Impact of vegetation pattern and wind speed on thermal environment in building group

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Abstract. Vegetation pattern and wind speed have a significant impact on outdoor thermal environment. This paper takes the air temperature of pedestrian areas in building group as the analytical variable. The simulation software of ENVI-met is employed to analyze air temperature variations under different vegetation patterns, tree heights and wind speeds in Shanghai. Firstly, a lot of cases are established to analyze the impact of vegetation patterns on outdoor thermal environment. Secondly, different tree heights are talked about to analyze the impact on outdoor thermal environment. Finally, the impact of wind speed is added on the basis of previous cases. The simulation results show: The tree pattern has the best cooling effect in three vegetation patterns, which can reduce the temperature by about 1℃; Within a certain height range, the taller the tree is, the more obviously the thermal environment temperature reduces; Higher wind speed is beneficial to reduce the ambient temperature of pedestrian areas, but it will lead to intensified uneven temperature distribution and make pedestrians feel uncomfortable. The simulation results can provide references for the preliminary planning and design of building group.

Keywords. Building group, Vegetation pattern, Tree height, Wind speed, Outdoor thermal environment

1. Introduction
With developments of science and technology, the urbanization process has gradually accelerated, and the number of building groups presents a rapid growth trend. It leads to ambient temperature increasing, and affects residents’ health and comfort. The urban heat island (UHI) has an important impact on urban thermal environment and residents’ life, especially in building group. In recent years, the UHI effect caused by the urbanization is becoming more and more obvious. Just take China as an example, the annual average temperature in China is in increasing trend and it is 0.95℃ higher than other years (1961-2014) in 2015 [1].

The building group is the basic unit of urban areas. The urban environment can be formed by the micro-environment of several building groups and is mainly divided into two aspects. On the one hand, there are some natural factors which are uncontrollable, such as solar radiation, wind and weather [2-4]. On the other hand, there are some human factors which could be controlled, such as building layouts, vegetation, and water bodies [5-7]. If we can use human factors to guide urban planning and design rationally, some impacts of natural factors on outdoor environment would be better adjusted, especially in temperature decreasing. Therefore, the thermal environment temperature
in building group directly reflects the UHI intensity (Air temperature difference between urban and suburban). When the urban temperature gets lower, the UHI intensity will also reduce.

Vegetation is an efficient design strategy and has many advantages to improve the outdoor thermal environment in building group. It can form big shadows and decrease the environment temperature [8,9]. Reasonable vegetation patterns can effectively achieve passive cooling [10,11]. Vegetation density can determine the cooling effect within a certain range [12,13]. Therefore, seeking the best vegetation patterns and environmental optimization programs contribute to providing guidance on urban planning and design.

This paper takes the air temperature of pedestrian areas in building group as the analytical variable of thermal environment. The temperature is taken from the centerline temperature of the pedestrian area (X=59m, Y=59m) and the pedestrian area height is 1.4m. The simulation software of ENVI-met is employed to analyze air temperature variations under different vegetation patterns, tree heights and wind speeds in Shanghai. The highest outdoor temperature in Shanghai usually appears around 14:00, so in order to achieve better simulation results, this paper selects 14:00 as the simulation time. The results can provide references for the preliminary planning and design of building group.

2. Methodology
This paper mainly talks about the impact of vegetation pattern and wind speed on the thermal environment in building group. The simulation software of ENVI-met is employed to analyze urban micro-environment, which is developed by Micheal Bruse and Heribert Fleer in 1998 [14] and based on Computed Fluid Dynamics (CFD), thermodynamics and urban meteorology. This software can be used in comparison, analysis and evaluation of urban design.

2.1. Model description
The location is Shanghai, China. Shanghai is a typical hot summer and cold winter area in China. It is a typical developed city in the southeast of China and located on the east of the Yangtze River. It is also located in the north subtropical region of East Asia monsoon. Shanghai has a subtropical monsoon climate with distinct seasons, full sunshine and abundant rainfall.

The building group model is designed with reference to the Jiading Campus of Tongji University (as shown in Figure 1). The simulated area is a square area of 120m×120m. There are four buildings in this area, forming a building group unit with 16 meters wide, 32 meters long and 30 meters tall. The building is surrounded by vegetation, which is 12m from the building and the width is 6m. The pedestrian areas (sidewalk and motorway areas) are 12 meters wide. The model is shown in Figure 2.

2.2. Material parameters
In the whole model, the building surface is considered uniform and the material is concrete; the pedestrian areas pavement material is concrete; the vegetation ground material is loamy soil. The parameter information is shown in Table 1.
### Table 1. Material parameter table

| Location          | Material  | Roughness | Albedo | Emissivity |
|-------------------|-----------|-----------|--------|------------|
| Building surface  | Concrete  | 0.01      | 0.3    | 0.9        |
| Pedestrian pavement| Concrete  | 0.01      | 0.4    | 0.95       |
| Vegetation ground | Loamy Soil| 0.015     | 0.2    | 0.98       |

2.3. Vegetation patterns

There are three vegetation patterns, namely grass, shrubs and trees. The grass is 0.15 meters high. The shrub is privet with a height of 1.5m. The privet is a kind of deciduous shrub. During growing seasons, its leaf color is golden yellow with excellent ornamental effect. The privet is normally 1 to 2 meters high and 1.5 to 2 meters wide. It has strong adaptability and is not strict with soil conditions. It can adapt to the climate conditions in the south of the Yangtze River and the Yellow River basin in China. It rarely has the disease insect harm and is widely used in landscape design. The tree used in the model is populus, which is a kind of deciduous tree, generally 5~15 meters high, with developed root system, strong soil-fixing ability and disease resistance. It is always used as street trees.

2.4. Boundary conditions

The temperature, humidity and wind speed during the simulation is selected from summer typical meteorological day (TMD) in Shanghai, according to the national standard [15]. The dominant wind direction is southeast. The simulation time is 14:00 and the weather conditions are sunny and cloudless. In order to analyze the impact of vegetation patterns and wind speed on the thermal environment of pedestrian areas in building group, this paper has designed some cases, as shown in Table 2.

| Case | Vegetation pattern | Height (m) | Width (m) | LAD | Albedo | Wind speed (m/s) |
|------|--------------------|------------|-----------|-----|--------|-----------------|
| Case1| No vegetation      | ---        | ---       | --- | 0.2    | 3               |
| Case2| Grass              | 0.15       | ---       | 0.3 | 0.4    | 3               |
| Case3| Shrub              | 1.5        | 3         | 0.7 | 0.4    | 3               |
| Case4| Tree               | 5          | 5         | 0.4 | 0.7    | 3               |
| Case5| Tree               | 7          | 7         | 0.4 | 0.7    | 3               |
| Case6| Tree               | 9          | 9         | 0.4 | 0.7    | 3               |
| Case7| Tree               | 7          | 7         | 0.4 | 0.7    | 1               |

3. Results and discussion

In this paper, the air temperature of the main pedestrian areas in building group (Z = 1.4 m) of X = 59 m and Y = 59 m are selected for analysis respectively.

3.1. Impact of vegetation patterns on the thermal environment

By changing the vegetation patterns, the differences in thermal environment of pedestrian areas are analyzed. No vegetation, grass, shrubs and trees (Case1-Case4 in Table 2) are selected for comparison in Figure 3.
Figure 3. Air temperature in different vegetation patterns
(From left to right are no vegetation, grass, shrubs and trees.)

Due to the dominant wind direction, the temperature range in the northwestern part is obviously lower than other areas. Using the average ambient temperature at pedestrian areas’ height to compare with the outdoor air temperature, it can be found that different vegetation patterns have different impacts on the temperature of the outdoor thermal environment. By calculation, the outdoor air temperature is 30.9°C at 14:00, and the average ambient temperature without vegetation is 29.948°C; when the vegetation pattern changes to grass, the average ambient temperature is basically unchanged and the value is 29.946°C; when the vegetation pattern changes to shrubs, the average ambient temperature is reduced to 29.914°C; when the populus trees with a height of 5m are planted on both sides of the sidewalk and motor vehicle areas, the average ambient temperature is reduced to 29.881°C.

The air temperature at the pedestrian areas center line (X=59m and Y=59m) under these four conditions are analyzed respectively. The center temperature curve is drawn in Figure 4. Compared with no vegetation, the temperature of grass pattern is basically the same as no vegetation pattern; the temperature of shrub pattern is in the medium and the temperature of tree pattern is the lowest. Therefore, it can be considered that the vegetation patterns have a certain impact on the thermal environment of the pedestrian areas. Meanwhile, compared with the outdoor air temperature, tree pattern has the best effect, and cooling effect is relatively obvious, which can reduce the temperature by about 1°C.

Figure 4. The center temperature curve of pedestrian in different vegetation patterns
(On the left is the horizontal centerline and on the right is the vertical centerline)

3.2. The impact of tree height on the thermal environment
It can be seen from last part that the tree pattern has the most obvious impact on the temperature of outdoor thermal environment. By comparing tree heights, the differences of thermal environment in pedestrian areas are analysed. The populus of 5m, 7m, and 9m (Case4-Case6 in Table 2) are selected for comparison in Figure 5.

![Figure 5](image)

**Figure 5.** Air temperature in different heights of trees
(From left to right are 5m, 7m and 9m.)

Using the average ambient temperature at pedestrian areas’ height to describe the outdoor thermal environment, it can be found that the higher the tree is, the better the cooling effect becomes. By calculation, the average ambient temperature without vegetation is 29.948°C; when populus trees with a height of 5m are planted on both sides of the sidewalk and motor vehicle areas, the average ambient temperature is reduced to 29.881°C; when the height of populus trees is at 7m, the average ambient temperature is reduced to 29.835°C; when the populus trees are 9m, the average ambient temperature is reduced to 29.814°C.

The air temperature of the pedestrian areas center line (X=59m and Y=59m) under these three heights are analyzed, and the center temperature curve is drawn in Figure 6. Compared with no vegetation pattern, when the height of the populus is 5m and 7m, the temperature of the pedestrian areas is obviously reduced, and the temperature difference is larger when the tree is taller; when the height of the populus reaches 9m, the pedestrian areas’ temperature is close to the 7m pattern. Therefore, within a certain height range, the taller the tree is, the more obviously the temperature reduces, and it is considered that the optimum height of the populus is about 7m under this simulation condition. At the same time, the building's sunshine requirements should be considered when trees are used for vegetation design.

![Figure 6](image)

**Figure 6.** The center temperature curve of pedestrian in different tree height
(On the left is the horizontal centerline and on the right is the vertical centerline)
3.3. The impact of wind speed on the thermal environment

It can be seen from the last part that in a certain range the temperature is lower when the trees are taller. The optimum height is about 7m in this simulation. Therefore, the 7m populus is used as a reference standard to analyze the impact of wind speed on thermal environment of pedestrian areas in building group. The wind speeds of 1 m/s and 3 m/s (Case 6 and Case 7 in Table 2) are selected for comparison in Figure 7.

![Figure 7. Air temperature in different wind speed](image)

It can be seen that the wind speed also influences the temperature of the outdoor thermal environment. The greater the wind speed is, the more obvious the cooling effects are. By calculation, under the southeast wind dominated direction, when the wind speed is 1m/s, the average ambient temperature is 29.877°C; when the wind speed is 3m/s, the average ambient temperature is 29.835°C.

The air temperature at the pedestrian areas centre line (X=59m and Y=59m) under two wind speed conditions are analysed respectively, and the centre temperature curve is drawn in Figure 8. The higher wind speed contributes to the reduction of the ambient temperature in the pedestrian areas. The higher the wind speed is, the lower the ambient temperature becomes. However, when the wind speed increases, the fluctuation of the curve is more obvious, resulting in an unstable temperature variation in the entire pedestrian areas. It would make pedestrians feel uncomfortable. Therefore, it can be considered that the wind speed has an impact on the thermal environment of the pedestrian areas. The higher wind speed is beneficial to reduce the ambient temperature of the pedestrian areas, but the temperature distribution unevenness is intensified. This effect needs to be noticed when doing building layout design.

![Figure 8. The center temperature curve of pedestrian in different wind speed](image)
4. Conclusion
This paper analyses the impact of different vegetation patterns, tree heights and wind speeds on the thermal environment of the pedestrian areas in building group by numerical simulations. The conclusions are as follows:

1) The vegetation patterns have an impact on the thermal environment. The tree pattern has the best cooling effect with the temperature reduced by about 1°C compared with the outdoor air temperature;

2) The tree heights have an obvious impact on the thermal environment. Within a certain height range, the taller the tree is, the more obviously the outdoor thermal environment temperature reduces;

3) Wind speed has an impact on the thermal environment. Higher wind speed is beneficial to reduce the ambient temperature of the pedestrian areas, but it will lead to intensified uneven temperature distribution and make pedestrians feel uncomfortable.

The outdoor thermal environment in building group is a complicated problem. Therefore, in order to analyse this problem better, further research needs to be completed. This paper only considers the impact of two factors on the thermal environment of a building group unit. There are still many other factors which need to be discussed, such as water bodies, building layout and so on.

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