Research on Thermal Comfort of Activity Space under Viaduct in Mountain City —Take Chongqing Egongyan Bridge as an example

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ABSTRACT

Rapid development of cities has led to the shortage of land for residents' activities, while rational use of the space under urban viaducts can effectively alleviate this problem. The thermal environment of the space under the viaduct is a key factor that affects human comfort during activities. In this paper, the thermal comfort under the Egongyan Bridge in Chongqing was evaluated by winter thermal environment test, thermal sensational voting (TSV) and universal thermal climate index (UTCI). It was found that the sky view factor (SVF) had a stronger linear correlation with UTCI than the spatial height width ratio (H/B). Furthermore, pedestrians pay attention to environmental thermal parameters mainly in the aspect of sunshine. This study provides a reference for the thermal environment optimization of the space under viaducts in the future, and provides a basis for the sustainable development of the city.

INTRODUCTION

With the development of economy, the scale of cities expands rapidly. Emergence and rapid development of viaducts bring convenience to transportation of urban residents, but they also occupy a lot of urban space. There exists a mass of spaces covered by elevated structures in almost every city. The contradiction between urban population growth and land reduction is becoming increasingly prominent. In recent years, domestic and foreign scholars have conducted a large number of studies on the lower space of viaducts, such as its land use form, relationship with urban streets, functional design of space reuse, etc. . However, research on human comfort during taking activities in these spaces is relatively lacking. At present, existing studies with regard to thermal environment and humidity conditions are also regional and cannot be applied to other cities with distinct geographical differences.

The landform of Chongqing is mainly mountainous and hilly, which accounts for 70% of the land area of the Chongqing. So it is called "Mountain City". Affected by terrain, a lot of spaces under the viaducts with obvious terrain height difference and large scale are produced. Chongqing is located in hot summer and cold winter region of China, and the outdoor environment is greatly influenced by the mountain pattern. Therefore, problem of outdoor thermal environment comfort in winter and summer is prominent, which needs to be solved urgently. In this paper, the under space of Chongqing Egongyan Bridge with typical mountain height difference characteristics was selected as the research object. According to the difference of space height width ratio (H /B), five measuring points were selected. Through the thermal environment parameter experiment and pedestrian subjective thermal sensation questionnaire, the space thermal environment condition and pedestrian thermal perception with different height width ratio and sky view factor were analysed.

METHOD

Research object and region

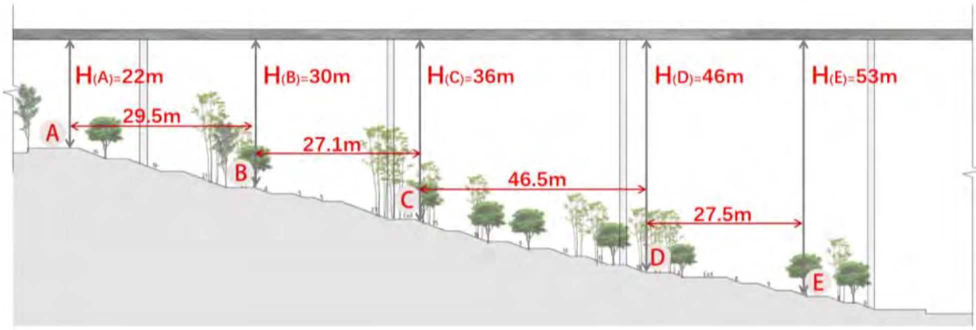
- Climatic characteristics

Chongqing, located in the southeast of Sichuan Basin and the upper reaches of the Yangtze River. It straddles the Tibetan Plateau and the Yangtze Plain between 105°11′-110°11′ east longitude and 28°10′-32 °13′ north latitude. Chongqing belongs to the hot summer and cold winter region. In Addition, affected by atmospheric circulation and surrounding mountains, cold waves are not easy to invade the city. Frost and snow are rarely seen. The coldest monthly average temperature can reach about 10℃, higher than other cities of the same latitude such as Wuhan and Shanghai.

- Geographical location of research object

The space under the bridge of Egongyan Bridge with typical mountain characteristics was selected as the research object. Affected by the mountainous terrain, there is a large area of open space under the bridge. Egongyan Bridge (Figure 1) is located in Jiulongpo District across the Yangtze River, which is a

Table 1. distribution of measuring points

Point	A	B	C	D	E
Testing Point					
					
Rayman Software process					
SVF	0.173	0.139	0.124	0.104	0.119
H/B	0.615	0.838	1.015	1.312	1.446

river crossing channel connecting Jiulongpo District and Nanan District in Chongqing. There are many residential areas around the bridge. The population distribution is of high density, and the demand for outdoor space is considerably strong (Figure 2). However, the area of land available for outdoor activities in the surrounding areas is extremely limited. Therefore, many residents around the Egongyan Bridge exercise nearly every day under the bridge. In addition, a small number of tourists visit here as well. The utilization of space under the bridge is quite high (Figure 3). Therefore, it is significant to evaluate and analyze the thermal environment of the space, so as to take appropriate measures to improve the comfort.

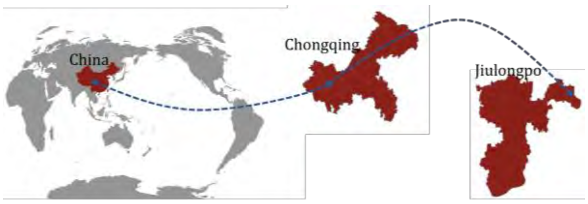


Figure 1.Geographical location

Figure 2.Resident activities

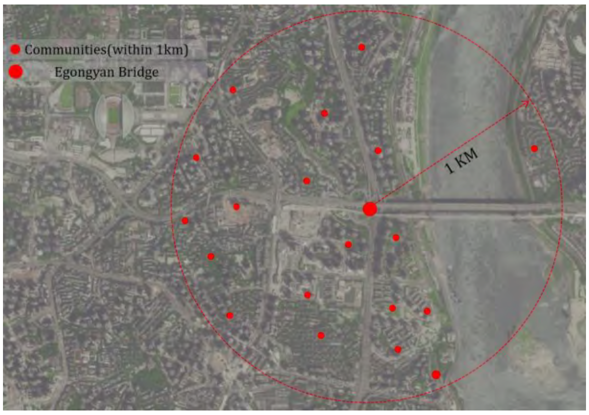


Figure 3.Distribution of surrounding communities

Experiment Plan

- Thermal environment test

According to the average climate data of Chongqing typical year (2005) (Figure 4, Figure 5), the coldest month temperature in winter is 4-11℃. In addition, Egongyan Bridge is close to several residential areas, and the surrounding population is dense. Residents, especially the elder, have a strong demand for outdoor space. People's activities in winter are mainly within 8:00-18:00 in the daytime. Therefore, the experiment was taken during 8:30-18:30 on January 11, 2021. Distribution of measuring points is shown in Table 1. The fisheye photos are processed by RayManPro software. SVF value of each measuring point is calculated. Height of the space and width covered by the bridge are measured, then value of H/B is obtained.

According to the difference of H/B and SVF, five measuring points are selected.

Tested microclimate parameters included air temperature, air humidity, wind speed, dry bulb temperature, wet bulb temperature, black bulb temperature and fisheye photos. Furthermore, height and width of each tested space were measured. In the experiment, equipments conforming to IOS7726 standard were used, and the time interval of other parameters except fisheye photos was 5mins. Finally, the average value of every 30mins was taken for analysis. The equipments for temperature, humidity and wind speed were all set 1.5m above the ground. It should be noted that due to the equipment failure, the black ball temperatures at point D and E were not recorded. However, due to the fact that platforms of point D and E are located at places where there is no direct solar radiation all day, the influence on radiation temperature is small. Therefore, in this study, the black ball temperature of D and E is replaced by air temperature respectively.

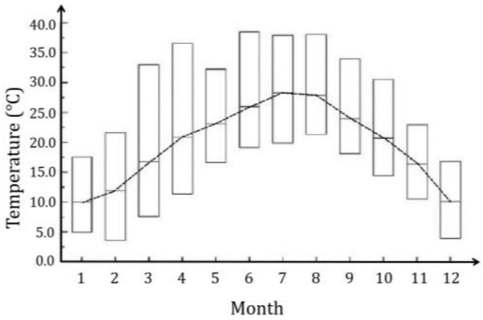


Figure 4.Temperature distribution of typical year

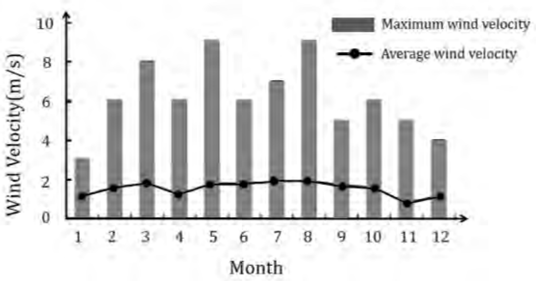


Figure 5.Wind velocity distribution of typical year

- Questionnaire Survey

In addition to thermal environment test, this study also conducted a questionnaire survey on the subjective thermal sensation of the people who took activities in the space under Egongyan Bridge. The questionnaire consists of three parts: 1 The basic information of the respondents, including age and source. 2 The subjective opinion about the microclimate parameters of the space including sunshine, temperature, humidity and wind speed. 3 The subjective thermal sensational voting.

A total of 110 questionnaires were distributed and 101 valid questionnaires were collected.

RESULTS

Results of thermal environment test

The data collected from the weather station shows the solar radiation of the whole day on the tested day (Figure 6). The maximum hourly solar radiation reaches 300W/m^2 at 13:00pm, which represents the typical sunshine level in winter of Chongqing. Although it is far lower than the national average value. Hourly temperature and humidity of the day are shown in Figure 7.

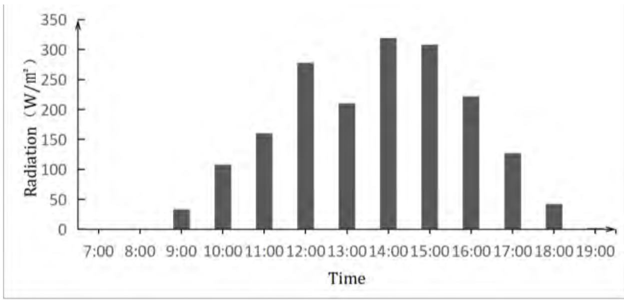


Figure 6.Hourly solar radiation

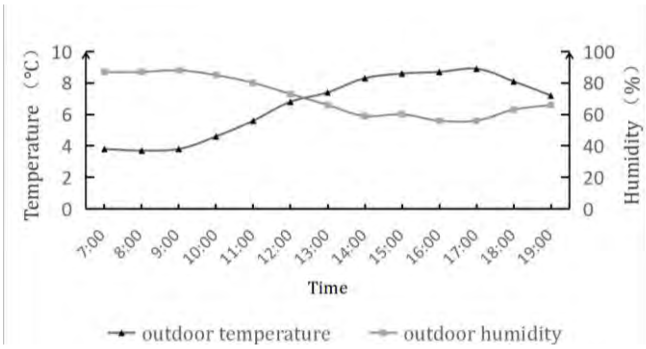


Figure 7.Hourly temperature and humidity

The measured air temperature, air humidity and wind speed were analysed (Figure 8). It can be seen that the temperature change trend of the five points in the test period is basically the same. The average temperature during the tested period is in the range of 7.0-8.0℃. However, the average temperature of point A of only 7.0 ℃ is lower than that of other measuring points. The maximum temperature of point A is also lower than that of other measuring points, only reaching 8.1 ℃. But the wind velocity of point A keeps staying at a high value all day, and the maximum instantaneous wind velocity reached 1.93m/s (Figure 9). The average wind velocity of the whole day for point A is also much higher than that of other measuring points, reaching 0.8m/s. In contrast, point B is in the state of low wind velocity all day, the average wind velocity is only 0.08m/s, which is the lowest of all the measuring points. The distribution of relative humidity is shown in Figure 10. The average relative humidity of point E is the smallest among all the measuring points, with an average relative humidity of 63.0%. In general, the relative humidity at each measuring point is basically consistent.

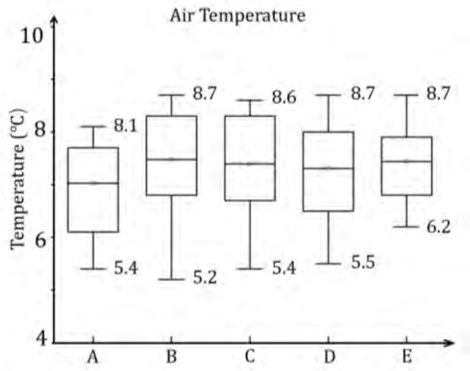


Figure 8.Air temperature of each point

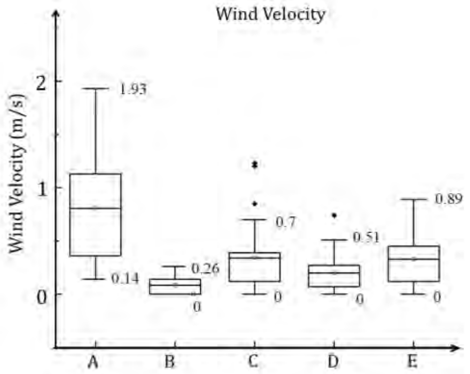


Figure 9.Wind velocity of each point

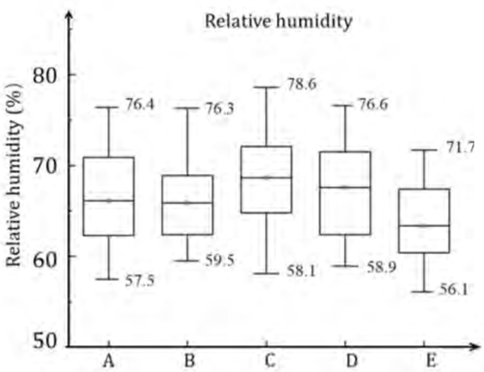


Figure 10.Relative humidity of each point

Results of Questionnaire Survey

- Source of pedestrian

As can be seen from the pie chart of pedestrian source and age distribution in Figure 11 and Figure 12, more than 50% of the interviewees are local permanent residents, with a small number of tourists. It indicates that the residents of the surrounding area have a high demand for outdoor activity space. According to the age distribution analysis, it can be found that more than half of the interviewees are over 50 years old, which indicates that the elderly people have a higher demand for outdoor activity space among the residents near the Egongyan Bridge.

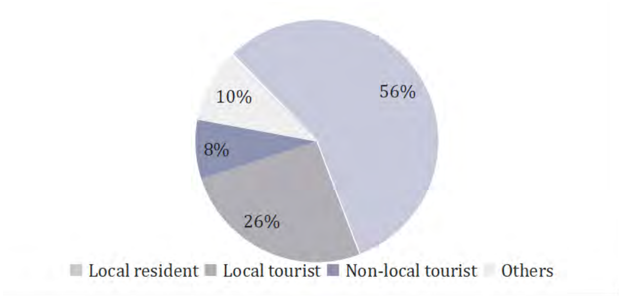


Figure 11.Pedestrian source

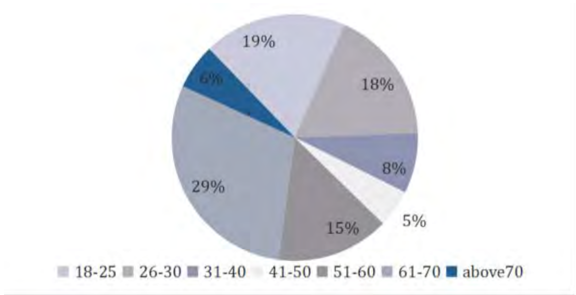


Figure 12.Age distribution

- Acceptance voting of thermal parameters

The results of the acceptance voting of environmental thermal parameters are shown in Figure 13.

It can be found that the sunshine acceptability of Point E is significantly lower than that of the other four points, and more than 50% of interviewees consider the sunlight at Point E to be "Unacceptable" or "Totally unacceptable". For temperature, the results for A, D and E are similar, with about 35% of interviewees voting "Unacceptable" or "Totally unacceptable". For humidity, point B comes out best, with all interviewees rating it as either "Acceptable" or "Totally acceptable". In terms of wind speed, point A performs the worst, with nearly 50% of interviewees rating wind velocity as "Unacceptable" or "Totally unacceptable", followed by point D. Other tested points are in good condition.

- Thermal sensational voting (TSV)

It can be seen from Figure 14 that subjective thermal comfort of point A and E is relatively poor, because option "Very uncomfortable" accounts for 3.4% and 10% respectively. The best situation appears at point B, with only 6.3% of the interviewees voted "Uncomfortable" or "Very uncomfortable". The proportion of "Uncomfortable" or "Very uncomfortable" at point C and D are lower than that of point A and point E, which accounts 28.6% and 20% respectively.

The results of the survey on the environmental factor most expected to be improved are shown in Figure 15. For the parameter of sunshine, interviewees from all the five points shows obvious demand. The highest demand emerges at point C and point E, accounting for proportion of 61.9% and 55.0% respectively.

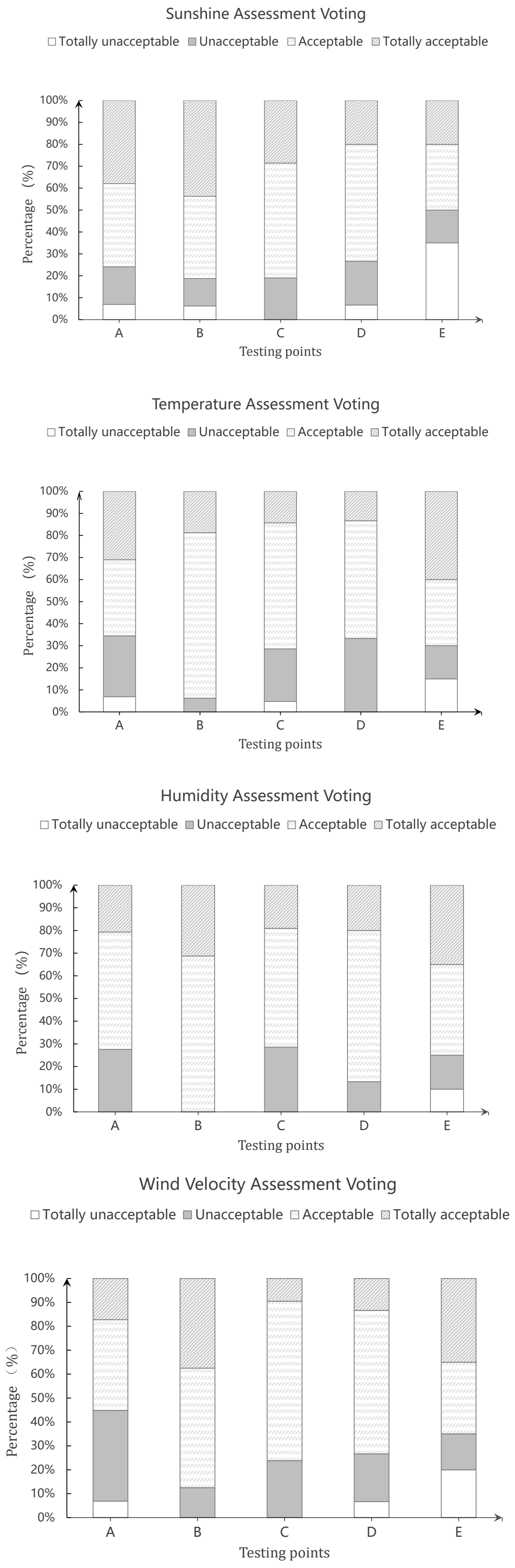


Figure 13.Thermal parameters assessment

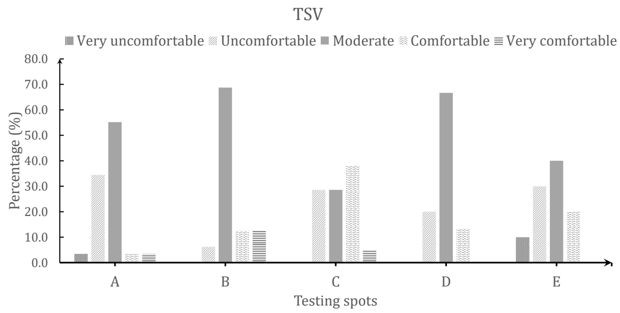


Figure 14.TSV of each point

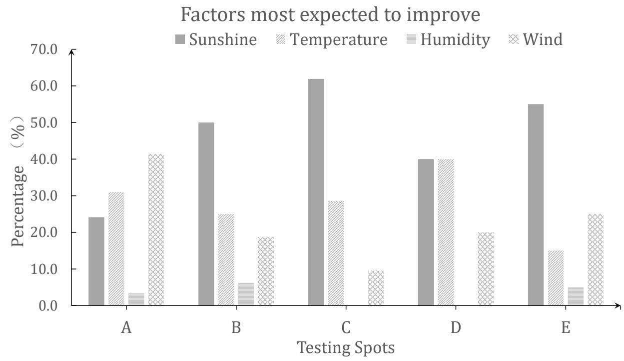


Figure 15. Factors most expected to improve

Results of Thermal comfort evaluation

In the outdoor experiment, the average radiation temperature (Tmrt) can be calculated from the black ball temperature (Tg), air temperature (Ta) and wind velocity (Va) by formula [1]:

$$T_{mrt} = \left[(Tg + 273.15)^4 + \frac{1.1 * 10^8 * V_a^{0.6}}{\varepsilon * D^{0.4}}(T_g - T_a)\right]^{0.25} - 273.15 \qquad (1)$$

Where:

ε is The emissivity of the black ball thermometer, D is the diameter of the black ball thermometer(mm), the diameter of the large black ball is 150 mm, and the diameter of the small black ball is 50 mm.

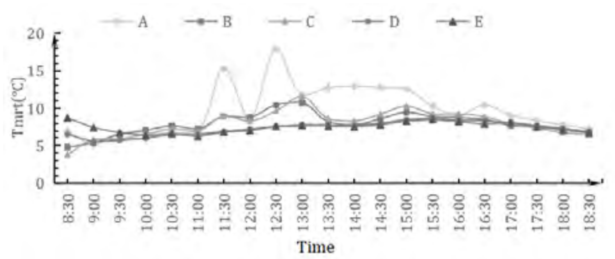


Figure 16.Tmrt of each point

The Tmrt results of each point is shown in Figure 16. It can be found that during the measurement period from 11:00 to 15:00, the average radiation temperature at point A is significantly higher than that at other points. The maximum value reaches 18.0℃, and lasts for 4 hours when it exceeds 10℃. This is because point A has the largest SVF, and it receives the most solar radiation during the day. In addition, Tmrt at point A increased sharply at 11:30 and 12:30, which may be due to a sharp increase in wind speed. The maximum value of Tmrt at B and C is around 13:00.

However, changing was not obvious for point D and point E. In general, except for point A, the changing trend of Tmrt of other points is basically the same. Tmrt keeps stable in the range of 6-10 ℃. This indicates that there is an obvious lack of solar radiation in the space under the Egongyan Bridge.

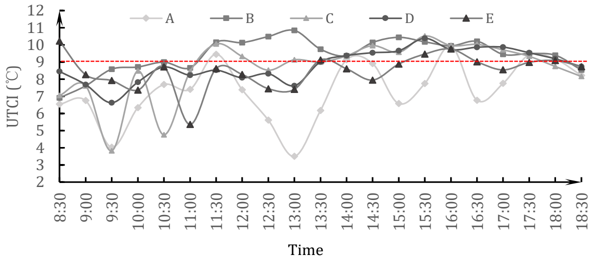


Figure 17.UTCI of each point

The Bioklima Software is taken to calculate UTCI through inputting four parameters including air temperature, relative humidity, wind velocity and average radiation temperature. The UTCI results are shown in Figure 17. It can be seen that UTCI of point A changes most severely. It drops to 3.50 ℃ sharply at 13:00 because of the increase of wind velocity. The UTCI of other points fluctuates between 7-9℃ in the whole day, keeping in the state of "slight cold stress". Due to the low wind velocity and adequate solar radiation, UTCI of point B reaches 9 ℃ around 13:00 and achieves "no thermal stress" state.

DISSCUSSION

Analysis of thermal environment test results

As can be seen from the test results of thermal environment, point A has the largest SVF and receives the most direct sunlight in winter. However, the air in the space cools down rapidly due to the winter opening towards the dominant wind direction. The heating effect of solar radiation is not as obvious as the cooling effect of cold air. This leads to a rapid drop in temperature. While point B and D are better surrounded by mountain structure and greenery, so the wind speed is lower and the temperature is higher.

Analysis of Questionnaire Survey

According to the acceptability voting of environmental thermal parameters, it is found that the acceptability of solar radiation at point E is the lowest of the five points. Because point E is located at the lowest altitude and sheltered by the southward mountains, which results in no direct solar radiation all day. Due to the influence of the cold wind, the interviewees' dissatisfaction with the wind environment is the highest at point A. This can be attributed to the lack of sunshine in Chongqing compared with the national average. Furthermore, the southward shelter under Egongyan viaduct makes sunlight situation worse. Therefore, all points reflect the demand for sunlight. In addition, none of the five measuring points show the expectation of humidity improvement. Because more than 80% of the interviewees were local people in Chongqing, and they had been used to the humidity in Chongqing from long time living here.

Analysis of factors affecting thermal comfort evaluation

The relevant factors affecting the thermal comfort of the under space of Egongyan Bridge are analyzed respectively (Figure 18, Figure 19). The R2 value of 0.46 reflects that the linear correlation between UTCI and SVF is larger than that of H/B, whose R2 value is mere 0.18. This shows that the difference of enclosure height by surrounding plants and the southward mountain leads to the difference of solar radiation and wind speed at each point, which finally leads to the difference of UTCI.

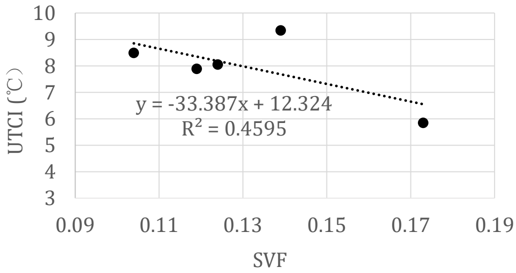


Figure 18.Correlation between SVF and UTCI

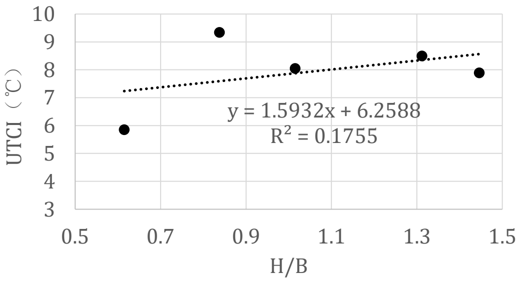


Figure 19.Correlation between H/B and UTCI

Thinking and deficiency

First of all, it is necessary to select the under space of Egongyan Bridge in Chongqing as the research object. On the one hand, the surrounding population is of high density, thus there is a strong demand for outdoor activities. On the other hand, the lower space of Egongyan Bridge is huge enough, therefore, efficient utilization of the space can alleviate the problem of shortage of urban public activity land. Furthermore, thermal comfort is a significant factor of solving the problem. Secondly, referring to the existing research, the experimental day was selected according to the typical year of Chongqing (Figure 4, Figure 5). Through the winter thermal environment test, subjective questionnaire survey and UTCI, the thermal comfort evaluation can be obtained. This result can provide reference to a certain extent. Finally, indeed, test results of only one day is relatively not adequate. It is suggested that the thermal comfort related experiments of this kind space can be carried out for more days in order to improve accuracy.

CONCLUSION

The results are as follow: The linear correlation between SVF and U TCI is stronger (R2=0.46) than that of H/B (R2=0.18). The subjective thermal perception questionnaire showed that about 46.2% of the interviewees care most about the sunshine condition. The sunshine level of Chongqing is on the low side in the whole country. Under the limited condition, measures such as movable reflector should be taken to improve the solar radiation level under viaducts. In this way, it can reach closer to the average level of Chongqing, so as to improve the thermal comfort of the activity space under viaducts. Through the combination of objective thermal environment test and subjective thermal questionnaire survey, this paper evaluates the thermal environment under the Egongyan Bridge from the quantitative and qualitative point of view. Finally the mechanism of environmental factors affecting crowd activities can be explored. This should also provide reference for creating a more comfortable activity space under the viaduct in the future as well as basis for the sustainable development of the city.

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