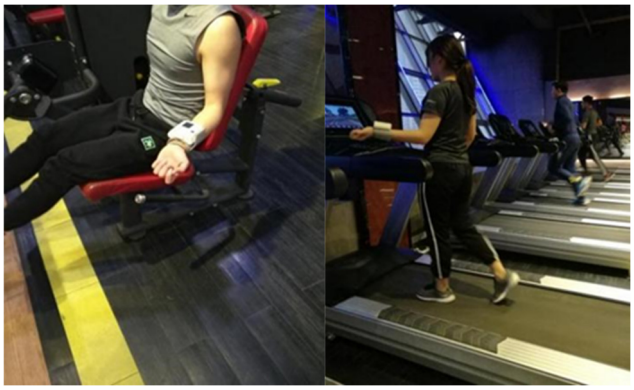


Figure 2. Field pictures of measuring HR.

2.3.2. Clothing Insulation Calculation

People usually adjust their clothes according to the climate changes. However, in the fitness places, people generally wear light sportswear during exercise. In the questionnaire, subjects selected their clothing based on a given list of possible clothing. Based on their selection of clothing, the total clothing insulation was calculated via the following equation [24]:

$$I_{cl} = 0.835 \sum I_{clu,i} + 0.161 \quad (1)$$

2.3.3. BMI Index

According to the results of the questionnaire, the participants' physical condition was represented by their Body Mass Index (*BMI*), which is an internationally accepted index to indicate fatness and thinness of an individual [26]. *BMI* for normal Chinese people is in the range of 18.5 to 23.3 [27]. If the BMI is less than 18.5, it means they are underweight, if the *BMI* is higher than 23, it indicates that they are overweight.

BMI calculation:

$$BMI = \frac{BW}{H^2} \quad (2)$$

2.3.4. Operative Temperature and Mean Radiant Temperature

Indoor thermal conditions can be represented by the operative temperature (T_{op}), which is calculated using Equation (3):

$$T_{op} = \frac{h_r t_{mr} + h_c t_a}{h_r + h_c} \quad (3)$$

In the analysis, h_c is calculated according to the *ASHRAE Handbook* [28]. A constant value of 4.7 W/(m^2·°C) was assumed for h_r [28].

The mean radiant temperature (t_{mr}) was calculated according to Equation (4) from EN ISO 7726 [29], as follows:

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

When v_a was less than 0.2 m/s or the difference between t_{mr} and ta was less than 4 °C, Top could be calculated via Equation (5) [28].

$$T_{op} = \frac{t_{mr} + t_a}{2} \quad (5)$$

2.4. Participants

A total of 742 questionnaires were collected during the whole survey, of which 740 were valid. There were 308 valid questionnaires in winter, 219 in the transition season, and 203 in summer.

The age distribution of participants of each season is shown in Figure 3. Most of the participants were young people aged from 20 to 30, which occupied approximately 74 to 80% of the participants. The participants' age distribution was almost the same in each season.

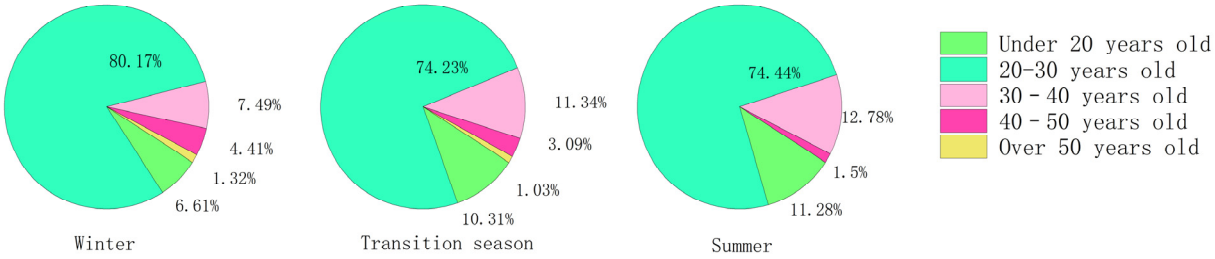


Figure 3. Distribution of Age.

There were no significant difference about the characters of participants among the three seasons. According to statistics, the ratio of male and female participants in the survey was close to 1:0.86. Approximately, 81% of the participants kept exercising in the fitness center every week. Most participants were college students and office workers, which occupied 88% on average. About 73% of the respondents' *BMI* values were within the normal range, and 23% of participants were overweight.

3. Results

3.1. Environmental Parameters

The environmental parameters of temperature, RH, and CO_2 concentration are shown in Figure 4. In most conditions, the indoor air velocity was less than 0.1 m/s, which is not shown in the figure. The spatial distribution of indoor air temperature and RH was quite uniform, and the mean values of the 10 measuring points in each investigation are shown in Figure 4a,b. The CO_2 distribution was not quite uniform in the fitness center; the measured data at 10 points of each season are shown Figure 4c.

Figure 4a shows the indoor and outdoor air temperature during the investigation. As the investigation proceeded, both the indoor and outdoor temperature increased during seasonal change. The indoor temperature of the fitness center was maintained in the range of 15 to 20 °C in winter, 20 to 27 °C in the transition season, and 25 to 28 °C in summer. The difference between indoor and outdoor temperature was the largest in winter, and the average difference was 5.5 °C. The temperature difference during spring and summer was much smaller.

Figure 4b shows the changes of indoor and outdoor RH. The outdoor RH was generally higher than the indoor RH, but the difference was not significant. In summer, the indoor RH was higher with an average value of 65%. In winter, the indoor RH was lower, and remained in the range of 30% to 45%. In spring (transition season), the indoor RH was in the range of 50% to 65%. In general, the indoor RH was in the range of 30% to 70%, which was in the recommended zone for indoor RH [30].

Figure 4c shows the CO_2 concentration at each measuring point. It can be seen that the concentration of CO_2 was the highest in winter, followed by the transition season, and then summer. In summer, the fitness center introduced fresh air via mechanical ventilation, which guaranteed that the air freshness and the CO_2 concentration was the lowest. In the transition season, the fresh air was introduced via natural ventilation, and the ventilation effect was not as good as that in summer, and the average carbon dioxide concentration became higher. In winter, the floor heating system was running without

mechanical ventilation, and the opening of windows was quite limited due to cold air intrusion. This led to higher CO_2 concentration in winter. The CO_2 concentration at the ten measuring points was similar in summer, but quite different during winter and spring. The CO_2 concentration was in the range of 600 to 800 ppm in summer, 1000 to 1700 ppm during spring, and 1100 to 2200 ppm in winter. The concentration of CO_2 at measuring point 7 was usually higher than the other points during winter and spring. The average CO_2 concentration at this point reached 2126 ppm in winter and 1710 ppm in spring. This measuring point was located in the treadmill area, which usually had more people exercising there. The CO_2 concentration at measuring points 1 and 10 was usually much smaller. These two points were in the aerobic and spinning rooms, and normally there were less people exercising there.

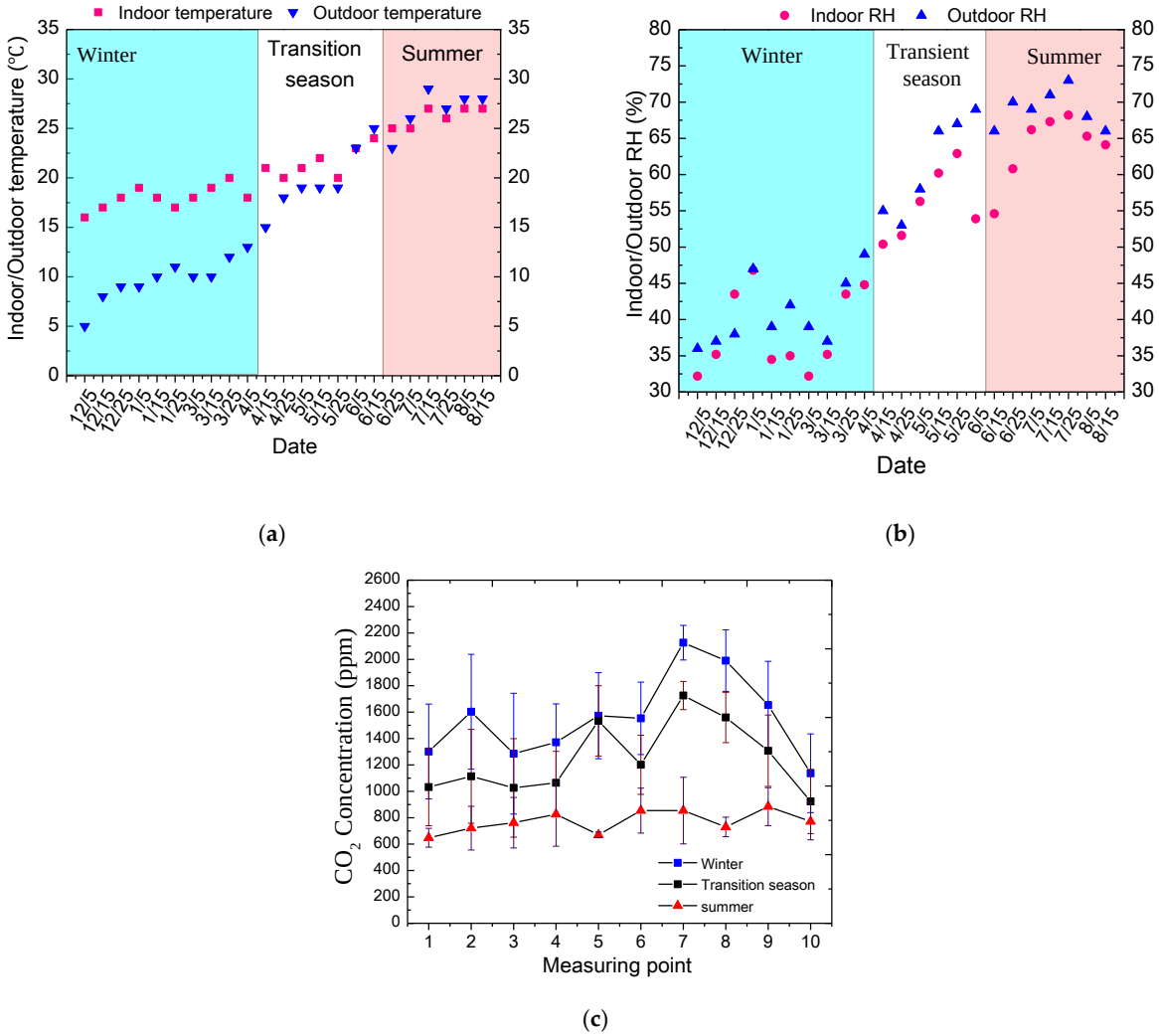


Figure 4. Environmental parameters. (**a**) Indoor and outdoor air temperature, (**b**) indoor and outdoor RH, (**c**) the CO_2 concentration.

3.2. Individual Parameters Affecting Thermal Comfort

3.2.1. Clothing Insulation

Based on the questionnaires, most people were wearing thin sports tops, pants, and sports shoes during exercising. There were three typical clothing styles:

Style 1: underwear, sports T-shirt, sports shorts, short socks, and sports shoes, with an approximate clothing insulation value of 0.4 clo.

Style 2: underwear, sports T-shirt, sports pants, short socks, and sports shoes, with an estimated clothing insulation value of 0.5 clo.

Style 3: underwear, long-sleeved sports shirt, sports pants, short socks, and sports shoes, with a clothing insulation value of about 0.6 clo.

The statistics of clothing are shown in Figure 5. The three types of clothing were worn by participants in all seasons, but the proportion of people dressed in the three styles varied in different seasons. There were more people dressed in Style 3 in winter, and more in Style 1 in summer. The proportion of people in Style 2 did not change much, which was in the range of 32% to 42% in each season.

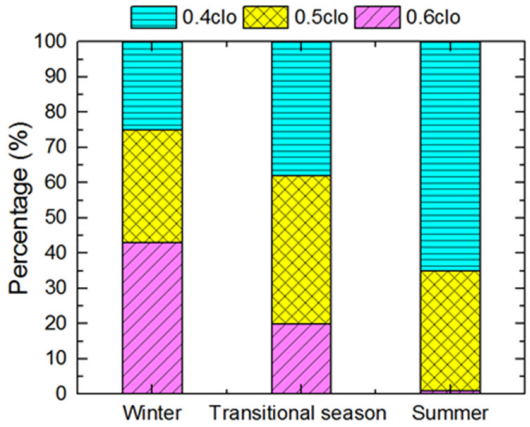


Figure 5. Statistics of clothing insulation in each season.

3.2.2. MR

The MR was estimated based on the measured HR of each subject. As individual MR varied greatly, the participants were divided into three groups based on their MR, which were the low MR group with an MR of less than 3 met, the medium MR group with an MR in the range of 3 to 5 met, and the high MR group with an MR higher than 5 met. The proportion of each group is shown in Figure 6. In each season, the proportion of the medium MR group was the largest, which increased from 51% in winter to 65% in summer. The proportion of the low MR group tended to decrease from winter to summer. The proportion of the high MR group was only 10% in winter, and it increased to approximately 20% in the other seasons.

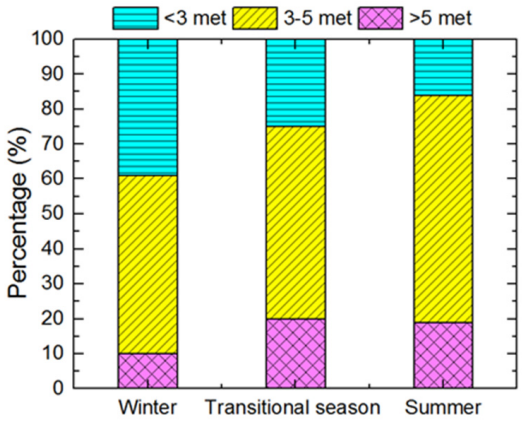


Figure 6. Percentage of people with different metabolic rate by season.

3.3. Questionnaires

3.3.1. Thermal Sensation and Thermal Preference

Figure 7 shows the variation of mean TSV during investigation. The mean TSV was in the range of −0.5 to 1 in winter, 0 to 1.5 in the transition season, and 0.5 to 2 in summer. In general, the mean TSV increased as operative temperature increased.

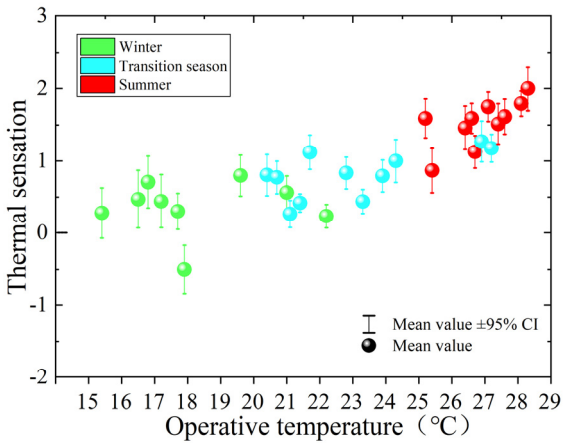


Figure 7. Thermal sensation vote (the explanation of black symbol applies for all colors in the figure).

Figure 8 shows the results of thermal preference. The thermal preference decreased as operative temperature increased, indicating that people were expecting a cooler environment. The mean thermal preference vote was in the range of −0.5 to 0.5 during winter, −1 to 0.2 during the transition season, and 0 to 2 in summer.

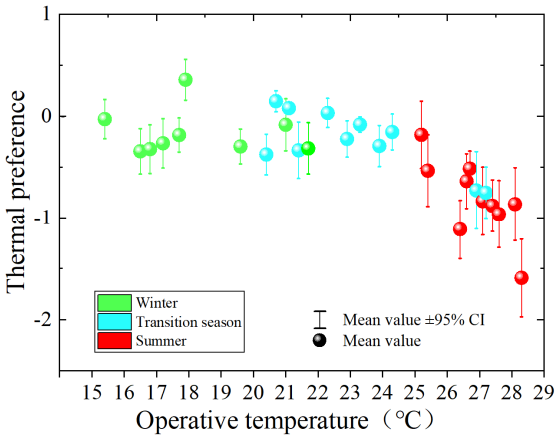


Figure 8. Thermal preference.

It can be noticed that both the mean TSV and mean thermal preference votes changed more quickly as operative temperature increased in summer. In winter and the transition seasons, people could reduce their clothes if they felt warm or hot during exercise, while in summer most people's clothing insulation was 0.4 clo, which was the minimum value for proper clothing in public. Additionally, the mean TSV and mean thermal preference fluctuated with the increase in operative temperature. The main reason was that the distribution of clothing and MR were not exactly the same in each survey.

The correlation of thermal sensation and thermal preference was analyzed further considering the influencing factors of MR and season. The results are shown in Figure 9.

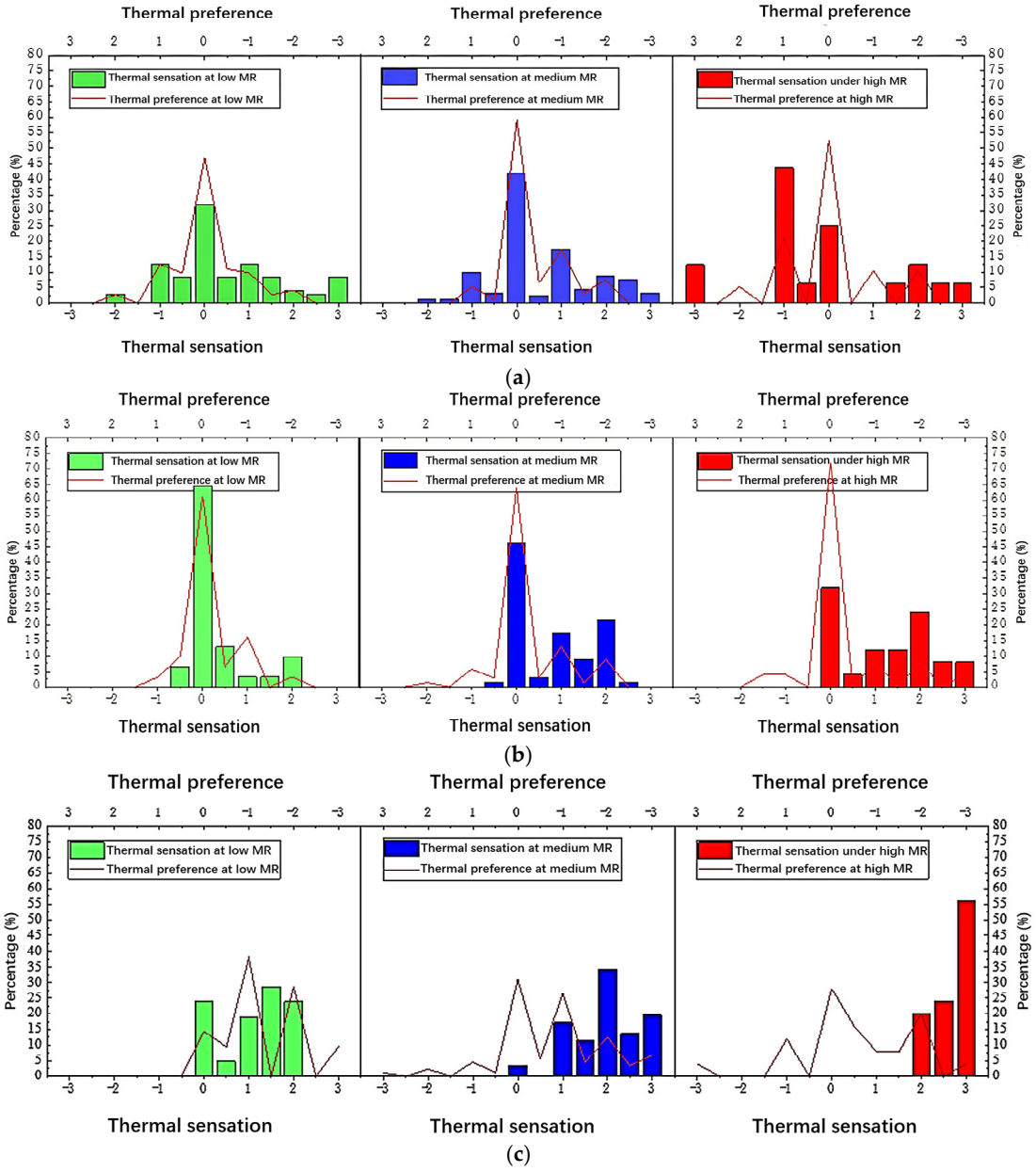


Figure 9. Statistics of thermal sensation and thermal preference, (**a**) winter, (**b**) transition season, and (**c**) summer.

For the low MR group, the distribution of the TSV and thermal preference vote were basically synchronous in the three seasons, i.e., when people felt neutral, most of them expected no change in the thermal environment, and if they felt warm or cool, they would expect a cooler or warmer environment.

For the group with the medium MR, the distribution of the TSV and thermal preference vote was similar to those of the low MR group in winter and transition seasons. In summer, most people's TSV was in the range of 1 to 3 (96.6%). However, more people (40.1%) expected no change or wanted more warmth, which indicated that there was some separation between the two votes.

This separation became more obvious for the high MR group. During winter, approximately 25% people voted 0 for TSV, while more than 50% wanted no change; approximately 44% voted for −1, while only 20% wanted more warmth. In the transition season, more than half of participants' votes were on the warm or hot side, while 72% expected no

change. For the summer condition, 56% of people voted for 3, while the proportion of those expecting it to be colder was less than 5%.

This separation may be caused by the aim of the workout. People performing high MR activities in fitness centers may have a higher expectation to keep fit, and they may prefer to sweat a lot during exercise. Therefore, most of them would not expect a colder environment when they feel hot. Zhai et al. state that people expect more air flow rather than a lower temperature during exercise [6]. Air flow can improve sweat evaporation more quickly than by lowering the temperature. In winter, most people who feel cold do not expect the temperature to rise, perhaps because the cool environment is conducive to sweat evaporation. Based on the above analysis, we speculate that the thermal preference under a high MR may be related to the promotion of sweat evaporation.

It can also be noticed that during winter and transition seasons, participants' thermal sensation was not increased as MR increased. This was due to adjustment in clothes and variation of indoor temperatures during surveys.

3.3.2. Thermal Comfort and Overall Thermal Satisfaction

The results of thermal comfort are shown in Figure 10. The mean thermal comfort vote (TCV) was in the range of 0.3 to 1 in winter, 0.2 to 1.1 in the transition season, and 0.6 to 1.5 in summer. In general, the TCV tended to decrease and then increase as operative temperature increased. Participants felt more comfortable when operative temperature was in the range of 20.5 to 24.5 °C during the transition season. The TCV was the highest during summer, indicating that participants felt more uncomfortable in summer than in the other seasons. This was because that most of them felt warm or hot in summer.

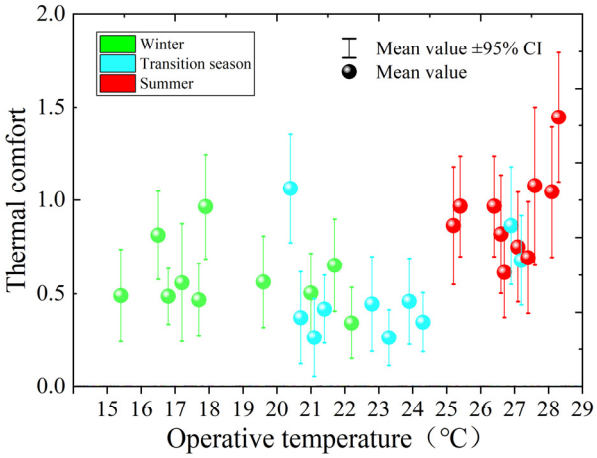


Figure 10. Thermal comfort vote.

The changes in the overall thermal environment satisfaction vote with operative temperature are shown in Figure 11. Most of the votes were in the range of 0.7 to 1.5, indicating that subjects thought the thermal environment was in the margin of satisfying. It was noticed that when operative temperature was around 27 °C, participants felt more satisfied in the transition season than in summer. In general, the difference of the satisfaction vote among seasons was quite small compared with previous subjective votes.

The statistics of the TCV and thermal satisfaction vote are shown in Figures 12 and 13 considering the impact of season and MR.

From Figure 12, in the same season, the TCV tended to increase as MR increased, indicating that people felt less comfortable. Under the same MR level, the TCV was the highest in summer, and the TCV difference between winter and the transition season was negligible.

According to Figure 13, the overall thermal environment satisfaction vote did not change much as MR increased in each season. The satisfaction vote in the transition season was a little lower than in the other seasons. However, the difference was not significant.

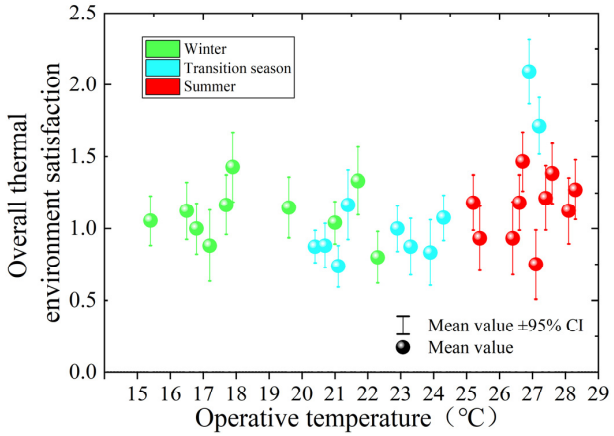


Figure 11. Overall thermal environment satisfaction.

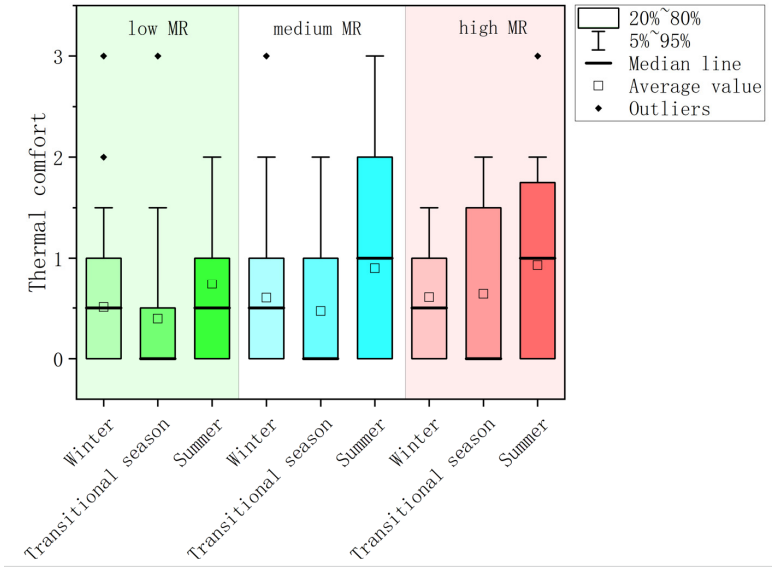


Figure 12. Statistics of the TCV (green part shows the data of low MR group, the red part shows the data of high MR group).

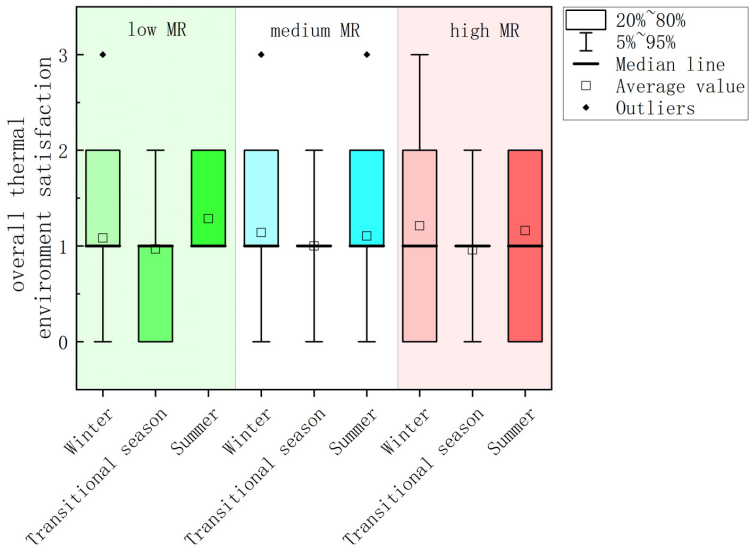
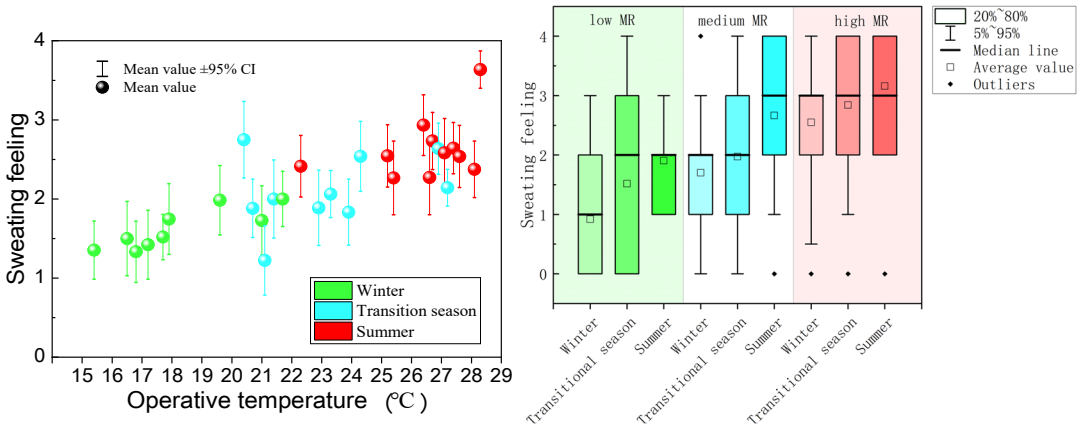


Figure 13. Statistics of thermal satisfaction.

3.3.3. Sweat Feeling

The results of sweat feeling are shown in Figure 14. From Figure 14a, the mean sweat feeling was higher than 1 in all conditions, indicating subjects sweated during exercising. The sweat feeling increased as operative temperature increased during seasonal change. It was in the range of 1 to 2.5 in winter, 1 to 3 in the transition season, and 2 to 3 in summer. Figure 14b shows the effect of MR and season on sweat feeling. As expected, participants' sweat feeling increased as MR increased. For the same MR condition, subjects' sweat feeling became higher when the season changed from winter to summer.

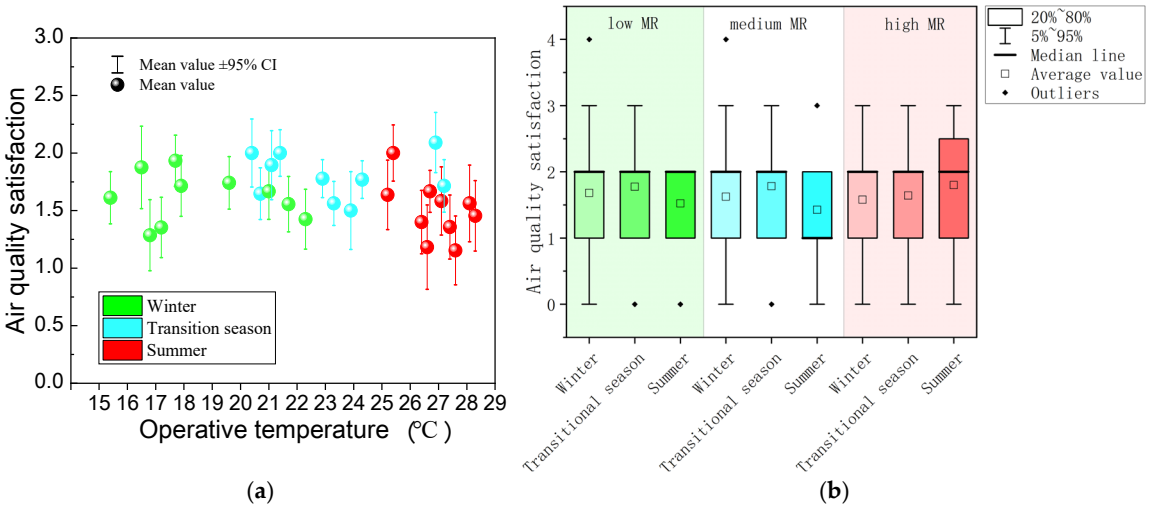


(**a**) (**b**)

Figure 14. Sweat feeling, (**a**) changes with operative temperature, (**b**) effect of MR and season.

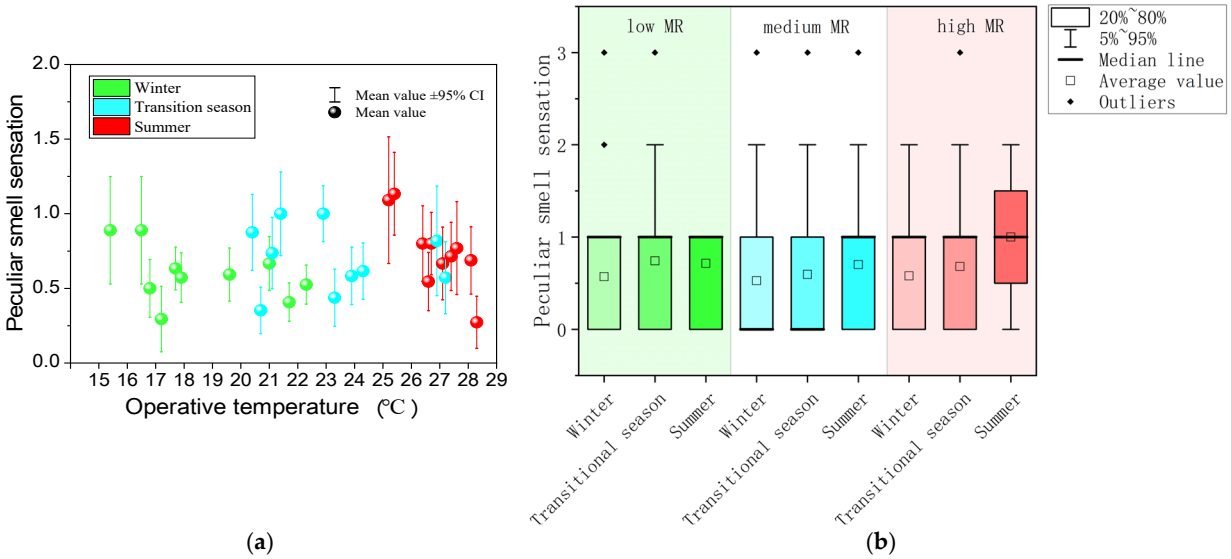
3.3.4. Air Quality Satisfaction and Smell Sensation

Participants' responses to indoor air quality are shown in Figures 15 and 16. Figure 15 displays the change in air quality satisfaction. In general, the air quality satisfaction did not change much as operative temperature increased. For the three seasons, most of the time the air quality satisfaction vote was in the range of 1 to 2, indicating participants felt that they were satisfied or slightly unsatisfied by the air quality. The changes in the air quality satisfaction vote with MR and season were not significant.



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

Figure 15. Air quality satisfaction, (**a**) changes with operative temperature, (**b**) effect of MR and season.



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

Figure 16. Smell sensation, (**a**) changes with operative temperature, (**b**) effect of MR and season.

Figure 16 shows the results of smell sensation. The change in the smell sensation with operative temperature was not obvious. Most of the smell sensation votes were in the range of 0.2 to 1, meaning that participants felt nothing or a slight smell. As to the effect of season, the mean smell sensation vote tended to increase from winter to summer. However, the difference was quite small. In winter and the transition seasons, when MR increased, the vote did not change, while in summer it increased a little in summer.

4. Discussion

4.1. The Applicability of the PMV Model

It has been reported that the prediction of the PMV model is not accurate when MR increases. We calculated PMV based on measured indoor thermal environmental parameters and individual factors. The PMV was compared with participant's TSV in the three seasons respectively, as shown in Figure 17. Both PMV and TSV increased as MR increased. The increment of PMV with MR was quicker than that of TSV. The linear fit of TSV and PMV shows that there was a scissors gap between the two lines. The deviation of PMV tended to become larger as MR rose. It can be noticed that when the deviation did not exceed ±0.5, the MR was in the range of 2.5 to 4.5 met in winter, less than 3 met in the transition season, and less than 2.5 met in summer. This indicated that the MR range decreased when PMV can predict thermal sensation accurately as the temperature increased during seasonal change. A study by Fletcher et al. suggests that when PMV is used, MR should be lower than 2 met [10]. In this study, the MR range was related to seasons or indoor temperatures.

Linear equations between TSV and PMV in the three seasons are regressed:

$$\text{Winter: } TSV = 0.53 + 0.405\,PMV\ (R^2 = 0.676,\ p < 0.001) \quad (6)$$

$$\text{Transition season: } TSV = 0.52 + 0.418\,PMV\ (R^2 = 0.706,\ p < 0.001) \quad (7)$$

$$\text{Summer: } TSV = 0.31 + 0.459\,PMV\ (R^2 = 0.725,\ p < 0.001) \quad (8)$$

From the equations, the linear relations for winter and transition seasons were quite similar. The equation for summer was a little different, in which the gradient was higher than the others.

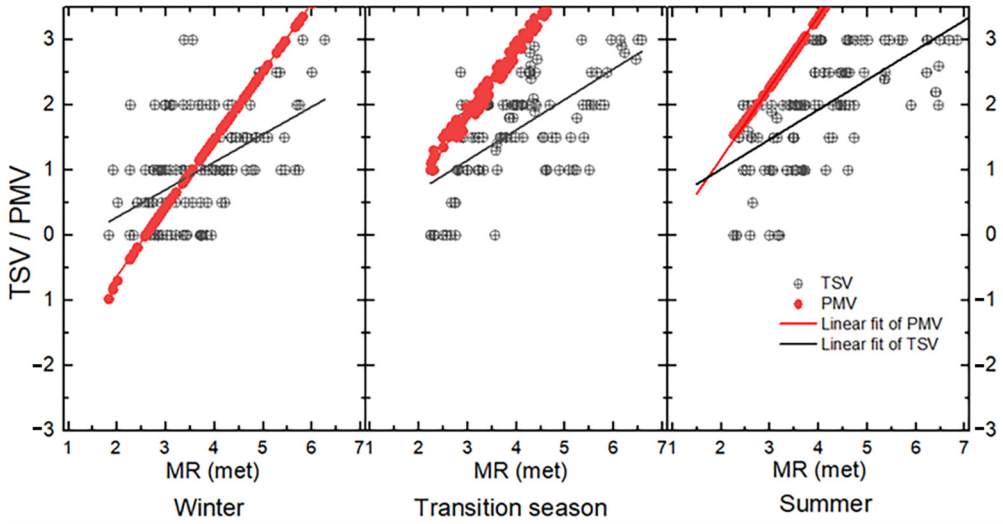


Figure 17. Comparison of TSV and PMV.

Inevitably, the above comparison has some limitations. The ceiling effect may affect the results as the maximum scale for TSV is 3, while the calculated PMV can be larger than 3. Based on the votes lower than 2, there was still the tendency for a scissors gap, and the gap may become smaller if the scales of TSV can be extended.

4.2. The CO_2 Concentration and Indoor Air Quality

In the investigation, CO_2 concentration was measured. The results show that the CO_2 concentrations in summer were lower than those in the transition season and winter. According to EN 15251 [31], the recommended indoor CO_2 concentration can be categorized into four levels, see Table 5. The maximum CO_2 concentration should be controlled under 800 ppm above outdoors. The outdoor CO_2 concentration was approximately 400 ppm during the investigation. The measured CO_2 concentration fell in the range of category I and II in summer. In the other two seasons, it fell in category III/IV, and in some cases became higher than the recommended level. During summer, a mechanical ventilation system is used and the CO_2 concentration is much lower. In spring time, natural ventilation is adopted, which could not ensure sufficient ventilation and lead to higher CO_2 concentration. During winter, centralized heating is used in the form of floor heating. Most of the concerns were focused on the indoor temperature in winter, and the fresh air combined with the air-conditioning system were not operated. During winter, the air change was accomplished by opening windows. As opening windows can introduce cold air and impact the indoor temperature, the windows sometimes were closed all the time. This leads to the poor ventilation in winter and causes the higher CO_2 concentration.

Table 5. Recommended CO_2 concentration above outdoor concentration [31].

Category	Corresponding CO_2 above Outdoors in ppm
I	350
II	500
III	800
IV	<800

The association of CO_2 concentrations with health and perceived air quality have been reported in many studies [32]. At the concentration range encountered in normal indoor environments (350–2500 ppm), CO_2 is not thought to be a direct cause of health effects [33]. The CO_2 concentration inside the fitness center was in the normal range and should not lead to health risks. However, the votes of indoor air quality showed that participants felt that the indoor air quality was in the zone between satisfying and unsatisfying, and

they felt that there was a slight peculiar smell. Additionally, since people are the dominant indoor source of CO_2, the increase in indoor CO_2 concentration is usually considered a good surrogate for the indoor concentrations of bioeffluents (e.g., body odors). Other indoor pollutants may be generated and vary in rough proportion to occupant-generated CO_2; for example, emissions from indoor equipment [33]. Therefore, it is suggested that mechanical ventilation should be used all year round to lower the CO_2 concentration in fitness centers. Furthermore, the distribution of CO_2 in the fitness center was quite different. To achieve uniform distribution, zone control would be better for the ventilation system.

The CO_2 concentration in the three seasons was quite different. We found it surprising that the results of the subjective response about indoor air quality and peculiar smell showed that there was no significant difference among seasons. We think there may be two possible reasons. Firstly, participants performing higher intensity activities release more CO_2 [34], and the CO_2 may stay around their breathing zone, which therefore makes them insensitive to the environmental CO_2 level. Secondly, the indoor temperature and humidity in summer were higher than those in winter and the transition season. According to studies, the subjective response to air quality at higher temperature and humidity will become worse [30,35]. Tian et al. found that the perceived air quality and air freshness correlated linearly with the enthalpy of air [36].

4.3. Effect of the Psychological Factor

In the introduction chapter, we assumed that the psychological factor may lead to a different thermal response to environment, e.g., during passive or active activities people may have different thermal sensations under similar conditions. In order to verify this assumption, participants' TSVs in this study were compared with those of workers in reference [21]. The investigation of workers was conducted in summer and the MR of workers was 2.2 met. The data of the lower MR group in summer were compared. The PMV index of the two studies were also calculated respectively. The results are shown in Figure 18.

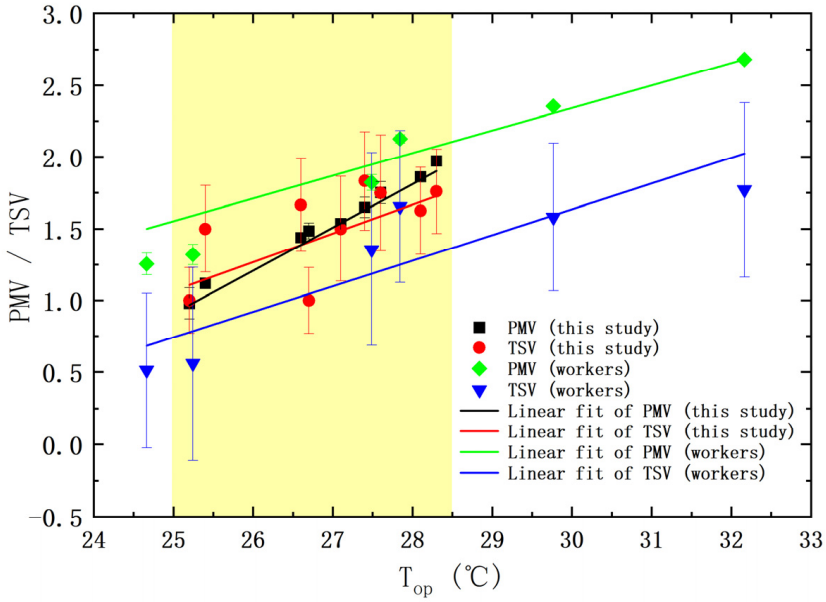


Figure 18. Comparison of TSV (the yellow part covers the temperature range of the gym in summer).

The operative temperature range in the investigation for workers was much wider than that of this study. The comparison was therefore performed mainly within the same operative temperature interval, i.e., 25–28.5 °C. For workers, PMV was higher than TSV in all temperature conditions. The change in the two indexes with operative temperature were almost parallel, and the average difference was approximately 0.7 scales. For people

exercising in the fitness center, the difference between PMV and TSV was much smaller and the scissors gap appeared between the two indicators. The TSVs of the subjects in this study were a little higher than those of workers, and the mean difference was approximately 0.34 scales. This indicates that people in the fitness center felt warmer than workers in the factory under similar temperature conditions. However, these results cannot support the assumption about the effect of the psychological factor. The factory uses natural ventilation in summer, while the fitness center has an air conditioning system. Additionally, the clothing insulation of workers was in the range of 0.6 to 0.7 clo, while for people in the center it was in the range of 0.4 to 0.5 clo. Furthermore, the MR in the two investigations was not exactly the same.

According to the above analysis, the assumption of psychological effect cannot be supported by the current data. Nevertheless, it can be expected that the TSV of fitness center users will further increase if their clothing insulation increases to the same level as workers, and the TSV difference between the two groups will increase. For workers, they stay in a naturally ventilated workshop and their thermal adaptation to environment leads to lower TSV under a similar thermal environment.

4.4. Others

In this study, the MR was estimated based on measured HR. It has been reported that the temperature of the environment has some influence on HR [37,38]. The HR usually becomes higher as temperature increases. This factor has not been considered in the estimation of MR. This may explain the changes in MR in different seasons, e.g., there were less people who were in the high MR group in winter. When participants were undertaking the same activity, their HR may become lower in a lower temperature environment, and the estimated MR becomes smaller. Although this negligence had little impact on the overall result, it would be better to measure the MR via more precise methods in future studies.

When people feel thermally neutral, most of them will expect no change in the thermal environment, and if they feel warm or cool, they usually expect a cooler or warmer environment. The analysis of the TSV and thermal preference vote for the medium and higher MR groups showed that there was some separation between the two indexes. The separation became more pronounced for the high MR group. For these two groups, when they felt cool (in winter), warm, or hot, most of them would prefer no change. The sweat feeling of the high MR group was much higher than the other groups. We think this may be related to the aim of the fitness activity, and the thermal environment should be conducive to the evaporation of sweat. It was also possible that the medium and high MR group had a higher tolerance for the thermal environment. These points need to be studied further.

The results of the TCV showed that the high MR group felt less comfortable compared to the low and medium group in the same environmental conditions. The sweat feeling of the high MR group was higher than the other groups, indicating that the high MR group may have a higher sweating rate and skin wetness, which are related to thermal comfort.

The analysis of the overall thermal environment satisfaction vote showed that people felt more satisfied during the transition season. During the investigation, the indoor temperature was in the range of 20 to 25 °C for most of the time, and the RH was in the range of 50 to 65%. Such a thermal environment may be more suitable for people who work out in fitness centers. This temperature range is similar to that reported by Shaharon et al. [20]. However, this point needs further verification.

It should be noticed that the investigators visited the fitness center during the later afternoon and evening to collect more questionnaires. The measured outdoor and indoor environmental parameters were for this time span, and cannot fully represent the environmental conditions during other time periods.

This investigation was conducted in Qingdao, a city located in the cold climate. The indoor thermal environmental of gym are controlled by air-conditioning and a heating system during summer and winter. The results can be extrapolated to gyms located in regions with a cold climate, or those with air-conditioning or/and heating systems.

Considering the effect of local climate on thermal requirements and thermal adaptation, the results may not be applied to people living in different climatic conditions. Further study can be conducted in gyms located in different climates to explore the effect of climate on people's thermal requirements during exercise.

5. Conclusions

In this study, a field investigation of the thermal environment and thermal comfort in a fitness center was conducted during winter, spring, and summer. The thermal environment parameters were measured and thermal response from people in the center were collected. The main findings are listed in the following.

- The indoor temperature of the fitness center was maintained in the range of 15 to 20 °C in winter, 20 to 27 °C in the transition season, and 25 to 28 °C in summer. The overall thermal environment satisfaction vote for different MR groups showed that most participants were satisfied with the thermal environment in the three seasons.
- The comparison of TSV and PMV showed that the prediction of PMV for the exercising people was not accurate. There was a scissors gap between the two indexes with the change in MR in the three seasons. If the deviation of PMV was kept within ± 0.5, the MR should be in the range of 2.5 to 4.5 met in winter, less than 3 met in the transition season, and less than 2.5 met in summer.
- A separation between the TSV and thermal preference vote was found for the medium and high MR groups. For these people, they may not prefer to cooler environment when they feel warm or hot.
- The indoor CO_2 concentration was quite different in the three seasons, and the distribution in the fitness center was not uniform. The CO_2 concentration in winter was the highest, and the lowest was in summer. The ventilation methods had a great impact on the CO_2 concentration. However, the subjective response to indoor air quality and smell showed that there was no significant difference among seasons. Most participants just felt a little unsatisfied about the indoor air quality and that there was a little peculiar smell in all seasons.
- Comparison showed that the TSV of workers and exercising people was different in the similar indoor temperature condition and MR level. However, due to the difference in thermal adaptation, clothing, etc., the results cannot support the assumption that the psychological factor may affect thermal sensation.
- In general, the inside environment of the fitness center in each season can basically meet the thermal comfort needs of exercising people. From the perspective of improving the air freshness, ventilation in the transition season and winter needs to be further enhanced.

Author Contributions: Conceptualization, H.W. and Y.H.; methodology, H.L.; formal analysis, R.H.; writing—review and editing, K.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 52378100.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. The experiments were approved by the University Ethics Committee (IRB number: QDU-HEC-2023081, 25 March 2023).

Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wei, X.; Chen, Y.; An, J.; Xu, X.; Yu, S.; Xu, C.; Yu, H.; Li, A. China Fitness Industry Data Report (2020). Available online: https://www.fxbaogao.com/pdf?id=2710497&query=%7B%22keywords%22:%222020%E4%B8%AD%E5%9B%BD%E5%81%A5%E8%BA%AB%E8%A1%8C%E4%B8%9A%E6%95%B0%E6%8D%AE%E6%8A%A5%E5%91%8A%22%7D&index=0&pid=.2020-5-1 (accessed on 6 June 2021).
2. Yang, L.; Gao, S.; Zhao, S.; Zhang, H.; Arens, E.; Zhai, Y. Thermal comfort and physiological responses with standing and treadmill workstations in summer. *Build. Environ.* **2020**, *185*, 107238. [CrossRef]
3. Wang, H.; Hu, S. Experimental study on thermal sensation of people in moderate activities. *Build. Environ.* **2016**, *100*, 127–134. [CrossRef]
4. Wang, H.; Hu, S. Analysis on body heat losses and its effect on thermal sensation of people under moderate activities. *Build. Environ.* **2018**, *142*, 180–187. [CrossRef]
5. Tsuzuki, K.; Iwata, T. Thermal comfort and thermoregulation for elderly people taking light exercise. *Indoor Air* **2002**, *2*, 647–652.
6. Zhai, Y.; Zhao, S.; Gao, Y.; Song, W.; Yang, L.; Zhang, H.; Arens, E. Preferred temperatures with and without air movement during moderate exercise. *Energy Build.* **2020**, *207*, 109565. [CrossRef]
7. Ji, T.; Yuan, W.; Li, D.; Yang, J.; Ji, L. Simulation and Experimental Study on the Influence of Environmental Parameters on Human Thermal Comfort in Sports. *China Sport Sci.* **2015**, *35*, 67–72. [CrossRef]
8. Zhang, Y.; Zhou, X.; Zheng, Z.; Oladokun, M.O.; Fang, Z. Experimental investigation into the effects of different metabolic rates of body movement on thermal comfort. *Build. Environ.* **2020**, *168*, 106489. [CrossRef]
9. Huang, X.; Zhang, Q.; Wang, Z.; Ma, X. Thermal sensation under high-intensive exercise in naturally ventilated gymnasiums in hot-humid areas of China: Taking basketball players for example. *Indoor Built Environ.* **2020**, *31*, 139–154. [CrossRef]
10. Fletcher, M.J.; Glew, D.; Hardy, A.; Gorse, C. A modified approach to metabolic rate determination for thermal comfort prediction during high metabolic rate activities. *Build. Environ.* **2020**, *185*, 107302. [CrossRef]
11. Revel, G.; Arnesano, M. Perception of the thermal environment in sports facilities through subjective approach. *Build. Environ.* **2014**, *77*, 12–19. [CrossRef]
12. Ji, T.; Yuan, W.; Yang, J.; Ji, L.; Su, Y.; Riffat, S. Improved Model and Experimental Study on Human Thermal Comfort of Sports in Gymnasium. *Build. Energy Environ.* **2017**, *36*, 11–15. [CrossRef]
13. Fantozzi, F.; Lamberti, G. Determination of thermal comfort in indoor sport facilities located in moderate environments: An overview. *Atmosphere* **2019**, *10*, 769. [CrossRef]
14. Bao, Y.; Feng, X. Overview of the IAQ indicators influencing on the Fitness effect. *Fujian Sports Sci. Technol.* **2015**, *34*, 4–6. [CrossRef]
15. Lu, D.; Shen, Y. Research and analysis of body-building environment of gymnasium. *J. Sports Sci.* **2012**, *33*, 9–17. [CrossRef]
16. Wang, L.; Lv, J.; Sun, H. Study on Thermal Comfort of Air Conditioning Terminal of Gym in Winter. *Build. Energy Environ.* **2019**, *38*, 65–68.
17. Di Gilio, A.; Palmisani, J.; Pulimeno, M.; Cerino, F.; Cacace, M.; Miani, A.; de Gennaro, G. CO_2 concentration monitoring inside educational buildings as a strategic tool to reduce the risk of Sars-CoV-2 airborne transmission. *Environ. Res.* **2021**, *202*, 111560. [CrossRef]
18. Pan, C.Y.; Hsu, H.C.; Huang, K.W. Real-Time Control of the Air Volume in Ventilation Facilities by Limiting CO_2 Concentration with Cluster Algorithms. *IEEE Trans. Ind. Electron.* **2023**, *70*, 12894–12903. [CrossRef]
19. Pinto, N.; Hatakeyama, K. Thermal Comfort Assessment: A study towards workers' satisfaction in metal industry. In Proceedings of the International Conference on Human Systems Engineering and Design: Future Trends and Applications, Reims, France, 25–27 October 2018; Springer: Cham, Switzerland, 2018; pp. 95–100.
20. Shaharon, M.; Jalaludin, J. Thermal comfort assessment-A study toward workers' satisfaction in a low energy office building. *Am. J. Appl. Sci.* **2012**, *9*, 1037–1045.
21. Wang, H.; Sun, L.; Guan, H.; Hu, S. Thermal environment investigation and analysis on thermal adaptation of workers in a rubber factory. *Energy Build.* **2018**, *158 Pt 2*, 1625–1631. [CrossRef]
22. Wang, H.; Liu, L. Experimental investigation about effect of emotion state on people's thermal comfort. *Energy Build.* **2020**, *211*, 109789. [CrossRef]
23. *ANSI/ASHRAE Standard 55*; Thermal Environmental Conditions for Human Occupancy. ASHRAE: Atlanta, GA, USA, 2017.
24. *The European Standard EN ISO 10551*; Ergonomics of the Thermal Environment—Assessment of the Influence of the Thermal Environment Using Subjective Judgment Scales. ISO: Geneva, Switzerland, 2019.
25. *The European Standard EN ISO 8996*; Ergonomics of the Thermal Environment—Determination of Metabolic Rate. ISO: Geneva, Switzerland, 2004.
26. Molini, V.; Nubé, M.; Boom, B. Adult BMI as a health and nutritional inequality measure: Applications at macro and micro Levels. *World Dev.* **2010**, *38*, 1012–1023. [CrossRef]
27. Zhou, B. Predictive values of body mass index and waist circumference to risk factors of related diseases in Chinese adult population. *Chin. J. Epidemiol.* **2002**, *23*, 5–10. [CrossRef]
28. ASHRAE. *ASHRAE Handbook-Fundamentals (I-P Edition)*; ASHRAE: Atlanta, GA, USA, 2017.
29. *EN ISO 7726*; Ergonomics of the Thermal Environment—Instruments for Measuring Physical Quantities. ISO: Geneva, Switzerland, 2001.

30. Lei, F.; Clausen, G.; Fanger, P.O. Impact of temperature and humidity on the perception of indoor air quality during immediate and longer whole-body exposures. *Indoor Air* **1998**, *8*, 276–284. [CrossRef]
31. *EN 15251*; Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Comite Europeen de Normalisation: Brussels, Belgium, 2007.
32. Ganesh, G.; Sinha, S.; Verma, T.; Dewangan, S.K. Investigation of indoor environment quality and factors affecting human comfort: A critical review. *Build. Environ.* **2021**, *204*, 108146. [CrossRef]
33. Seppänen, O.; Fisk, W.; Mendell, M. Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. *Indoor Air* **1999**, *9*, 226–252. [CrossRef]
34. Yang, L.; Wang, X.; Li, M.; Zhou, X.; Liu, S.; Zhang, H.; Arens, E.; Zhai, Y. Carbon dioxide generation rates of different age and gender under various activity levels. *Build. Environ.* **2020**, *186*, 107317. [CrossRef]
35. Toftum, J.; Jørgensen, A.; Fanger, P.O. Upper limits of air humidity for preventing warm respiratory discomfort. *Energy Build.* **1998**, *28*, 15–23. [CrossRef]
36. Tian, X.; Deng, Y.; Wargocki, P.; Liu, W. Effects of increased activity level on physiological and subjective responses at different high temperatures. *Build. Environ.* **2021**, *201*, 108011. [CrossRef]
37. Wells, G. The effect of external temperature changes on heart rate, blood pressure, physical efficiency, respiration, and body temperature. Research Quarterly. *Am. Phys. Educ. Assoc.* **1932**, *3*, 108–121.
38. Madaniyazi, L.; Zhou, Y.; Li, S.; Williams, G.; Jaakkola, J.J.; Liang, X.; Liu, Y.; Wu, S.; Guo, Y. Outdoor temperature, heart rate and blood pressure in Chinese adults: Effect modification by individual characteristics. *Sci. Rep.* **2016**, *6*, 21003. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.