sustainability

MDPI

Article

Investigation and Prediction of Outdoor Thermal Comfort under Different Protection and Activity Intensity Conditions in Summer in Wuhan

Xiaoyu Cai [1], Xiaofang Shan [1,2], Zeng Zhou [3], Xin Kang [1,2] and Qinli Deng [1,2,*]

[1] School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan 430070, China; caixiaoyu@whut.edu.cn (X.C.); xfshan@whut.edu.cn (X.S.); xkang@whut.edu.cn (X.K.)
[2] Hainan Institute, Wuhan University of Technology, No. 5 Chuangxin Road, Sanya 572024, China
[3] School of Urban Design, Wuhan University, 8 Donghu Nan Road, Wuhan 430072, China; haomaoz@whu.edu.cn
* Correspondence: deng4213@whut.edu.cn

Abstract: In the context of normalized epidemic prevention and control, the impact of masks and protective clothing on personal thermal comfort cannot be overlooked. To investigate the thermal comfort of outdoor personnel under various protective conditions, this study took Wuhan as an example and evaluated the outdoor thermal comfort of subjects under different protection and activity conditions through thermal environment monitoring, physiological measurements, and thermal comfort questionnaires. The results show significant differences in the PET thermal comfort baseline under various protective conditions. To address the problem that most areas have not yet established state-specific thermal comfort baselines, a State Outdoor Comfort Index (SOCI) model was developed to correct the insensitivity of PET indicators to clothing thermal resistance and metabolic rate. Finally, the performance of the SOCI model was evaluated through statistical indicators, demonstrating its good predictive capability. This study provides appropriate quantitative indicators to improve the thermal comfort of outdoor personnel.

Keywords: outdoor thermal comfort; PET; State Outdoor Comfort Index; activity intensity; protective intensity

Citation: Cai, X.; Shan, X.; Zhou, Z.; Kang, X.; Deng, Q. Investigation and Prediction of Outdoor Thermal Comfort under Different Protection and Activity Intensity Conditions in Summer in Wuhan. *Sustainability* **2024**, *16*, 3628. https://doi.org/10.3390/su16093628

Academic Editors: MªCarmen Guerrero Delgado and José Sánchez Ramos

Received: 5 March 2024
Revised: 16 April 2024
Accepted: 24 April 2024
Published: 26 April 2024

1. Introduction

With the predominance of the omicron variant, the prevention and control of neo-coronavirus pneumonia has become a regular requirement [1]. Although the peak of the pandemic has passed, we still need to remain vigilant and consider the transmission of other viruses such as influenza in order to better carry out virus prevention and control work in the future. Protective equipment such as masks and medical protective clothing can prevent viruses from adversely affecting human health. They have a good protective effect on people's lives and health during epidemics, and can effectively prevent the spread of viruses [2,3]. Research has shown that although masks and protective clothing can effectively reduce the efficiency of virus transmission, wearing them can affect physical performance and attention levels, and their material characteristics can also hinder human heat dissipation and moisture dissipation, which can have a certain impact on individuals' physiology and psychology, thereby affecting their thermal comfort [4,5]. Thermal comfort determines whether urban residents tend to spend more time in comfortable outdoor spaces due to the positive effects of a good outdoor thermal environment on the physical and mental health of active residents. Therefore, it is of comparative importance to explore the effects of different protection conditions on human thermal comfort in summer outdoor environments.

Since the end of the last century, thermal comfort research has received widespread attention from the academic community [6]. Indoor thermal comfort is typically achieved through fixed setpoints controlled by HVAC systems to create a stable and neutral thermal environment [7]. One widely accepted approach to expanding the comfort range is to transform static and uniform indoor thermal environments into dynamic and asymmetric environments, such as natural ventilation, personal comfort systems [8–12], and spatial heating for specific time periods [13]. However, various microclimate conditions in outdoor spaces lead to subjective responses to outdoor thermal environments that differ greatly from those in indoor spaces. Compared to indoor thermal comfort, outdoor thermal comfort experiments are relatively scarce due to the difficulty in controlling outdoor thermal parameters [14].

Current outdoor thermal comfort research primarily aims to determine the neutral temperature and the range of acceptable temperatures, as well as to improve the thermal environment of urban spaces. Regarding the thermal comfort of users in city squares in hot and humid subtropical climates, studies have shown that the thermal acceptance range of residents in this region falls between 21.3 °C and 28.5 °C PET, which is higher than the 18 °C to 23 °C PET range observed in European regions [15]. In a study conducted in Rome, Italy, the neutral PET values for hot and cold seasons were determined through regression analysis, and the thermal neutral range was established [16]. In a survey conducted in Mianyang, China, it was found that PET can be used to effectively assess the thermal comfort of people living in hot summers and cold winters [17]. In experiments conducted in Anatolia, a semi-arid region with cold summers, the researchers proposed the Turkish Outdoor Comfort Index (TOCI) tailored to the local climate [18]. In comparative experiments on indoor and outdoor thermal comfort, studies have shown that people generally exhibit lower sensitivity to changes in outdoor thermal environments compared to air-conditioned environments, and their thermal comfort range is typically wider [14].

Some scholars have explored the thermal comfort of individuals under protective conditions. In humid and hot environments, there are thermal stress risks associated with the design of medical protective clothing, which necessitates guidelines for safe work [19]. Even in non-hot environments, the impermeable design of protective clothing significantly increases the risk of heat stress [20,21]. In both low-temperature and high-temperature environments, different types of masks have varying effects on subjective thermal sensation [22]. In hot weather conditions, the behavior of wearing masks is less influenced by urban microenvironments and more affected by the time of day [23]. In indoor spaces during summer, different forms of personal protective equipment have varying effects on human thermal sensations, leading researchers to establish corresponding models for thermal comfort prediction [24].

Several studies have investigated the thermal comfort of people engaged in different physical activities. During outdoor activities, individuals in motion tend to feel comfortable when it is slightly warm [25]. The metabolic rate of the human body varies during different exercise periods, significantly affecting the thermal perception and thermal comfort of participants [26]. Airflow influences the thermal comfort of individuals during exercise, and participants have different temperature preferences at different metabolic rates [27]. During moderate activity in neutral to cool environments (22–26 °C), the thermal regulation of sweat affects thermal sensation, reducing neutral skin temperature [28]. Exercise induces significant changes in the thermal sensitivity of different parts of the body, with exercise intensity significantly affecting thermal comfort and physiological responses [29].

There is relatively limited research on the thermal comfort of individuals engaged in outdoor activities under different protective measures. This study aimed to assess the subjective heat perception and physiological responses of individuals in outdoor summer environments at different levels of protection and activity intensity. The contributions of this work are as follows:

The thermal sensation and thermal comfort outdoors under different levels of protection and activity intensity were assessed, clarifying thermal benchmarks (i.e., the neutral temperature and neutral temperature range) under different outdoor conditions.

The applicability of the physiological equivalent temperature (PET) index under different protection and activity intensity conditions was explored, establishing predictive models for thermal sensation and thermal comfort applicable to outdoor personnel, and providing quantitative indicators for improving the thermal comfort of outdoor workers.

2. Materials and Methods

2.1. Experimental Site and Environmental Parameters

Wuhan, as a representative city in a region characterized by hot summers and cold winters, holds significant research value, especially as the epicenter of the COVID-19 pandemic (Figure 1). An outdoor activity center in the community was chosen as the measurement location for this experiment. Outdoor activity centers play an important role in communities and typically include open spaces, recreational facilities, and activity areas, providing residents with a place to connect with nature and engage in social interactions. In the urban structure, outdoor activity centers play a crucial role for residents, improving the cohesion and vitality of urban communities. These centers serve as primary venues for diverse resident activities and community services. They are not merely places for urban residents' leisure and entertainment, but also serve as vital links enhancing interaction between urban communities. They are an indispensable component of urban development.

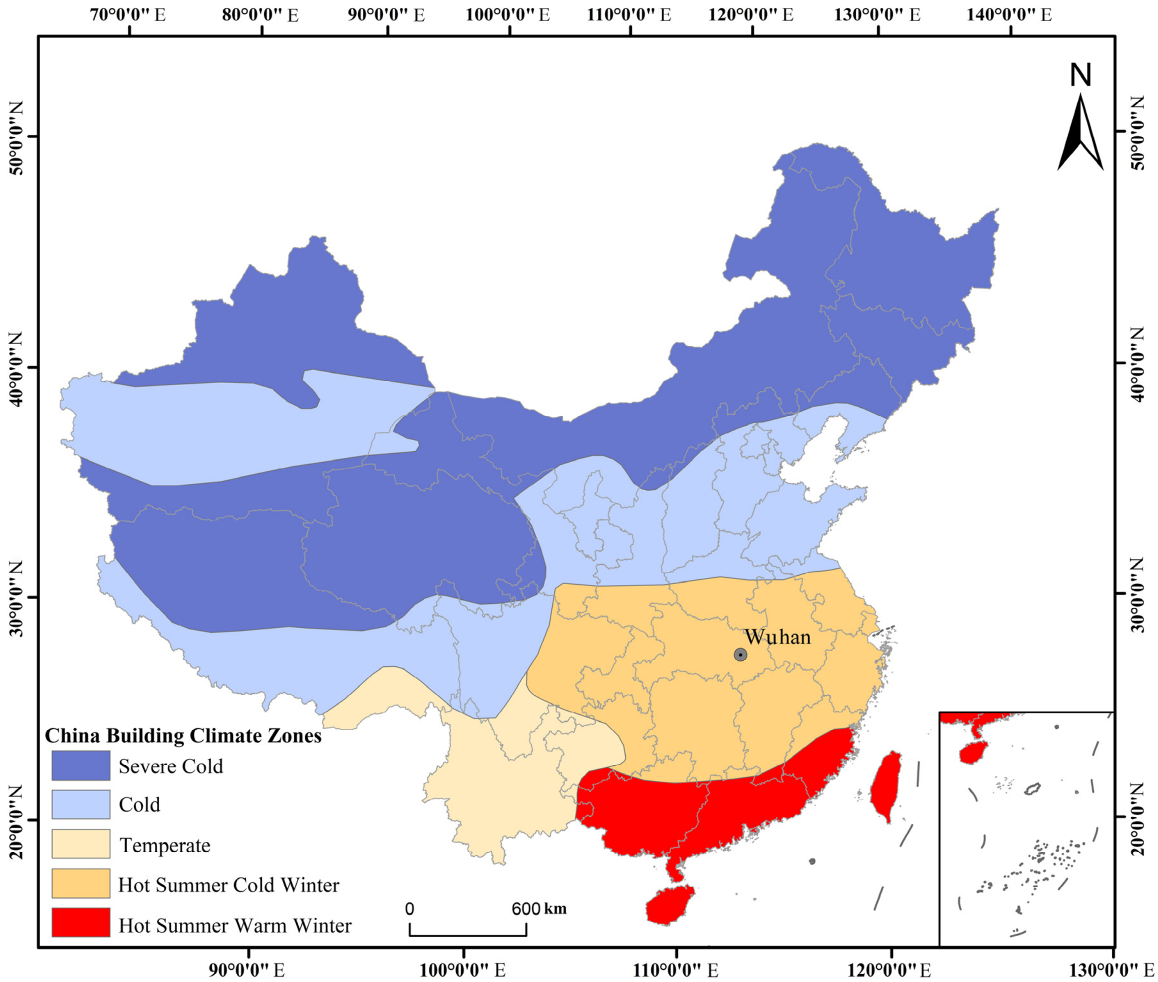

Figure 1. Geographical location of Wuhan on the climate map.

The data in Figure 2 illustrate the daily average temperature, maximum temperature, minimum temperature, and relative humidity in Wuhan for the year 2021. August is the hottest month of the year, while January is the coldest. The temperature ranges from −4.7 °C to 36.2 °C, with an average monthly temperature of 32.2 °C and a low of 0.9 °C.

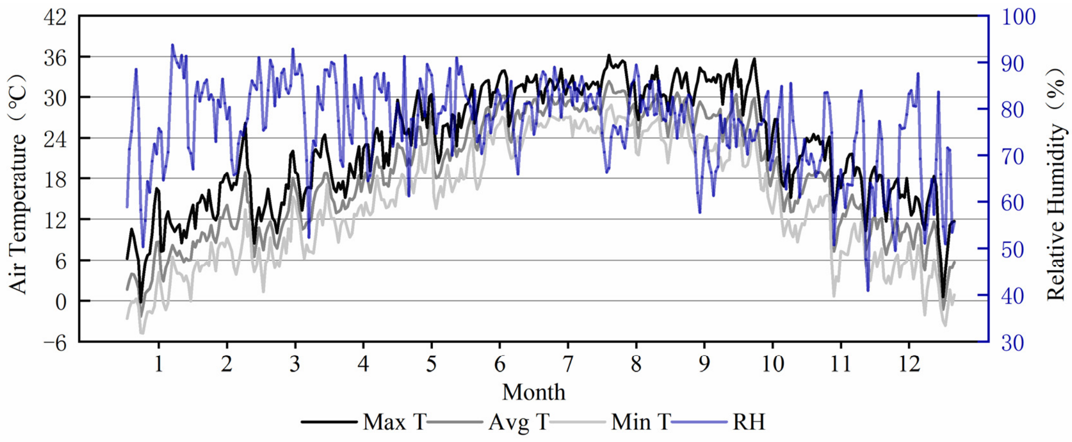

Figure 2. Annual meteorological parameters of Wuhan in 2021.

Prior to the experiment, continuous monitoring of the weather was conducted for one week, selecting the typical summer climate of Wuhan for the experiment. Although September is not the hottest time of the year in Wuhan, it is still considered representative of the summer climate due to the long duration of summer in Wuhan. The experiment was conducted on 17 September 2022, with the weather parameters at the test site on that day shown in Figure 3. The meteorological parameters at the outdoor activity center where the tests were conducted were similar to the outdoor meteorological parameters in Wuhan during the summer of 2021, making them highly representative of the meteorological conditions in Wuhan.

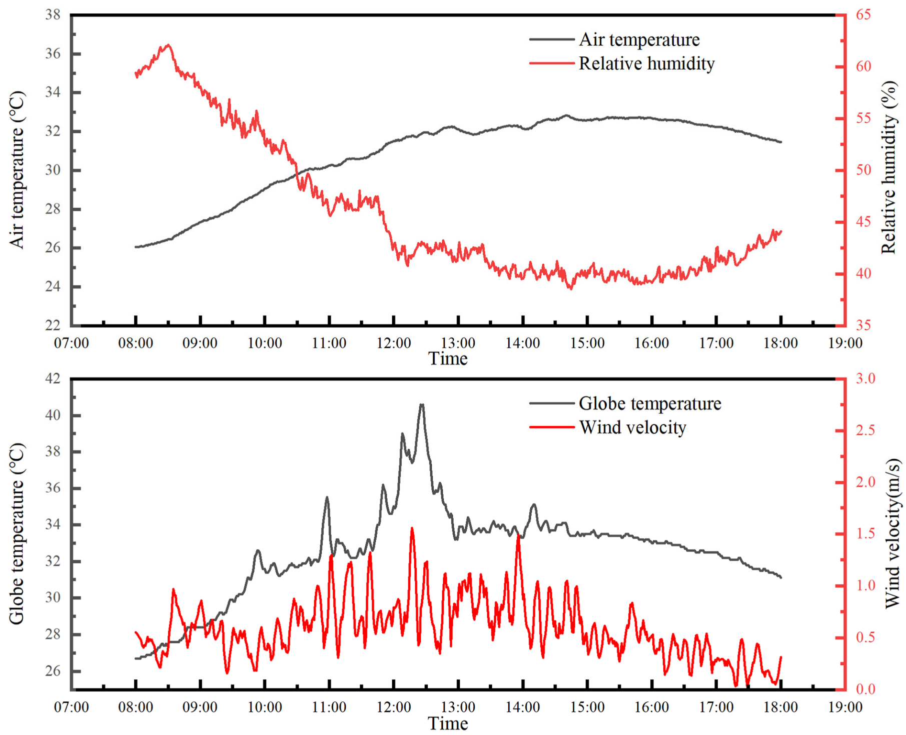

Figure 3. Diurnal fluctuations of meteorological parameters at the observation sites.

2.2. Measurements

2.2.1. Objective Measurements

The testing instruments were selected with reference to ASHRAE 55 [30] and ISO 7726 [31], and their ranges and accuracies were established in accordance with the relevant regulations. The measurement of human physiological parameters mainly includes the measurement of body temperature, human core temperature, heart rate, blood pressure and other parameters; according to [24], human thermal comfort is significantly correlated with body temperature, heart rate and other parameters. During our experiment, information about physiological parameters such as body temperature and heart rate was collected, according to which the thermal comfort of the subjects was investigated. A smartwatch (HONOR Magic Watch 2, Honor, Shenzhen, China) was used to measure the subjects' heart rate [32,33], and an iButton temperature logger (DS1922L, iButtonLink LLC, Whihewater, WI, USA) was used to measure their skin temperature [34]. The mean skin temperature (MST) was based on the temperatures of five parts of the human body, including the forehead, forehead, upper arms, lower back, and thighs, and was calculated using the formula proposed by Ruth Nielsen [35]:

$$T_{sk} = 0.15T_{forehead} + 0.19T_{chest} + 0.10T_{upper\ arm} + 0.19T_{low\ back} + 0.37T_{upper\ leg} \quad (1)$$

2.2.2. Questionnaire Surveys

A questionnaire was designed to collect the subject's name, age, gender, height, weight, and other information. Additionally, it collected information regarding thermal sensation and thermal comfort to reflect the volunteers' subjective evaluation of the thermal environment, as shown in Table 1.

Table 1. Questions in the questionnaire survey in this study.

Question 1	Grading your hot and cold sensations from left to right on a scale, based on how you feel at the moment, draw a horizontal line with a red pen on the corresponding scale.								
	Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot
	−4	−3	−2	−1	0	1	2	3	4
Question 2	Please tick the scale to indicate how you feel at the moment.								
	Comfortable	Slightly uncomfortable	Uncomfortable	Very uncomfortable	Unbearable				
	0	+1	+2	+3	+4				

2.3. Experiment Content and Procedure

2.3.1. Characteristics of the Volunteers

The experiment recruited 36 volunteers, as shown in Table 2. To minimize the effect of long-term thermal history on heat perception, the volunteers had all lived in the area for at least two years to ensure that they were acclimatized to this climate [36–38]. Due to the fact that young people are more sensitive to thermal environments compared to middle-aged and elderly individuals [39,40], the volunteers selected for this experiment were physically healthy college students with no cardiovascular diseases. They were all required to wear typical summer workwear. According to ASHRAE 55 [30] calculations, the volunteers' clothing insulation value was determined to be 0.31 clo.

Table 2. Basic information about the volunteers.

Gender	Count	Age	Height (cm)			Weight (kg)			BMI (kg/m^2)		
			Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Male	30	22–27	177.3	185	170	76.3	100	63	24.1	29.2	21.0
Female	6	22–27	164.3	166	163	50.6	53	47	18.5	19.9	17.1

2.3.2. Levels of Protection and Intensity of Activity

The protective levels included no protection, wearing masks, and wearing protective clothing. The masks used were three-layer disposable surgical masks, while the protective clothing was made of non-woven fabric as a one-piece medical isolation suit. Considering the high-temperature conditions and duration of the experiment during the summer season, we selected sitting and walking (at a speed of 0.89 m/s) as representative activities for outdoor residents based on the Compendium of Physical Activities [41]. The objective factors influencing different levels of protection and activity primarily manifest in variations in thermal resistance [4] and metabolic rate [21]. The combination of these factors resulted in six different states, as shown in Table 3 and Figure 4.

Table 3. Different states.

State	Protection Level	Activity Intensity	Clothing Insulation (Clo)	Metabolic Rate (Met)
1	Without protection	Sitting	0.31	1.3
2	Without protection	Walking	0.31	2.5
3	Wearing a mask	Sitting	0.40	1.3
4	Wearing a mask	Walking	0.40	2.5
5	Wearing medical protective clothing	Sitting	1.69	1.3
6	Wearing medical protective clothing	Walking	1.69	2.5

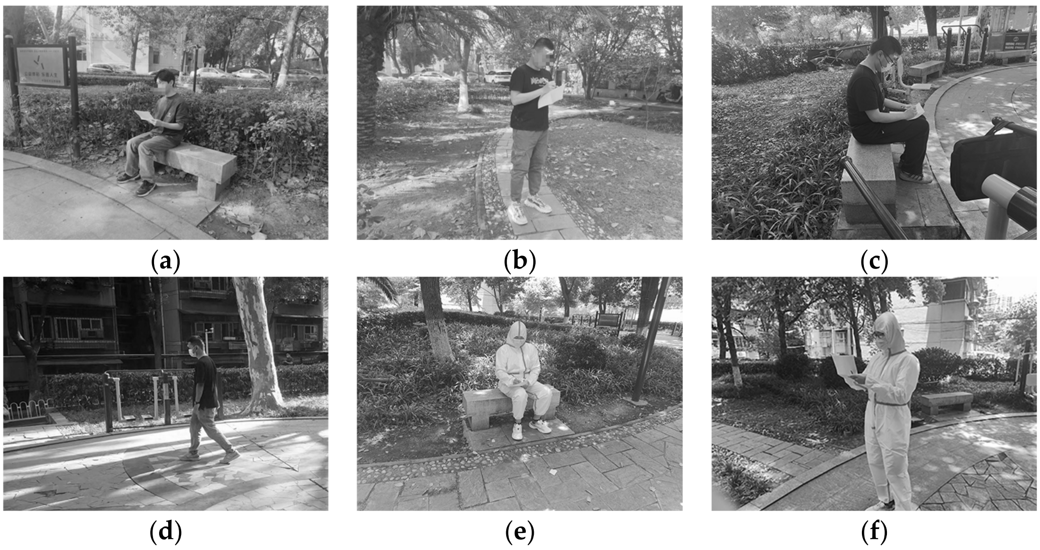

Figure 4. Subjects at different levels of protection and activity (state 1 (**a**), state 2 (**b**), state 3 (**c**), state 4 (**d**), state 5 (**e**), and state 6 (**f**)).

2.3.3. Experimental Procedure

The experiment recruited 36 healthy college students who were randomly divided into six groups, with each group undergoing measurement in one of the six states (Table 2). Considering the hot weather conditions outdoors and students' habit of taking afternoon breaks, the experiment was conducted from 8:00 AM to 12:00 PM and from 2:00 PM to 6:00 PM. To account for the adaptive adjustments of the human body to thermal environments, the experiment took place in shaded areas.

Fifteen minutes before the start of the experiment, the participants were instructed to put on the personal protective equipment and physiological monitoring devices at the experimental site. This allowed their bodies to acclimatize to the outdoor thermal environment and reach a stable state. The subjects were asked to complete a subjective questionnaire every 15 min, while the instrument recorded the air temperature, relative humidity, wind speed, black globe temperature, skin temperature at various points, and pulse rate every 1 min.

2.4. Selection of Evaluation Methods for Thermal Indicators and Predictive Models

To date, a total of 165 indices related to human thermal sensation have been developed [42], among which PET has been increasingly used in recent outdoor thermal comfort assessment studies to comparatively evaluate thermal comfort requirements in various environments [43]. In this study, the PET calculated via RayMan Pro 3.1 Beta Version was used to predict thermal comfort [44]. T_{mrt}, meteorological parameters (T_a, RH, V_a, and T_g), and subject attributes (height, weight, age, gender, clothing insulation, and metabolic rate) were entered into the Rayman software to calculate PET values for all subjects during the trial period.

The average radiant temperature (T_{mrt}) was calculated in accordance with ISO 7726 [31]:

$$T_{mrt} = \left[(T_g + 273)^4 + \frac{1.10 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}}(T_g - T_a)\right]^{\frac{1}{4}} - 273 \quad (2)$$

T_g, V_a, T_a, ε, and D refer to the globe temperature (°C), wind speed (m/s), air temperature (°C), emissivity (0.95), and diameter of the globe thermometer (0.05 m), respectively.

This study selected three statistical indicators to evaluate the applicability of the predictive models in outdoor spaces [45]. The three statistical indicators were as follows: (1) the gamma coefficient, used to describe the predictive ability of the corresponding thermal comfort model; (2) the correlation coefficient (Spearman), used to assess the sensitivity of residents to thermal comfort indicator values; and (3) the percentage of correct predictions, representing the percentage of agreement between the predicted thermal comfort indicator categories and the actual thermal sensation votes and indicating the actual predictive ability of the indicators.

3. Results and Discussion

A total of 1224 questionnaires were distributed in this experiment, and a total of 6 states of thermal comfort questions were investigated, with 204 questionnaires for each state. A total of 482 pulse rates were collected, as well as skin temperatures on the forehead, forearms, upper arms, lower back, and thighs, with 482 pieces of data for each site.

3.1. Statistical Analysis of Subjective Thermal Comfort

3.1.1. Thermal Sensation Voting

According to the results of thermal sensation voting (Figure 5), when comparing state 1 (no protection, sitting) and state 3 (wearing a mask, sitting), it can be observed that the effect of wearing a mask on thermal sensation is relatively small when sitting. The thermal resistance of the mask is only 0.09 clo, having a minor impact on the overall thermal resistance of clothing. However, when the activity state changes to walking, state 4 (wearing a mask, walking) has a slightly higher thermal sensation compared to state 2 (no protection, walking). Wearing a mask does have some impact on thermal sensation, but it is not significantly pronounced. In certain time periods, the thermal sensation of state 2 may exceed that of state 4, which could be attributed to the mask reducing the stimulation of hot air on the face, resulting in a relatively cooler sensation.

On the other hand, when wearing protective clothing, regardless of sitting or walking, there is a noticeable increase in thermal sensation. Protective clothing has a higher thermal resistance, which leads to a significant rise in thermal sensation. Especially when wearing protective clothing and engaging in physical activity such as walking, the increase in thermal sensation is more pronounced. This is because protective clothing limits the body's ability to dissipate heat. During aerobic exercise, the metabolic rate increases and the body generates more heat. However, due to the restrictions imposed by the protective clothing, the heat cannot be effectively dissipated, resulting in a significant increase in thermal sensation.

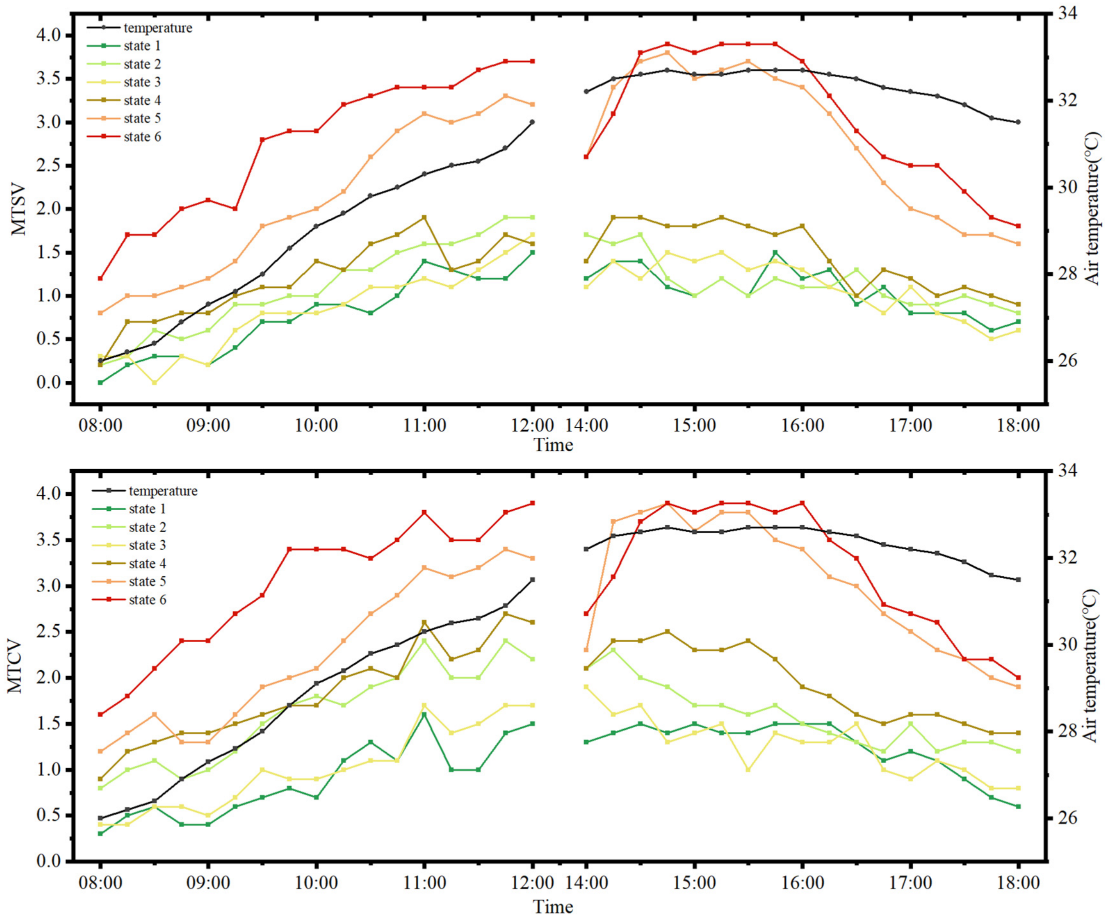

Figure 5. Thermal sensation and thermal comfort votes of personnel over time under different states.

3.1.2. Thermal Comfort Voting

According to the results of thermal comfort voting (Figure 5), when comparing state 1 (no protection, sitting) and state 3 (wearing a mask, sitting), the impact of wearing a mask on thermal comfort is relatively small when sitting. However, when walking, the effect of wearing a mask on thermal comfort becomes evident, and the thermal comfort of state 4 (wearing a mask, walking) is lower than that of state 2 (no protection, walking). This is because during walking, the body's metabolic rate increases, breathing intensifies, and respiratory heat dissipation is enhanced. Although the mask has a low thermal resistance, it hinders heat dissipation through respiration, leading to the exacerbation of discomfort. Unlike thermal sensation, we did not observe time periods when state 2 clearly exceeded state 4. This may be because the heat discomfort caused by the mask is more pronounced.

On the other hand, when wearing protective clothing, whether sitting or walking, thermal comfort significantly decreases. Protective clothing has a higher thermal resistance, which leads to a noticeable decrease in thermal comfort. Especially when wearing protective clothing and engaging in physical activity such as walking, the decrease in thermal comfort is more pronounced. The increase in clothing thermal resistance causes significant fluctuations in thermal comfort with meteorological parameters, resulting in an expanded range of voting outcomes.

3.2. Calculation and Analysis of PET Based on Various States

In order to explore the relationship between TSV (thermal sensation voting) and TCV (thermal comfort voting) and PET in different states, this study took PET as the independent variable and TSV and TCV values as dependent variables, respectively, and conducted linear regression analysis on the relationship between the voting results of the questionnaire and PET. Since the voting took place at the same time, the MTSV (average thermal sensation voting) and MTCV (average thermal comfort voting) are the mean value of all votes during that time period. As the summer temperatures were higher, the thermal neutrality data for certain states were remeasured during periods with lower temperatures.

3.2.1. Different Protection Conditions

Upon exploring the differences in thermal sensation between different protection states (Figure 6a and Table 4) by comparing states 1, 3, and 5 with states 2, 4, and 6, it is observed that as the thermal resistance of the clothing increases, the values of the thermal neutral temperature (NPET) also decrease. Additionally, the range of the thermal neutral temperature (NPETR) also decreases, suggesting that as the level of protection increases and the thermal resistance increases, the NPETR becomes smaller.

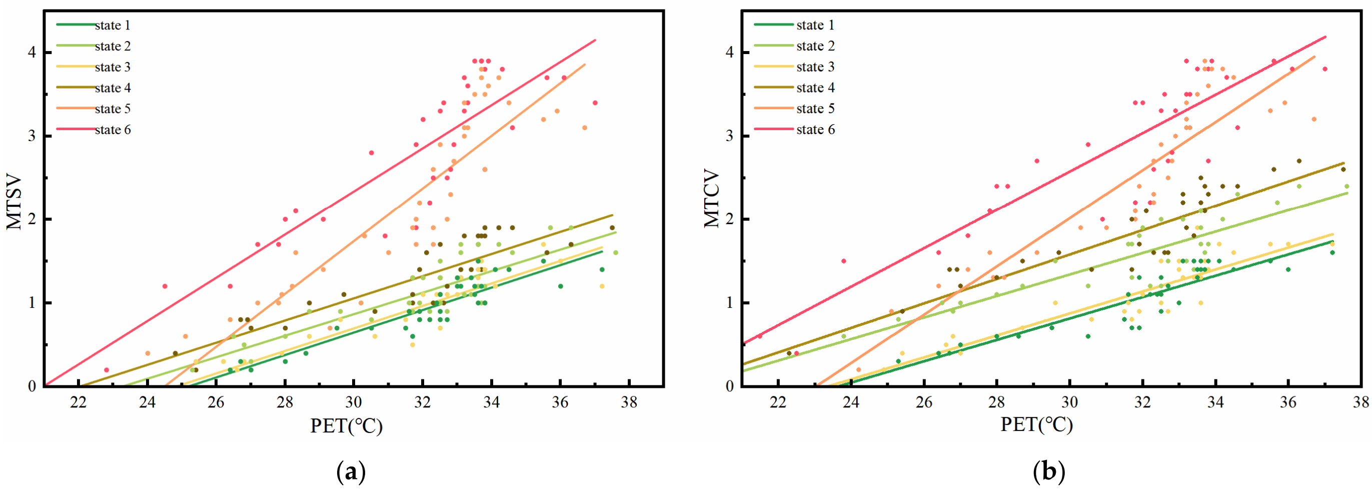

Figure 6. Correlation between PET and (**a**) MTSV/(**b**) MTCV under different states.

Table 4. Neutral temperature and comfort range under different states.

State	Regression Equation	NPET (TSV = 0)	NPETR (−0.5 < TSV < +0.5)
1	y = 0.1341x − 3.3758 (R^2 = 0.8493)	25.2 °C	28.9–21.4 °C (7.5)
2	y = 0.1285x − 2.9884 (R^2 = 0.7059)	23.3 °C	27.1–19.4 °C (7.7)
3	y = 0.1343x − 3.3334 (R^2 = 0.7829)	24.8 °C	28.5–21.1 °C (7.4)
4	y = 0.1324x − 2.9146 (R^2 = 0.7566)	22.0 °C	25.8–18.2 °C (7.6)
5	y = 0.3157x − 7.7276 (R^2 = 0.7852)	24.5 °C	26.1–22.9 °C (3.2)
6	y = 0.2586x − 5.4206 (R^2 = 0.7592)	21.0 °C	22.9–19.0 °C (3.9)
State	**Regression Equation**	**NPET (TCV = 0)**	**NPETR (−0.5 < TCV < +0.5)**
1	y = 0.1277x − 3.0138 (R^2 = 0.8043)	23.6 °C	27.5–19.7 °C (7.8)
2	y = 0.1286x − 2.5150 (R^2 = 0.7297)	19.6 °C	23.4–15.7 °C (7.7)
3	y = 0.1312x − 3.0592 (R^2 = 0.7994)	23.3 °C	27.1–19.5 °C (7.6)
4	y = 0.1462x − 2.8039 (R^2 = 0.7837)	19.2 °C	22.6–15.8 °C (6.8)
5	y = 0.2886x − 6.6399 (R^2 = 0.8032)	23.0 °C	24.7–21.3 °C (3.4)
6	y = 0.2301x − 4.3252 (R^2 = 0.7890)	18.8 °C	21.0–16.6 °C (4.4)

Upon examining the differences in thermal comfort between different protection states (Figure 6b and Table 4) by comparing states 1, 3, and 5 with states 2, 4, and 6, it can be observed that as the thermal resistance of the clothing increases, the values of NPET also decrease. Furthermore, the range of NPETR also decreases, suggesting that as the level of protection increases and the thermal resistance increases, the NPETR becomes smaller.

In comparison to TSV, TCV exhibits smaller NPET values, and the range of NPETR shifts towards lower values. This confirms that during summer, users only achieve comfort when they perceive a slightly cooler thermal sensation.

3.2.2. Different Activity Intensities

By exploring the differences in thermal sensation between different exercises (Figure 6a and Table 4) by comparing states 1 and 2, states 3 and 4, and states 5 and 6, respectively, it was found that as the intensity of the exercise increases, the values of NPET decrease. This indicates that as the intensity of the exercise gradually increases, people require lower temperatures to feel comfortable. The NPETR widens, indicating a slower change in thermal sensation with increasing metabolic rate and a reduced sensitivity to changes in thermal sensation as metabolic intensity increases. A study in Xi'an has demonstrated that the neutral temperature is negatively correlated with residents' activity levels, and the neutral temperature range widens as activity levels increase [46].

Upon examining the differences in thermal comfort between different exercises (Figure 6b and Table 4) by comparing states 1 and 2, states 3 and 4, and states 5 and 6, respectively, it was observed that with higher exercise intensity, the values of NPET decrease. This suggests that as the exercise intensity gradually increases, people require lower temperatures to feel comfortable. With higher exercise intensity, the NPETR decreases when clothing thermal resistance is low (comparing states 1 and 2 and states 3 and 4) but increases when clothing thermal resistance is high (comparing states 5 and 6). This confirms that with higher clothing thermal resistance, the influence of metabolic rate on thermal comfort becomes crucial. As the metabolic rate increases, there is a smaller slope in the regression equation, indicating a reduced change in thermal comfort and decreased sensitivity to changes in thermal comfort with increasing metabolic intensity. However, when the thermal resistance is relatively small, the metabolic rate may not be the main factor affecting thermal comfort. This may be because thermal comfort is influenced by multiple factors, which are more complex. According to the research findings of Lai, Shooshtarian, Enescu, and others, psychological and subjective factors can influence people's perception of thermal comfort, leading to discrepancies between their judgment and thermal sensation [37,47,48].

3.2.3. Differences in Thermal Benchmark under Various States

By fitting the average thermal sensation votes and PET indices, partial heat benchmarks for various states can be inferred, as shown in Table 5.

Table 5. Classification of thermal sensation in various states in Wuhan.

PET_{state1}	PET_{state2}	PET_{state3}	PET_{state4}	PET_{state5}	PET_{state6}	Thermal Perception	Grade of Physical Stress
				>35.6	>34.5	Very hot	Extreme heat stress
	42.7–50.5		40.9–48.4	32.4–35.6	30.6–34.5	Hot	Strong heat stress
36.4–43.8	34.9–42.7	36.0–43.4	33.3–40.9	29.2–32.4	26.8–30.6	Warm	Moderate heat stress
28.9–36.4	27.1–34.9	28.5–36.0	25.8–33.3	26.1–29.2	22.9–26.8	Slightly warm	Slight heat stress
21.4–28.9	19.4–27.1	21.1–28.5	18.2–25.8	22.9–26.1	19.0–22.9	Neutral	No thermal stress

According to a study by Fang et al., although the variation in clothing insulation from 0.3 to 1.2 has a negligible impact on PET and UTCI, it is essential to more accurately determine the influence of clothing on outdoor thermal comfort [49]. Comparative analysis reveals that as the levels of protection and activity intensity increase, there can be significant differences in the range of thermal sensations experienced in various states. These differences are related to changes in clothing insulation and metabolic rate [46,49]. When there are substantial changes in clothing insulation and metabolic rate, there can also be significant variations in the range of thermal sensations. For example, comparing state 1 and state 6, with clothing insulation ranging from 0.31 clo to 1.69 clo and the metabolic rate varying between 1.3 met and 2.5 met, when the individual in state 6 perceives heat, the individual in state 1 will only feel slightly warm. Therefore, it is not appropriate to determine outdoor thermal comfort for individuals using a unified thermal benchmark, considering the different states that may occur during summer. The research of Kruger, Potchter, Cheung, and others has long indicated that establishing corresponding thermal benchmarks is essential for better determining individuals' thermal comfort [42,50,51].

3.3. Skin Temperature and Heart Rate

Under different states, there are certain differences in average skin temperature among individuals (Figure 7). In terms of protective intensity, wearing a mask does not have a significant impact on the overall skin temperature, while wearing protective clothing has a noticeable effect on the average skin temperature. In terms of activity intensity, as the temperature increases, the overall skin temperature also rises. However, due to increased activity intensity becoming one of the main factors affecting skin temperature, the influence of temperature on states 4 and 2 becomes weaker compared to that for states 3 and 1 at low activity levels, resulting in a more stable trend in body temperature. Due to higher temperatures, when wearing protective clothing, the overall skin temperature remains at a higher level, with noticeable changes only occurring with temperature fluctuations.

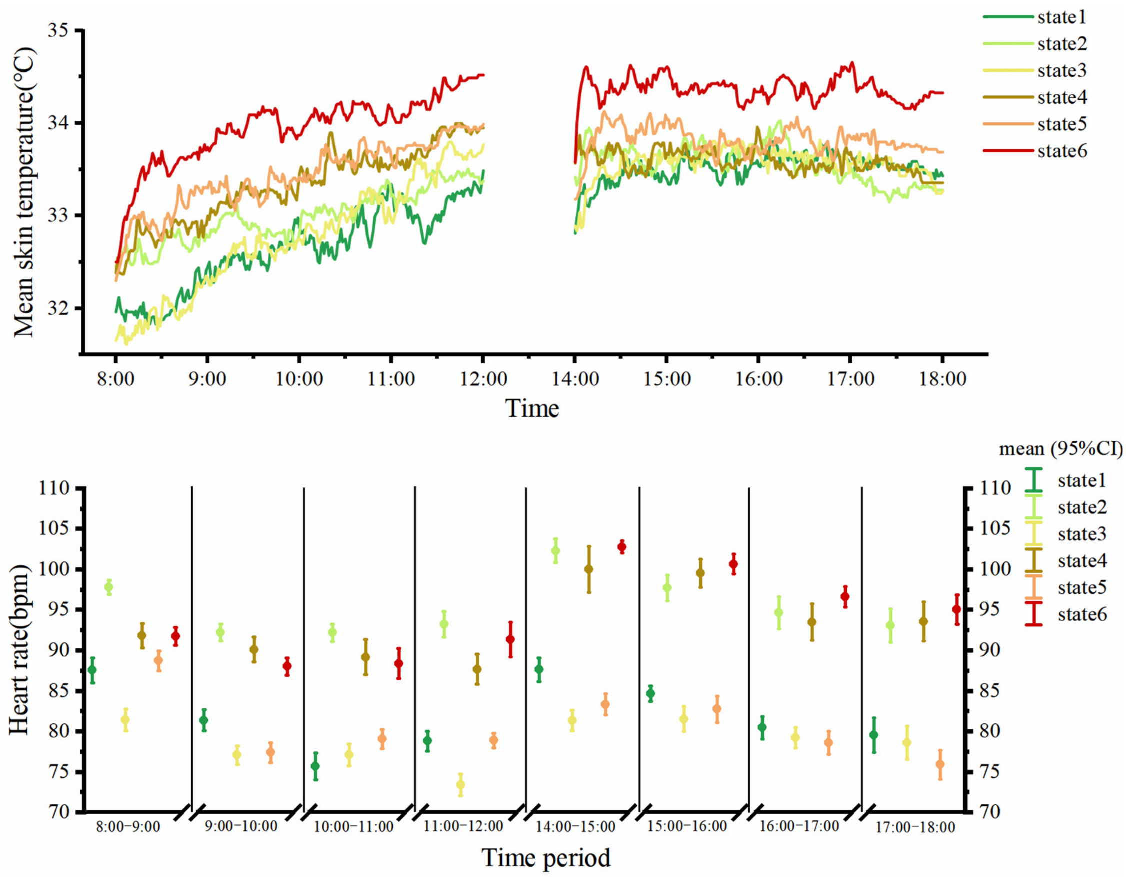

Figure 7. Fluctuations in average skin temperature and heart rate of individuals under different states over time.

Wang's research suggests that the psychological and physiological changes induced by different emotional states may have a certain impact on people's perception of the thermal environment [52]. There are many factors that can influence heart rate, including not only exercise but also unstable factors such as emotions and mental state. Therefore, for analysis purposes, the heart rate during the period from 15 min to 45 min after the start of the experimental phase was selected when the heart rate is relatively stable. The change in heart rate with activity intensity shows significant differences, but there are no significant changes with the variation of protection intensity (Figure 7). As the experiment progresses, both the physiological and psychological conditions of individuals tend to stabilize, leading to a continuous decrease in heart rate.

3.4. The Problems to Be Addressed and the Establishment of SOCI

Through research by multiple scholars, it has been discovered that thermal comfort benchmarks vary significantly across different regions due to climate variations. For example, Lin et al. found that the thermal comfort range for respondents in Taiwan is 21.3–28.5 °C PET, which is notably higher than in studies conducted in central and western Europe (18–23 °C PET) [15]. Therefore, scholars have established corresponding thermal comfort standards that are suitable for different regions and climates in order to better adapt to these differences [16–18,49,53–56]. However, there is relatively less research on the classification of more detailed outdoor occupant states, especially when considering the influence of climate in different regions, as the variations in these states would also differ. The differences in thermal comfort under different activity intensities have long been evident, such as in the research of Niu et al. [46]. In the previous section, PET indicators were used to analyze thermal sensation under various states. However, since PET indicators are insensitive to clothing thermal resistance and metabolic rate, a unified thermal standard cannot evaluate thermal sensation under all states. Therefore, it is necessary to analyze each state individually and establish corresponding thermal standards for each state. However, establishing thermal comfort standards that are applicable to different states may increase the workload unnecessarily, which is a question that this study aims to explore.

To address these issues, we established a model that can directly predict outdoor thermal comfort by increasing clothing thermal resistance and metabolic rate based on the PET index. This approach simplifies and enhances the effectiveness of using PET. The model aims to predict outdoor thermal comfort for different protection states of the population when facing epidemics or other diseases in order to address the problem that thermal standards for different states are not defined in most regions. In this study, 60% of the data were used as the training set to establish equations and define thermal standards, while 40% of the data were used as the validation set to evaluate thermal indices.

Taking into account PET, clothing thermal resistance, and metabolic rate, the best model, namely the State Outdoor Comfort Index (SOCI), was selected through a multivariate stepwise regression analysis. This selection was based on the significance of the partial regression coefficients of each variable and the adjusted R^2. The equation for the SOCI is represented as

$$\mathrm{SOCI} = 0.178\mathrm{PET} + 0.276\mathrm{Met} + 1.171\mathrm{Clo} - 5.557 \; (R^2 = 0.715) \tag{3}$$

3.5. Evaluation of the Applicability of Thermal Comfort Indicators

To evaluate the predictive effectiveness of the SOCI on thermal comfort voting by outdoor space users under various states, the applicability of the thermal index needed to be verified according to the three statistical criteria proposed in Section 2 (Figure 8). It can be observed that the gamma coefficient for both the SOCI and the physiological equivalent temperature (PET) is 0.732. This is because the parameters required for calculating thermal comfort indices are the same, demonstrating that SOCI and PET possess similar predictive potential. The correlation coefficient between the calculated SOCI values and actual thermal sensation voting is 0.817, surpassing the corresponding coefficient of 0.502 for PET. In comparison with PET, SOCI exhibits higher sensitivity to actual thermal sensation voting.

Analyzing the correct prediction percentages for all states, it is observed that the accurate prediction rate of SOCI is 60.0%, which is not significantly different from that of PET, which is 60.8%, indicating their similar predictive performance. Comparing the correct prediction percentages of thermal sensation in the six different states, it was found that in states 4, 5, and 6, SOCI outperforms PET in its predictive performance. Compared to PET, SOCI enhances the impact of clothing thermal resistance and metabolic rate on thermal sensation, allowing for a more accurate prediction of outdoor thermal comfort in complex conditions.

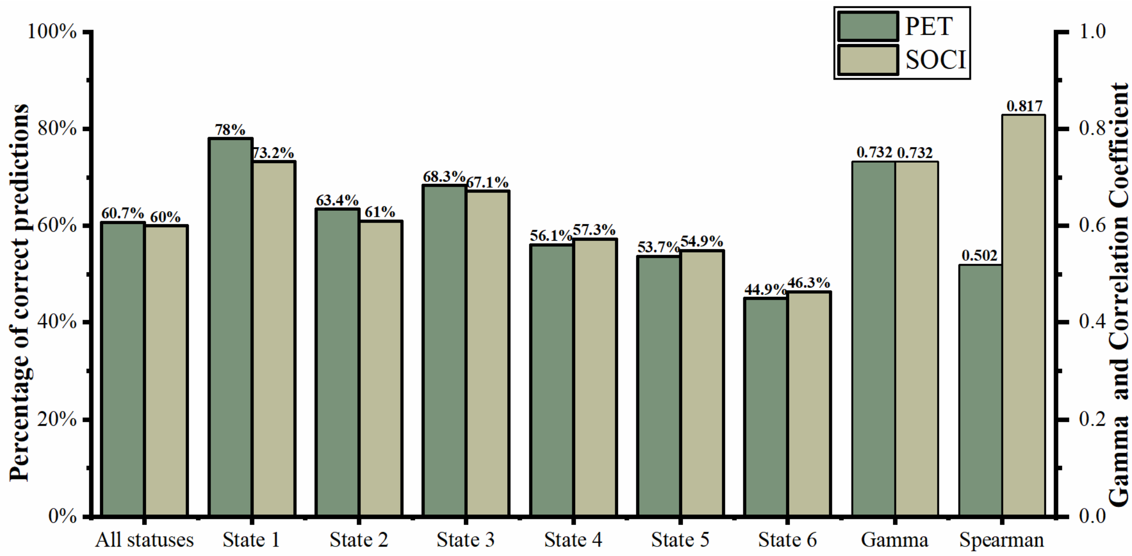

Figure 8. Prediction performance of PET and SOCI indices under various conditions.

The better prediction performance of PET is based on the well-defined heat benchmarks in this study, while the SOCI model demonstrates comparable predictive capability to PET using the established heat benchmarks. Therefore, for regions where heat benchmarks for different states have not been widely established, establishing a corresponding SOCI model undoubtedly takes higher priority. Although there is relatively less research on state-based thermal experiential indicators, Golasi et al. conducted field surveys in Rome, Italy, revealing that regional thermal experiential models such as GOCI and MOCI demonstrate better predictive capabilities for thermal comfort compared to indicators like PET, PMV, and UTCI. To some extent, these thermal experiential indicators better align with residents' thermal comfort [57].

3.6. Discussion

Currently, there is a lack of standardized methods for evaluating thermal comfort among protected populations, especially when considering activity intensity. The thermal comfort needs of protected populations require attention, particularly during periods of high summer temperatures. We have demonstrated the thermal baseline differences that exist outdoors among different protective measures and activity states. This study established appropriate quantitative metrics, confirming the feasibility and effectiveness of using the SOCI prediction model for thermal comfort prediction under various outdoor conditions. Future thermal comfort research could adopt similar methods to address the challenge of predicting outdoor thermal comfort for populations in various protective states during pandemics or other disease outbreaks. This will help address the problem that regions lack categorized thermal baselines or that thermal baselines are overly complex. Of course, an index sufficient for predicting thermal comfort will require calibration to be applicable to specific regions or climates [58].

The transferability or generalizability of our research findings still requires further verification, which is a fundamental critique of case studies [59]. In future research, the analytical framework needs to be expanded to obtain more convincing conclusions. Firstly, given the high outdoor temperatures in Wuhan during the summer, this study chose to conduct experiments in shaded areas, avoiding direct exposure to sunlight. However, this did not fully simulate human thermal responses and adaptive behaviors under full sunlight conditions. Subsequent experiments should consider this aspect. The thermal environment of different activity locations varies, and the types of personnel states considered in the study are relatively limited. Ideally, a more diverse range of environments and activity conditions should be explored and evaluated to expand the scope of the experimental research. Additionally, this experiment was conducted in Wuhan, located in central China, which is influenced by a subtropical monsoon climate characterized by hot summers and cold winters. In future research, to gain a more comprehensive understanding of people's thermal and physiological responses during outdoor activities in different climatic regions, the study scope should be broadened to cover a wider range of climatic conditions. This study mainly targeted young people, and its conclusions may not be entirely applicable to other age groups. Therefore, future research should broaden the age range of participants to evaluate the thermal comfort of a wider population.

4. Conclusions

This study evaluated the thermal differences among outdoor individuals in Wuhan during the summer season under different conditions through the assessment of the outdoor environment, subjective questionnaires, and physiological monitoring. It also corrected the insensitivity of the PET index to clothing thermal resistance and metabolic rate. The following conclusions were drawn:

When sitting still, the impact of wearing a mask on thermal sensation is minimal. Sometimes, wearing a mask can reduce the stimulation of hot air on the face and lower the thermal sensation. Increasing the thermal resistance of clothing causes thermal sensation and thermal comfort to be more susceptible to temperature fluctuations, so individuals wearing protective clothing may experience significant variations in thermal comfort throughout the day. As metabolic rate increases, thermal sensation and thermal comfort also increase.

The neutral temperature of thermal sensation and comfort is negatively correlated with the intensity of protection and activity. Their thermal neutral range is negatively correlated with increasing protective measures, while the thermal neutral range of thermal sensation is positively correlated with activity intensity. However, for thermal comfort, which depends on individual psychological and subjective feelings, the relationship between its thermal neutral range and activity intensity is not clear.

To address the issue of thermal sensation differences under different levels of protection and physical activity, we have developed the SOCI prediction model. This model aims to predict the thermal comfort of populations outdoors under various protective conditions during epidemics or other disease outbreaks in areas where there is not a state-level thermal baseline classification.

Author Contributions: Conceptualization, X.C. and Q.D.; Methodology, X.S., Z.Z. and X.K.; Resources, X.K. and Q.D.; Data curation, X.C. and Z.Z.; Writing—original draft, X.C. and X.S.; Funding acquisition, Z.Z. and Q.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China [Grant Number 51608405, 51808410], Hainan Province Science and Technology Special Fund [ZDKJ2021024].

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Natural Science Ethics Committee of Wuhan University (protocol code: WHU- NS- IRB2024001, date of approval: 27 March 2024).

Informed Consent Statement: Informed consent has been obtained from all volunteers.

Data Availability Statement: Data are contained within the article.

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

References

1. Yao, L.; Aleya, L.; Goldman, E.; Graff, J.C.; Gu, W.K. An alternative approach-combination of lockdown and open in fighting COVID-19 pandemics. *Environ. Sci. Pollut. Res.* **2022**, *29*, 82611–82614. [CrossRef] [PubMed]
2. Bo, Y.; Guo, C.; Lin, C.; Zeng, Y.; Li, H.B.; Zhang, Y.; Hossain, M.S.; Chan, J.W.M.; Yeung, D.W.; Kwok, K.O.; et al. Effectiveness of non-pharmaceutical interventions on COVID-19 transmission in 190 countries from 23 January to 13 April 2020. *Int. J. Infect. Dis.* **2021**, *102*, 247–253. [CrossRef] [PubMed]

3. Eikenberry, S.E.; Mancuso, M.; Iboi, E.; Phan, T.; Eikenberry, K.; Kuang, Y.; Kostelich, E.; Gumel, A.B. To mask or not to mask: Modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic. *Infect. Dis. Model.* **2020**, *5*, 293–308. [CrossRef] [PubMed]
4. Gholamreza, F.; Nadaraja, A.V.; Milani, A.S.; Golovin, K. Enhanced protection face masks do not adversely impact thermophysiological comfort. *PLoS ONE* **2022**, *17*, e0265126. [CrossRef] [PubMed]
5. Loibner, M.; Hagauer, S.; Schwantzer, G.; Berghold, A.; Zatloukal, K. Limiting factors for wearing personal protective equipment (PPE) in a health care environment evaluated in a randomised study. *PLoS ONE* **2019**, *14*, e0210775. [CrossRef] [PubMed]
6. Arif, M.; Katafygiotou, M.; Mazroei, A.; Kaushik, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sustain. Built Environ.* **2016**, *5*, 1–11.
7. Ryu, J.H.; Hong, W.H.; Seo, H.C.; Seo, Y.K. Determination of an acceptable comfort zone for apartment occupants in South Korea: An empirical analysis of cooling operation. *Build. Environ.* **2017**, *125*, 484–501. [CrossRef]
8. Rawal, R.; Schweiker, M.; Kazanci, O.B.; Vardhan, V.; Jin, Q.; Duanmu, L. Personal comfort systems: A review on comfort, energy, and economics. *Energy Build.* **2020**, *214*, 109858. [CrossRef]
9. Zhang, H.; Arens, E.; Zhai, Y. A review of the corrective power of personal comfort systems in non-neutral ambient environments. *Build. Environ.* **2015**, *91*, 15–41. [CrossRef]
10. Zhang, J.; Zhou, X.; Lei, S.; Luo, M. Energy and comfort performance of occupant-centric air conditioning strategy in office buildings with personal comfort devices. *Build. Simul.* **2022**, *15*, 899–911. [CrossRef]
11. Lei, Y.; Tekler, Z.D.; Zhan, S.; Miller, C.; Chong, A. Experimental evaluation of thermal adaptation and transient thermal comfort in a tropical mixed-mode ventilation context. *Build. Environ.* **2024**, *248*, 111043. [CrossRef]
12. Tekler, Z.D.; Lei, Y.; Peng, Y.; Miller, C.; Chong, A. A hybrid active learning framework for personal thermal comfort models. *Build. Environ.* **2023**, *234*, 110148. [CrossRef]
13. Duan, M.; Sun, H.; Wu, Y.; Lin, B. Method for evaluating the dynamic thermal performance of heating terminals based on an analysis of heat quantity and grade. *Energy Build.* **2021**, *252*, 111391. [CrossRef]
14. Liu, S.; Cao, B.; Zhu, Y. Experimental study on comparison of indoor and multiple outdoor thermal environments excluding visual and acoustic interference. *Sustain. Cities Soc.* **2023**, *94*, 104564. [CrossRef]
15. Lin, T.-P. Thermal perception, adaptation and attendance in a public square in hot and humid regions. *Build. Environ.* **2009**, *44*, 2017–2026. [CrossRef]
16. Salata, F.; Golasi, I.; Vollaro, R.D.; Vollaro, A.D. Outdoor thermal comfort in the Mediterranean area. A transversal study in Rome, Italy. *Build. Environ.* **2016**, *96*, 46–61. [CrossRef]
17. Cheng, B.; Gou, Z.; Zhang, F.; Feng, Q.; Huang, Z. Thermal comfort in urban mountain parks in the hot summer and cold winter climate. *Sustain. Cities Soc.* **2019**, *51*, 101756. [CrossRef]
18. Canan, F.; Golasi, I.; Ciancio, V.; Coppi, M.; Salata, F. Outdoor thermal comfort conditions during summer in a cold semi-arid climate. A transversal field survey in Central Anatolia (Turkey). *Build. Environ.* **2019**, *148*, 212–224. [CrossRef]
19. Kuklane, K.; Lundgren, K.; Gao, C.; Londahl, J.; Hornyanszky, E.D.; Ostergren, P.-O.; Becker, P.; Samuels, M.C.; Gooch, P.; Sternudd, C.; et al. Ebola: Improving the Design of Protective Clothing for Emergency Workers Allows Them to Better Cope with Heat Stress and Help to Contain the Epidemic. *Ann. Occup. Hyg.* **2015**, *59*, 258–261.
20. Potter, A.W.; Blanchard, L.A.; Friedl, K.E.; Cadarette, B.S.; Hoyt, R.W. Mathematical prediction of core body temperature from environment, activity, and clothing: The heat strain decision aid (HSDA). *J. Therm. Biol.* **2017**, *64*, 78–85. [CrossRef] [PubMed]
21. Potter, A.W.; Gonzalez, J.A.; Xu, X.J. Ebola Response: Modeling the Risk of Heat Stress from Personal Protective Clothing. *PLoS ONE* **2015**, *10*, e0143461. [CrossRef]
22. Zender-Swiercz, E.; Telejko, M.; Galiszewska, B. Influence of Masks Protecting against SARS-CoV-2 on Thermal Comfort. *Energies* **2021**, *14*, 3315. [CrossRef]
23. Milosevic, D.; Middel, A.; Savic, S.; Dunjic, J.; Lau, K.; Stojsavljevic, R. Mask wearing behavior in hot urban spaces of Novi Sad during the COVID-19 pandemic. *Sci. Total Environ.* **2022**, *815*, 152782. [CrossRef] [PubMed]
24. Liu, T.; Shan, X.; Deng, Q.; Zhou, Z.; Yang, G.; Wang, J.; Ren, Z. Thermal Perception and Physiological Responses under Different Protection States in Indoor Crowded Spaces during the COVID-19 Pandemic in Summer. *Sustainability* **2022**, *14*, 5477. [CrossRef]
25. Vanos, J.K.; Herdt, A.J.; Lochbaum, M.R. Effects of physical activity and shade on the heat balance and thermal perceptions of children in a playground microclimate. *Build. Environ.* **2017**, *126*, 119–131. [CrossRef]
26. Choi, J.-H.; Loftness, V.; Lee, D.-W. Investigation of the possibility of the use of heart rate as a human factor for thermal sensation models. *Build. Environ.* **2012**, *50*, 165–175. [CrossRef]
27. Zhai, Y.; Elsworth, C.; Arens, E.; Zhang, H.; Zhang, Y.; Zhao, L. Using air movement for comfort during moderate exercise. *Build. Environ.* **2015**, *94*, 344–352. [CrossRef]
28. Wang, H.; Hu, S. Experimental study on thermal sensation of people in moderate activities. *Build. Environ.* **2016**, *100*, 127–134. [CrossRef]
29. Li, S.; Jia, X.; Cao, B.; Liu, B.; Zhu, Y. Thermal comfort characteristics and heating demand of people with different activity status during extremely cold exposure. *Build. Environ.* **2023**, *228*, 109798. [CrossRef]
30. *ANSI/ASHRAE 55-2013*; Ashrae Standard 55. Thermal Environmental Conditions for Human Occupancy. ASHRAE: Peachtree Corners, GA, USA, 2013.

31. *ISO 7726:1998*; International Standard 7726. Ergonomics of the Thermal Environment—Instruments for Measuring. ISO: Geneva, Switzerland, 1998.
32. Nazarian, N.; Liu, S.; Kohler, M.; Lee, J.K.W.; Miller, C.; Chow, W.T.L.; Alhadad, S.B.; Martilli, A.; Quintana, M.; Sunden, L.; et al. Project Coolbit: Can your watch predict heat stress and thermal comfort sensation? *Environ. Res. Lett.* **2021**, *16*, 034031. [CrossRef]
33. Rathmann, J.; Beck, C.; Flutura, S.; Seiderer, A.; Aslan, I.; Andre, E. Towards quantifying forest recreation: Exploring outdoor thermal physiology and human well-being along exemplary pathways in a central European urban forest (Augsburg, SE-Germany). *Urban For. Urban Green.* **2020**, *49*, 126622. [CrossRef]
34. Lam, C.K.C.; Hang, J.; Zhang, D.; Wang, Q.; Ren, M.; Huang, C. Effects of short-term physiological and psychological adaptation on summer thermal comfort of outdoor exercising people in China. *Build. Environ.* **2021**, *198*, 107877. [CrossRef]
35. Nielsen, R.; Nielsen, B. Measurement of mean skin temperature of clothed persons in cool environments. *Eur. J. Appl. Physiol. Occup. Physiol.* **1984**, *53*, 231–236. [CrossRef] [PubMed]
36. Amin, R.; Teli, D.; James, P.; Bourikas, L. The influence of a student's 'home' climate on room temperature and indoor environmental controls use in a modern halls of residence. *Energy Build.* **2016**, *119*, 331–339. [CrossRef]
37. Lai, D.; Lian, Z.; Liu, W.; Guo, C.; Liu, W.; Liu, K.; Chen, Q. A comprehensive review of thermal comfort studies in urban open spaces. *Sci. Total Environ.* **2020**, *742*, 140092. [CrossRef] [PubMed]
38. Yao, J.; Yang, F.; Zhuang, Z.; Shao, Y.; Yuan, P.F. The effect of personal and microclimatic variables on outdoor thermal comfort: A field study in a cold season in Lujiazui CBD, Shanghai. *Sustain. Cities Soc.* **2018**, *39*, 181–188. [CrossRef]
39. Xiong, J.; Ma, T.; Lian, Z.; de Dear, R. Perceptual and physiological responses of elderly subjects to moderate temperatures. *Build. Environ.* **2019**, *156*, 117–122. [CrossRef]
40. Amindeldar, S.; Heidari, S.; Khalili, M. The effect of personal and microclimatic variables on outdoor thermal comfort: A field study in Tehran in cold season. *Sustain. Cities Soc.* **2017**, *32*, 153–159. [CrossRef]
41. Ainsworth, B.E.; Haskell, W.L.; Herrmann, S.D.; Meckes, N.; Bassett, D.R., Jr.; Tudor-Locke, C.; Greer, J.L.; Vezina, J.; Whitt-Glover, M.C.; Leon, A.S. 2011 Compendium of Physical Activities: A Second Update of Codes and MET Values. *Med. Sci. Sports Exerc.* **2011**, *43*, 1575–1581. [CrossRef] [PubMed]
42. Potchter, O.; Cohen, P.; Lin, T.-P.; Matzarakis, A. Outdoor human thermal perception in various climates: A comprehensive review of approaches, methods and quantification. *Sci. Total Environ.* **2018**, *631–632*, 390–406. [CrossRef] [PubMed]
43. Shooshtarian, S.; Ridley, I. The effect of physical and psychological environments on the users thermal perceptions of educational urban precincts. *Build. Environ.* **2017**, *115*, 182–198. [CrossRef]
44. Matzarakis, A.; Rutz, F.; Mayer, H. Modelling radiation fluxes in simple and complex environments--application of the RayMan model. *Int. J. Biometeorol.* **2007**, *51*, 34–323. [CrossRef] [PubMed]
45. Pantavou, K.; Santamouris, M.; Asimakopoulos, D.; Theoharatos, G. Evaluating the performance of bioclimatic indices on quantifying thermal sensation for pedestrians. *Adv. Build. Energy Res.* **2013**, *7*, 170–185. [CrossRef]
46. Niu, J.; Hong, B.; Geng, Y.; Mi, J.; He, J. Summertime physiological and thermal responses among activity levels in campus outdoor spaces in a humid subtropical city. *Sci. Total Environ.* **2020**, *728*, 138757. [CrossRef]
47. Enescu, D. Models and Indicators to Assess Thermal Sensation Under Steady-State and Transient Conditions. *Energies* **2019**, *12*, 841. [CrossRef]
48. Shooshtarian, S. Theoretical dimension of outdoor thermal comfort research. *Sustain. Cities Soc.* **2019**, *47*, 101495. [CrossRef]
49. Fang, Z.; Lin, Z.; Mak, C.M.; Niu, J.; Tse, K.-T. Investigation into sensitivities of factors in outdoor thermal comfort indices. *Build. Environ.* **2018**, *128*, 129–142. [CrossRef]
50. Kruger, E.; Rossi, F.; Drach, P. Calibration of the physiological equivalent temperature index for three different climatic regions. *Int. J. Biometeorol.* **2017**, *61*, 1323–1336. [CrossRef]
51. Cheung, P.K.; Jim, C.Y. Determination and application of outdoor thermal benchmarks. *Build. Environ.* **2017**, *123*, 333–350. [CrossRef]
52. Wang, H.; Liu, L. Experimental investigation about effect of emotion state on people′s thermal comfort. *Energy Build.* **2020**, *211*, 109789. [CrossRef]
53. Wei, D.; Yang, L.; Bao, Z.; Lu, Y.; Yang, H. Variations in outdoor thermal comfort in an urban park in the hot-summer and cold-winter region of China. *Sustain. Cities Soc.* **2022**, *77*, 103535. [CrossRef]
54. Lin, T.-P.; Matzarakis, A.; Hwang, R.-L. Shading effect on long-term outdoor thermal comfort. *Build. Environ.* **2010**, *45*, 213–221. [CrossRef]
55. Ndetto, E.L.; Matzarakis, A. Assessment of human thermal perception in the hot-humid climate of Dar es Salaam, Tanzania. *Int. J. Biometeorol.* **2017**, *61*, 69–85. [CrossRef] [PubMed]
56. Yahia, M.W.; Johansson, E.; Thorsson, S.; Lindberg, F.; Rasmussen, M.I. Effect of urban design on microclimate and thermal comfort outdoors in warm-humid Dar es Salaam, Tanzania. *Int. J. Biometeorol.* **2018**, *62*, 373–385. [CrossRef] [PubMed]
57. Golasi, I.; Salata, F.; de Lieto Vollaro, E.; Coppi, M. Complying with the demand of standardization in outdoor thermal comfort: A first approach to the Global Outdoor Comfort Index (GOCI). *Build. Environ.* **2018**, *130*, 104–119. [CrossRef]

58. Binarti, F.; Koerniawan, M.D.; Triyadi, S.; Utami, S.S.; Matzarakis, A. A review of outdoor thermal comfort indices and neutral ranges for hot-humid regions. *Urban Clim.* **2020**, *31*, 100531. [CrossRef]
59. Bao, Z.; Lee, W.M.W.; Lu, W. Implementing on-site construction waste recycling in Hong Kong: Barriers and facilitators. *Sci. Total Environ.* **2020**, *747*, 141091. [CrossRef]