Research on Outdoor Thermal Environment of Campus in Cold Area in Winter with Different Underlying Surfaces

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Abstract. Thermal environment has many influences on people who use outdoor space. The thermal environment of university campus is an important part of educational living space. In campus planning and design, the impact of landscape design on the thermal environment should be considered. This paper measures the thermal environment of the campus of Xi’an Eurasia University and conducts questionnaire survey to obtain the Library, East Gate Square, Nanshan Road, and Parking lot 4 different underlying surface characteristics of the impact on the thermal environment. The results show that the SET* correlation of different underlying surfaces: Library > East Gate Square > Nanshan Road > Parking lot. Shade, grassland, and water bodies can effectively reduce the average radiant temperature. Among them, the humidification and cooling effects of the shade are the best, and the cooling ability of the grass is second only to the shade. In the process of campus environment design, reasonable adjustment of the relationship between the shade of the grass and other underlying surfaces can effectively improve the outdoor thermal comfort of the campus in winter and create a comfortable outdoor activity place on the campus.

1. Introduction
The microclimate of outdoor space is an important factor that affects users’ use and evaluation of outdoor space[1]. Outdoor thermal comfort of university campus is an important subject to encourage students to engage in outdoor activities and interactions[2]. In recent years, many scholars have conducted a large number of studies on the outdoor thermal environment. Zhu Yuemei [3] et al. established a calculation model of outdoor thermal comfort with SET* as the evaluation index. Ishii [4] et al. compared several commonly used evaluation indexes and found that SET* is more suitable for outdoor thermal comfort evaluation. Jiang Yi [5] et al. conducted related studies on the thermal environment and comfort of university campuses in hot and humid areas in summer.

At present, researches on outdoor thermal environment are mostly concentrated in large cities or blocks, and there are few researches on microclimate in specific areas of campus. As students are a regular group of campus activities for a long time, it is particularly important to pay attention to the relationship between college students' thermal comfort and the environment. Xi’an belongs to the cold region of China, with mild cold and little rain in winter, dry and cold. By comparing the existing literatures, it is found that there are few studies on the thermal environment of winter campus in cold regions, and few studies choose SET* as the evaluation index of thermal environment. Therefore, this study took the campus of Xi’an Eurasia University as the research object. Based on fixed-point observation and in the form of thermal environment questionnaire survey, the average radiation temperature and SET* were selected as evaluation indexes to test and study the characteristic area of
the outdoor surrounding underlying surface of Xi’an Eurasia University in winter. The results of this study quantitatively analyzed the correlation between the outdoor thermal environment parameters, air temperature and SET*, and put forward effective ways to improve the outdoor thermal environment in winter, which provided ideas for the optimization of the outdoor thermal environment of the campus in cold areas.

2. Site text

2.1. Research area

The research area is located in Xi’an Eurasia University (108.9235 ’N 34.17768’ E), which is located in Dongyi Road, Yanta District, Xi’an, Shaanxi Province, China, and adjacent to Qingliang Mountain Park. The campus covers an area of 286 835.68 m², with a good campus greening rate of over 65%. There are many kinds of vegetation in the campus, mostly tall trees. The campus is mainly composed of teaching area, activity area and dormitory area. Based on the principle of representativeness and feasibility, in order to compare and analyze the differences of microclimate among different underlying surfaces, four observation points were selected in university for meteorological data observation after field survey. The distribution of the observation points is shown in Figure 1 and the observation site and the underlying surface are as follows:

| Fixed Point | 1          | 2          | 3          | 4        |
|-------------|------------|------------|------------|----------|
| Surface Type| Dark painted concrete | Asphalt | Lawn | Light-colored ceramic tiles |
| Shade Condition | Unshaded | Shade | Part of the shade | Unshaded |
| Note | | | Water nearby | |

Figure 1. Hand-drawn diagram of measuring point distribution
Table 2. Instrument model and parameter

| Measurement parameters | Measuring instrument | Instrument precision | Measuring range | Acquisition methods |
|------------------------|----------------------|----------------------|-----------------|-------------------|
| Wind speed             | ±(0.2+0.03 V)m/s, V is wind speed | ±1°                  | The default 0~50 m/s (0~60 m/s can be customized) | Automatic           |
| Wind direction         | 8 indicated directions /0~360° measurement | 0.0~999.9 MCG/m3/0 to 20 micrograms per cubic meter | Temperature Range: -40~+125 °C (-40~257 °F) | Automatic           |
| PM<sub>2.5</sub>/PM<sub>10</sub> parameters | Outdoor weather station | 0.2 micron | Automatic | Automatic |
| Temperature/Humidity   | 0~ 100% RH           | Humidity range: 0~ 100% RH | Manual          |                   |

The experiment was conducted from December 1st to December 31st, 2020 for one month of data collection. The test time lasted from 9:00 in the morning to 21:00 in the evening. Data collection of air temperature, relative humidity, surface temperature, black bulb temperature, wind speed, inhalable particles and other parameters was conducted every 10 min at each measuring point, and the measuring point was 1.5m above the ground (the height of pedestrian level was selected). The instrument is selected according to the relevant requirements of ISO 7726 1998<sup>[6]</sup>, and it meets the accuracy and sensitivity of the test, as shown in Table 2. In the final data, two consecutive weather parameters on December 10 and December 11 are relatively stable as the analysis objects.

A total of 511 questionnaires were distributed during the survey, and a total of 495 valid questionnaires were issued. In order to make the questionnaire data more intuitive and effective, this experiment adopts a combination of practical measurement and questionnaire survey. The questionnaire is divided into two parts. The first part includes the basic information of the subjects, and the second part includes the thermal sensation status, thermal acceptability and expectation change of the subjects.

3. Results and analysis

3.1. Air temperature and relative humidity analysis

Table 3 shows the air temperature distribution over different types of underlying surfaces. In the two-day test, the air temperature on Nanshan Road was the lowest, and the maximum difference between the air temperature above the Parking lot reached 9 °C. Due to the difference in reflectivity and the presence of water nearby, the temperature above the light-colored tiles in the East Gate Square is lower than that over the dark concrete in the Parking lot, indicating that the water surface has an evaporative cooling effect. However, due to the lack of shading measures over the water, the air temperature above the water is higher than that under the trees on Nan Shan Road. The evaporation capacity of the water surface is much stronger than that of the grassland, but the water body is kept away from the measuring point, so the air temperature over the grassland is higher than the air temperature over the water surface but the difference is not significant. Therefore, the ability of different underlying surfaces to reduce the ambient air temperature is in order of shade>water>grass> ground.

In the test process, the relative humidity data of four different types of underlying surfaces were collected. As shown in the table, the relative humidity of Nanshan Road is the highest, and the value of Parking lot is the lowest. The highest average relative humidity appeared in Nanshan Road, and the lowest average relative humidity appeared in the Parking lot. Due to the influence of water and wind direction, the air humidity in the East Gate Square is obviously higher than that in the Parking lot. The relative humidity above the concrete and grass is about the same. Therefore, the ability to improve the relative humidity of air in the environment can be as follows: shade>water>grass> ground.
Table 3. Air temperature in different underlying surface areas /℃

| Project       | East Gate Square | Nanshan Road | Parking lot | Library |
|---------------|------------------|--------------|-------------|---------|
| Mean air temperature | 16.47            | 12.7         | 18.79       | 16.67   |
| Maximum       | 18.19            | 13.47        | 20.82       | 18.57   |
| Minimum       | 14.04            | 11.69        | 16.13       | 14.38   |

Table 4. Relative humidity parameters in different underlying surface areas /%

| Project       | East Gate Square | Nanshan Road | Parking lot | Library |
|---------------|------------------|--------------|-------------|---------|
| Mean relative humidity | 66.94            | 78.99        | 53.48       | 58.86   |
| Maximum       | 84.00            | 91.43        | 74.13       | 79.09   |
| Minimum       | 49.88            | 66.54        | 32.83       | 38.63   |

3.2. Underlying surface temperature analysis

The surface temperature of the underlying surface not only affects the air temperature and relative humidity at the pedestrian height \(^7\), but also has a great influence on the comfort of people living nearby \(^8\). Hourly temperature changes of different underlying surfaces are shown in Figure 2. As can be seen from Fig. 2, the hourly surface temperature of each measuring point varies greatly but its changing trend is basically the same. The overall surface temperature distribution trend is concrete>light-colored tiles>asphalt>grass, that is, Parking lot> East Gate Square >Nanshan Road>Library.

In two days, the peak value was the surface temperature of the concrete in the Parking lot, and the peak and valley were the surface temperature of the grass in the library, with a difference of 16 °C. Although the underlying surface of Nanshan Road is asphalt, it is shaded by trees, while the concrete underlying surface of the Parking lot is exposed to the sun without any shading, resulting in poor cooling effect. The results show that the problem of excessively high temperature of the underlying surface can be improved by effective shading and cooling measures.

3.3. Mean radiation temperature analysis

Herrington et al. indicated that the mean radiant temperature (Tmrt) and wind velocity played a more important role on human response than temperature in the outdoor environment. Mean radiation temperature (Tmrt) means that the radiative heat exchange between the surface temperature of an imaginary isothermal surface and the surrounding environment is equal to the heat exchange between the actual non-isothermal surface and the surrounding environment. The calculation method of Tmrt is as follows:

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T_{mrt} = [(T_g + 273)^4 + (1.10 \times 10^8 \nu^0.6)(T_g - T_a)/(\varepsilon D^0.4)]^{1/4} - 273
\]

Where, Tg and Ta are black bulb temperature and air temperature (°C); V is air speed (m/s); D is the radius of the black sphere (m), 0.15m; \(\varepsilon\) is the absorption rate of black sphere, taking 0.95.
Figure 3. Mean radiant temperature of different underlying surfaces

As shown in Figure, the variation of the mean radiation temperature in each underlying surface area. As can be seen from the Figure 3, the mean radiation temperature in Parking lot is the highest and fluctuates the most within two days. The second is the East Gate Square, which is due to the presence of a body of water near the light-colored tiles which can reduce the mean radiation temperature. During the test period, the mean radiation temperature at Nanshan Road varied gently and the Tmrt was the smallest, with a maximum of more than 21 °C compared with other measurement points. It can be seen that tall trees play a direct shading role in reducing solar radiation. Therefore, considering the landscape design, tall trees, grassland and water can weaken the mean radiation temperature to a certain extent.

3.4. SET* index and correlation analysis
Standard effective temperature SET* means that in the environment under certain conditions, if the average skin temperature and skin humidity at this time are the same as the actual environment and the actual clothing thermal resistance conditions, then the air temperature in the standard environment is the standard effective temperature SET* of the actual environment. The environmental test data of this survey is processed according to the standard effective temperature index, as shown in Figure 4. The standard effective temperature change curve during the test period is similar to the average radiation temperature change curve. The standard effective temperature of the Parking lot in the west area and the East Gate Square fluctuated greatly, and the maximum difference is 16 °C and 13 °C. Except in the evening, the overall temperature values of both were higher than the library and Nanshan Road. The results show that trees and grass can directly reduce the fluctuation range of SET* and SET*.

Figure 4. Standard effective temperatures for different underlying surface

Figure 5 shows the correlation between the average radiation temperature of different underlying surfaces and the standard effective temperature. In this figure, the average value of Tmrt is positively correlated with SET*. It mainly depends on the value of the correlation coefficient R2. When different types of underlying surfaces increase in different proportions, the closer R2 is to 1, the greater the correlation between the two. Finally, the SET* correlation of different underlying surfaces is obtained:
Library > East Gate Square > Nanshan Road > Parking lot, indicating that the nature of the underlying surface will affect the correlation coefficient between the average radiation temperature and SET*.

![Figure 5. Correlation analysis diagram of standard effective temperature](image)

3.5. Thermal comfort analysis

Figure 6 is the frequency distribution of the subjects’ Thermal Sensation Vote (TSV). There are a total of 495 valid questionnaires in this survey. Among them, slightly hot, moderate and slightly cold are the main distributions of hot sensation voting. This indicates that the human body can accept the thermal environment around different underlying surfaces during most of the test period. Comparing the different underlying surfaces, it can be found that the students feel colder near the water body and hotter on the hard ground, and the moderate heat sensation accounts for the highest proportion of 45% in the grass and the shade. At the same time, when interviewing the activity areas where the subjects are willing to stay, it was found that more than 33% of the subjects were willing to move or stay under the grass and the shade, further indicating that the grass and the shade can well play a role in cooling and moisturizing, and improve the thermal comfort of human body.

![Figure 6. Thermal sensation voting of different underlying surfaces](image)
4. Conclusions

(1) The average air temperature of hard ground in the campus Parking lot is higher than other underlying surfaces, and the minimum is Nanshan Road. The air temperature of the underlying surface is consistent with the ability to increase the relative humidity of the air: shade > water > grass > ground.

(2) The size of SET* will be affected by different underlying surfaces, and the correlation between the average radiation temperature and SET* is also affected by the nature of the underlying surface. Among them, the average radiant temperature of the library has the largest correlation with SET*, and the SET* of the Parking lot has the least correlation. In addition, there is a linear relationship between air temperature and black bulb temperature, but the correlation decreases with the increase of solar radiation intensity.

(3) Both the tree shade and the grassland have the ability of evaporation cooling, and the tree shade is larger than that of grass. The maximum difference in surface temperature between the two is 6.88 °C. At the same time, the surface temperature of grass and tree shade is lower than that of ground, and the maximum difference is 20.5 °C and 9 °C respectively. This is also consistent with the tendency of most students to choose to walk in the shade of trees and grass.

(4) Through effective shading and cooling measures, such as planting tall trees, laying lawns, adding water landscape, the temperature of the underlying surface and the average radiation temperature can be reduced, and the cooling effect of trees is the best. The maximum difference of ground temperature and air temperature between the Parking lot without shade and the avenue of Nanshan Road with shade is 15 °C and 6 °C. This also provides ideas for the future campus construction in cold areas to create a more comfortable outdoor thermal environment by using its regulating function of cooling and humidification.

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References

[1] Zefeng, Huang Bin, Cheng Zhonghua, et al. Outdoor thermal comfort and adaptive behaviors in a university campus in China's hot summer-cold winter climate region[J]. Building and Environment, 2019, 165:1-2

[2] Manat Srivanit, Kazunori Hokao. Evaluating the cooling effects of greening for improving the outdoor thermal environment at an institutional campus in the summer [J]. Building and Environment, 2013, 66:158-160

[3] Zhu Yuemei, Yao Yang, etc. Establishment of outdoor environment thermal comfort model [J]. Building Science, 2007(06): 1-3

[4] Ishii A, Katayama T, Shiotsuki Y, et al. EXPERIMENTAL STUDY ON COMFORT SENSATION OF PEOPLE IN THE OUTDOOR ENVIRONMENT [J]. Journal of Architecture Planning & Environmental Engineering, 1988, 386(386):28-37

[5] Jiang Yi, Zhao Lihua, Meng Qinglin. Study on thermal comfort of urban pedestrian space in hot and humid area in summer [J]. Chinese Journal of Civil and Environmental Engineering, 2020, 42(03):174-182

[6] Ergonomics of the thermal environment-Instruments for measuring physical quantities: ISO7726 [S]. International Organization for Standardization, Geneva, 1998:156-158

[7] Tzu-Ping, Lin Yu-Feng, Ho, Yu-Sung Huang. Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan[J]. Building and Environment, 2006, 42(12):4124-4126

[8] ASHRAE. Handbook of fundamentals[M]. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 2001