# SIMULATION ANALYSIS AND DESIGN OPTIMIZATION OF CAMPUS OUTDOOR THERMAL ENVIRONMENT UNDER COMPOUND ENERGY SUPPLY SYSTEM

by

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*In order to solve the problem of quantitative analysis of the impact of greening facilities on outdoor near-ground temperature, the author proposed the simulation analysis and design optimization of campus outdoor thermal environment under the compound energy supply system. On the basis of UAV aerial survey data, ENVI-met was used to establish two schemes of actual and non-vegetation in the study area, and the thermal environment was simulated and compared. The experimental results show that: UAV tilt photography can quickly obtain orthophoto images and high precision 3-D information of the research area, and ENVI-met modelling is more flexible and cheaper. The correlation coefficient between the results and the measured results is >0.9, and the root mean square error is 0.6 ℃, the simulation results can reflect the distribution of temperature in the study area well. Vegetation and turf had obvious cooling effect, the area of high temperature area (>36 ℃) in the study area without vegetation increased by 34%, the area of predicted mean vote (PMV > 4.5), which is an evaluation index of human thermal response (cold and heat sensation), increased by 17%. In the vertical direction, the cooling effect of vegetation on the ground can be extended to 15 m. In conclusion vegetation and greenery can reduce the temperature near the ground through transpiration, effectively improve the urban thermal environment, and improve human comfort.*

Key words*: ENVI-met, numerical simulation, outdoor thermal environment, micro climate*

## Introduction

The types and applications of energy reflect the needs of social development and are restricted by the level of science and technology. From the point of view of regional resources, various types of energy resources in China are mainly planned and operated separately, which increase capital cost, decrease energy consumption, and cause environment pollution. Furthermore, from the point of view of local users, it is difficult for a single power supply system to achieve a high utilization rate of electronic resources even in view of meeting the basic needs of users. In this context, energy efficiency as a result of increased energy consumption has occurred at a historic moment, namely, in some regions, in all linkages between energy production, supply, storage and consumption, *g*. Technology and management have been used to realize the integrated and integrated utilization of energy, gas, heat, and cooling energy, which

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provides an important way to solve the regional energy consumption and optimization problems, fig. 1.


**Figure 1. Composite energy supply system**

## Literature review

Field measurement is the main means of urban thermal environment research, using measured data, we can study the changes of urban thermal environment and analyze the influencing factors of thermal environment. Because only limited data can be obtained from field measurement, it is difficult to fully reveal the urban scale thermal environment. With the development of remote sensing technology, thermal infrared remote sensing provides a new platform for the study of urban outdoor thermal environment, however, for complex urban structure, it still cannot meet the requirements for the study of micro-scale thermal environment such as blocks [1].

Puntaier *et al*. [2] developed the numerical simulation analysis software ENVI-met of urban microclimate by studying the thermal dynamic relationship between buildings, air, vegetation and soil, it is suitable for studying small scale microclimate, and can quantitatively analyze the change characteristics of microclimate. The ENVI-met numerical simulation software has been widely used by domestic and foreign scholars to study the lay-out of urban landscape pattern, simulate the thermal environment of blocks and analyze the influencing factors of microenvironment. Microclimate simulation research generally obtains some quantitative information such as buildings, vegetation distribution and underlying surface needed for ENVI-met modelling through field investigation, collecting information manually is a tedious and time-consuming task. Due to the limitation of spatial resolution, there are still few reports on the application of remote sensing to urban microclimate simulation at street valley scale [3, 4].

## Methods

### *Research data*

The study area is located in the campus of a university (36° 40′ N, 117° 00′ E), with an area of 480 m × 480 m, which belongs to the temperate monsoon climate with hot and rainy summer.

The drone platform is a DJI Phantom 4pro with 20 million pixel CMOS sensors, orthophoto was acquired by aerial flight in the research area, and orthophoto image Mosaic was performed based on the UAV image processing software Pix4D, in order to obtain the orthophoto map of the study area. Since ENVI-met can only recognize the base map in BMP format, ArcGIS software is used to cut the image and transform the image format.

In order to accurately capture quantitative data such as building heights and road widths, firstly, image control points should be evenly distributed in the study area through

GPS connection with CORS station, and the SMART3D software should be used to establish the real 3-D model and DSM of the study area for the acquired aerial survey data of the study area, the height of buildings and vegetation in the study area was calculated by combining the digital elevation model. The information needed to establish the ENVI-met model, such as road width and water area, can be obtained through the calculationol of its software [5].

### *Research methods*

The 6:00 on July 10, 2017 was selected as the starting date of the simulation, the simulated primary air level parameters were obtained by the measurement system, and the local air station data were taken as background data, for other parameters, the default values provided by ENVI-met are adopted, the total simulation duration is 24 hours, and a set of data is output every 1 hour, the output data mainly includes temperature, wind speed, relative humidity and other indicators [6]. Four nested grids were set outside the main model area to reduce the influence of the external environment on the simulation, simple forcing function was used in the simulation process, hourly temperature and relative humidity were input to correct the simulation parameters, thus, the simulation accuracy is improved, the basic parameter settings of ENVI-met simulation parameters are shown in tab. 1.

**Table 1. The ENVI-met simulation basic input parameter setting table**

| | Parameter | Parameter values |
|---|---|---|
| Simulation settings | Total simulation duration [hour] | 24 |
| | Output time interval [min] | 60 |
| | Number of nested grids | 4 |
| Initial parameter settings | Simulation start date | 2017/7/10 |
| | Simulation start time | 6:00 |
| | The initial temperature [K] | 299.7 |
| | 10 m high wind speed [$ms^{-1}$] | 3 |
| | 10 m high wind direction [°] | 90 |
| | 2 m high relative humidity [%] | 65 |
| | 2500 m specific humidity [$gkg^{-1}$] | 8 |

The RMSE and mean absolute percentage (MAPE) were used to evaluate the simulation results, respectively:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - x_i'\right)^2}{n}} \tag{1}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|x_i - x_i'\right|}{x_i}\times 100\% \tag{2}$$

where $x_i$ is the simulated value and $x'_i$ – the measured value. n is the measured number of times. Both RMSE and MAPE can reflect the degree of deviation of the simulated value from the measured value, and the smaller the value of the two, the higher the simulation accuracy [7].

### *Composite energy supply system*

The integrated circuit is composed of power grid, fuel grid and renewable energy grid. From power conversion devices such as CHP, EB, and GB, the power on the input side is converted into electricity, heat and other energy sources and transmitted to the user. In addition, in order to allocate energy reasonably, there are energy storage devices such as electric energy storage and thermal energy storage [8].

Under the same supply reliability condition, the equipment configuration capacity under the constraint of improved index is smaller than that under the constraint of traditional index, and the corresponding annual comprehensive cost is lower. Due to the time scale difference of electrical load and thermal load, the traditional reliability calculation method which is consistent with electrical load is too conservative. During the interruption of heat load supply, the calculation of heat deficiency load expectation based on temperature changes is more accurate and flexible, which can reduce the system equipment configuration capacity and avoid redundant investment of equipment. It can be seen that the improved reliability index is of more guiding significance in the actual energy system planning and analysis.

## Results and discussion

### *The ENVI-met simulation results of campus thermal environment*

Simulate the change of temperature and relative humidity at test Point 1 within 24 hours, and compared with the measured data obtained from the handheld weather station, the results are shown in figs. 2 and 3. The temperature measurement accuracy is in good agreement with the temperature gradient, with a correlation coefficient of 0.96, RMSE of 0.68 °C and MAPE of 1.94. Simulated relative humidity is also related to the measurement of relative humidity. The correlation coefficient is 0.94, and RMSE and MAPE of relative humidity are 2.5 and 3.9, respectively, both in the permissible error, indicating that enbe can simulate the city microenvironment better [9, 10]. Because the measured data is easily affected by the surrounding environment, there will be errors between the measured value and the simulated value. In order to better evaluate the reliability of the simulation results, error comparison and analysis were made between the measured and simulated values of the five measured points in the study area, and their average values were calculated, as shown in tab. 2. The correlation coefficient was

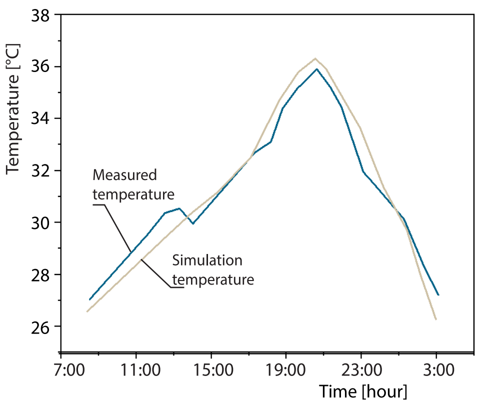


**Figure 2. Measured and simulated values of the measured Point 1 (1.4 m height) in the study area**

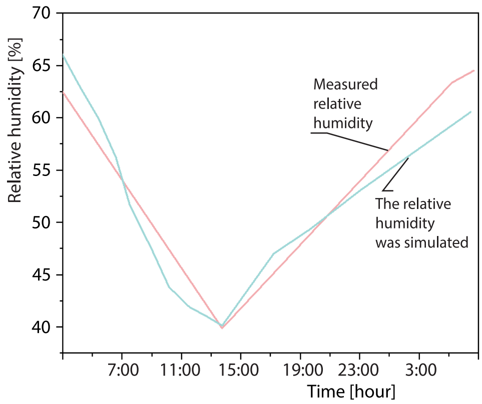


**Figure 3. Comparison between the measured and simulated values of the measured Point 1 (1.4 m height) in the study area**

> 0.9, indicating good fitting effect between the measured and simulated values. The RMSE and MAPE of temperature are within the allowable range of error, indicating that the error between the measured and simulated values is small. The RMSE and MAPE of relative humidity were less than 5%, indicating that the simulation could well reflect the reality.

**Table 2. Statistical table of quantitative evaluation of prediction ability of ENVI-met model**

| | The evaluation index | | |
|---|---|---|---|
| Evaluation of the amount | The correlation coefficient | RMSE | MAPE [%] |
| The temperature (1.4 m high) | 0.94 | 0.60 °C | 1.47 |
| Relative humidity (1.4 m high) | 0.95 | 2.60% | 3.83 |

### *Temperature simulation analysis*

In order to analyze the temperature distribution of the study area and its influence on the time variation of the study area, the simulation results of the time representation of the subject are selected. At 10:00 hours, the highest temperature in the study area was 32.4 °C, and the highest temperature appeared above the asphalt road. Because of the small heat capacity of asphalt, when subjected to solar radiation, the asphalt heats up rapidly and has changed to the air near the ground environment. The lowest temperature is 29.2 °C, and the lowest temperature is mainly distributed near the water body and the shadow area of buildings. Compared with the region, the specific heat capacity of the water body is larger, and the temperature increases slowly under the same electric field. The temperature near the top of the water body is lower than the temperature near the surrounding region [11]. The temperature difference is 3.2 °C, and the temperature varies greatly with space. Plants absorb heat from transpiration, reduce temperature above grassland, but the cooling effect of green space is not obvious, because of grassland area and small leaf area. The trees and forests on both sides of the road have some blockages of solar radiation, resulting in temperature near lower than open area [12, 13].

### *Analysis of simulation results of the no-vegetation scheme*

In order to study the influence of vegetation on temperature distribution and PMV in the study area, the ENVI-met model was modified to replace vegetation and lawn in the original model with bare soil, the basic parameter Settings of the model simulation are the same as the actual situation with vegetation before, and the distribution characteristics of temperature and PMV in the campus are simulated when vegetation is removed [14, 15].

#### *Influence of vegetation on temperature distribution*

The temperature distribution under the two schemes was counted at 14:00, the maximum and minimum temperatures in the study area under the actual status scheme at 14:00 were 37.56 °C and 33.04 °C, respectively, the maximum and minimum temperatures without vegetation were 37.66 and 33.08 °C, respectively, and there was no change in the maximum and minimum temperatures under the two schemes. In order to more intuitively reflect the influence of vegetation on the temperature distribution in the study area, the histogram of the temperature distribution in the study area was statistically analyzed, as shown in fig. 4, in the case of no vegetation, the area >36 °C in the study area accounts for about 77%, an increase of 34% compared with the actual scheme, it can be seen that the temperature in the study area increased significantly after the removal of vegetation in the campus [16].

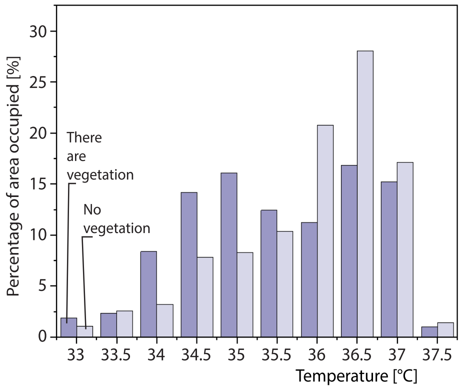


**Figure 4. Histogram of temperature distribution at 1.4 m height under two schemes in the study area at 14:00**

The temperature difference map between the non-vegetation scheme and the actual scheme at the pedestrian height of the study area at 14:00, after removing the vegetation, the overall temperature in the study area increased compared with the actual situation, among them, the difference of temperature in the area with vegetation removal is large, mainly because the sun directly radiates the underlying surface after vegetation removal, which increases its temperature, and the transpiration of vegetation disappears. The near-ground temperature in the shadow of the building changes little with the disappearance of vegetation [17]. According to statistics, the average temperature difference of the study area under the two schemes is 1-1.2 °C, although the temperature difference is not too large, the area of the high temperature area in the study area increases significantly. It can be seen that vegetation and greening can effectively reduce the near-ground temperature and reduce the high temperature area.

### *Influence of vegetation on outdoor thermal comfort distribution*

The difference map of PMV between the no-vegetation scheme and the actual scheme at 14:00 in the study area, after removing the vegetation, the PMV level in the study area increased, and the PMV value above the asphalt pavement near the ground increased significantly, with an average increase of 1 level. In the devegetated areas, radiation and transpiration disappear due to vegetation shielding, PMV levels also increased. In the shadow of buildings and near water bodies, PMV levels changed little after removing vegetation. The histogram of PMV distribution of pedestrian height at 14:00 in the study area was statistically analyzed, as shown in fig. 5, before removing vegetation, in the study area, the area with PMV > 4.5 accounted for 77% of the total area, and the area with PMV > 4.5 in the no-vegetation scheme was as high as 94%, an increase of 17% compared with the actual situation [18].

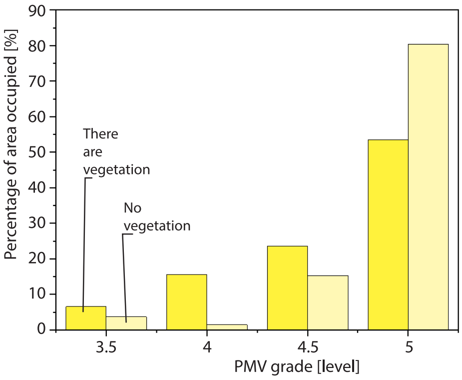


**Figure 5. Histogram of PMV distribution at 1.4 m height under two schemes in the study area at 14:00**

In order to study the vertical cooling effect of vegetation on temperature and the effective height of solar radiation warming near the ground under the condition of no vegetation, take the simulated output data at 10:00 (heating period) as an example to make the trend chart of temperature variation with height under two conditions, as shown in fig. 6, the cooling effect of vegetation near the ground was obvious, and the cooling effect gradually weakened with the increase of vertical height. When the height is about 15 m, the temperature at this point is basically the same in both cases [19]. Then, with the increase of height, the temperature changes at vertical height are basically the same in both cases, with the error within 1%. Above the height of 15 m, the temperature in the absence of vegetation is slightly lower than that in the presence of vegetation, mainly because in the absence of vegetation, the air above the study area moves faster, taking away some of the heat. In conclusion, the effective height of vegetation for cooling near the ground in the study area in the vertical direction is about 15 m.

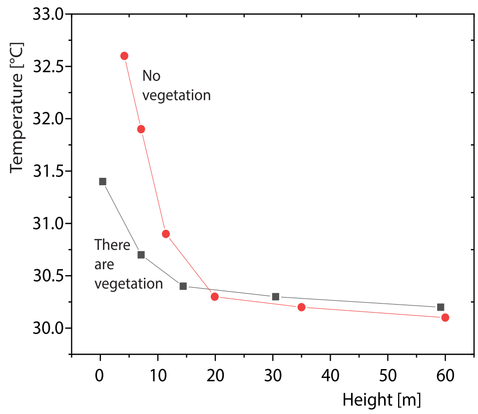


**Figure 6. Variation of temperature with height in the study area under no vegetation scheme and the actual scheme at 10:00**

## Conclusion

The authors put forward the simulation analysis and design optimization of the campus outdoor thermal environment under the compound energy supply system, the UAV tilt photography can quickly obtain high resolution orthophoto images and high precision 3-D information of the research area, which can meet the needs of micro-scale thermal environment research such as blocks, and the acquisition method is more flexible and the cost is lower. The ENVI-met evaluated the thermal environment simulation results of the study area, the correlation coefficient between simulated temperature and measured temperature is 0.94 > 0.9, RMSE and MAPE are 0.6 °C and 1.47%, respectively, the prediction accuracy of simulation is high and can reflect the actual situation more accurately. Vegetation has obvious cooling effect. After removing the vegetation, compared with the simulation of the actual situation, the temperature of 1.4 m height in the study area increased by 1-1.2 °C on average. The temperature in the shadow of buildings and near water bodies changed little after removing vegetation. Under the no-vegetation scheme, the high temperature area (>36°C) in the study area increased by 34% compared with the actual situation, and the area of PMV > 4.5 increased by 17%. The effective vertical height of the cooling effect of vegetation on the ground can be extended to 15 m, the temperature variation of the two cases with vertical height > 15 m without vegetation and the actual situation is basically the same, and the error is within 1%. It can be seen that vegetation and greenery can reduce the temperature near the ground through transpiration, effectively improve the urban thermal environment and improve human comfort.

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