Research on the Influence of Underlying Surface Reflectivity on the Thermal Environment of Campus
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ABSTRACT

With the acceleration of urbanization, the scale of cities is expanding unceasingly. As a matter of fact, significant changes have happened in urban ground cover materials, leading to changes in the storage, radiation and transfer of air heat, as well as the energy balance, which correspondingly enforced the heat island effect. In the paper, by the method of numerical simulation, we conducted a research to study the influence caused by reflectivity of ground cover materials on the thermal environment at a Jinan campus. The results showed that increases in the reflectivity had little effect on the wind velocity near the surface, but made the air temperatures near the surface drop. Meanwhile, increasing the ground reflectivity raises the mean temperatures of air radiant in the area far off over the ground.

INTRODUCTION

Due to the rapid development of urbanization in our country, a large amount of land has been reclaimed, while the original tree and lawn are deteriorating, replaced by tall buildings and urban square. A large number of high reflectivity roads took the place of the original vegetation cover of the pavement. Compared with the original vegetation, the underlying surface of the urban area has had a great change, leading to worsening problems in urban thermal environment. The negative effect caused by the heat island effect is obvious, which seriously affects the comfort of outdoor activities. So it has important practical significance to study the thermal environment around buildings.

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In regard to the current research situation, the research of urban thermal environment has become an interdisciplinary field and the research papers are also very profound, which also achieved a lot of results.\textsuperscript{[1-13]} However, the same as other disciplines in the atmospheric sciences, the research progress of urban thermal environment can not be separated from the progress of observation, numerical simulation and laboratory simulation. In this paper, a numerical simulation method is used to study the influence of surface reflectivity on the campus wind environment and thermal environment in a university in Jinan and to analysis its change rule.

**THERMAL ENVIRONMENT INFLUENCE FACTORS AND CONTROL EQUATION**

**Influencing Factors of Thermal Environment**

In recent years, many domestic and foreign scholars have carried out the experimental research and numerical simulation on the micro environment of residential district and summarized the following factors that affect the outdoor thermal environment: solar radiation intensity, air temperature and humidity, wind velocity and direction, building surface and underlying surface temperature, ground long wave radiation intensity, the greening of urban vegetation, water distribution, traffic exhaust heat, densely populated and anthropological heat, act. Considering the above factors and research limitations, in order to create a comfortable outdoor thermal environment, this paper focuses on the two most important indicators of wind speed and air temperature of quantitative research, combined with examples of simulation of the actual building residential outdoor thermal environment, and gives some concrete and practical measures to improve the thermal environment of the cell.

**Control Equation of Thermal Environment**

The physical governing equations of the thermal environment include mass conservation equation, momentum conservation equation, $k-\varepsilon$ equation and energy conservation equation. The forced flow that makes the wind speed larger is far greater than the natural convection so that the effect of the buoyancy can be ignored. Conversely, when the velocity is small, natural convection not being neglected, you will need to consider the effect of buoyancy. Due to the influence of plant canopy, the modified governing equations are as follows:

Continuity equation:

$$\frac{\partial \rho}{\partial \tau} + \frac{\partial (\rho u_i)}{\partial x_i} = 0$$

(1)

Momentum equation:

$$\frac{\partial (\rho u_i u_i)}{\partial \tau} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right]$$

(2)

Energy equation:
\[
\frac{\partial (\rho T)}{\partial \tau} + \frac{\partial (\rho u_i T)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \alpha \left( \frac{\partial T}{\partial x_j} + \frac{\partial T}{\partial x_i} \right) \right]
\]  

(3)

\[ k-\varepsilon \quad \text{Equation:} \]

Turbulent kinetic energy equation:

\[
\frac{\partial (\rho k)}{\partial \tau} + \frac{\partial (\rho u_i u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \sigma - Y_m
\]

(4)

Diffusion equation:

\[
\frac{\partial (\rho \varepsilon)}{\partial \tau} + \frac{\partial (\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu}{\sigma_k} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{\varepsilon} \frac{\varepsilon}{k} (G_k + C_3 G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}
\]

(5)

Here \( \rho \) is the fluid density, kg/m\(^3\); \( u_i \) is the direction velocity, m/s; \( u_j \) is the direction velocity, m/s; \( \mu \) is the gas viscosity coefficient, Pa \( \cdot \) s; \( P \) is the gas pressure, Pa. \( \alpha \) is the thermal diffusion coefficient, m\(^2\)/s; \( T \) is the gas temperature, K; \( P \) is the gas pressure, Pa. \( G_k \) indicates the turbulent kinetic energy generated by the velocity gradient of the laminar flow, kg/(m \( \cdot \) s); \( G_b \) is the turbulent kinetic energy generated by the buoyancy, kg/(m \( \cdot \) s); \( Y_m \) is due to the fluctuations in the diffusion of the transition in the compressible turbulent flow, kg/(m \( \cdot \) s); \( k \) is the turbulent kinetic energy, m\(^2\)/s; \( \varepsilon \) is the turbulent energy dissipation rate, m\(^2\)/s; \( C_\varepsilon = 0.07 \sim 0.09, C_{1\varepsilon} = 1.41 \sim 1.45, C_{2\varepsilon} = 1.9 \sim 1.92 \).

INFLUENCE OF THERMAL ENVIRONMENT SIMULATION OF PHYSICAL MODEL

Physical Model and Mesh Generation

This paper applies a college in Jinan, which is located in the Tenth Century Avenue Road, as the research object. The campus covers an area of more than 2500 acres, of which the dormitory area is 70 million square meters, with 23 buildings as the carrier. The highest building has six floors, with a height of 30m and the lowest 3 floors with a height of 15 meters.

Figure 1. Sketch map of campus plane.
In order to make the numerical simulation calculations more convenient and easy to operate, the simulation of the thermal environment of the campus is made simply as follows, in the case of almost no impact on the simulation results: without considering the underlying surface evaporation rates, building layout and density as well as active heat of teachers and students on the influence of thermal environment on campus. In order to increase the calculation accuracy of the numerical simulation of campus thermal environment, we used unstructured mesh method on campus teaching buildings and dormitories building in addition to constructions around the grid with local refinement method, as the meshing shown in Fig.2.

**Boundary Conditions**

For the simulation of the thermal environment of the campus, this model selects the typical wind direction at two o’clock in the summer as the initial condition. The reflectivity of the underlying surface of the campus is set as shown in Table 1.

<table>
<thead>
<tr>
<th>The reflectivity of the underlying surface</th>
<th>soil pavement</th>
<th>asphalt pavement</th>
<th>concrete pavement</th>
<th>Brick pavement</th>
<th>exterior wall</th>
<th>tree</th>
<th>lawn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.15</td>
<td>0.30</td>
<td>0.50</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

**THE EFFECT OF SURFACE REFLECTIVITY ON WIND THERMAL ENVIRONMENT**

The reflectivity of the asphalt pavement, concrete pavement and brick pavement in the campus is different, so the paper has a simulation analysis of the influence of different road surface reflectivity’s on the thermal environment of the campus. Fig.3 is the velocity field distribution vector map of the ground height 1.5 meters under the different ground surface reflectivity. Fig.4 is the temperature field...
distribution contour map of the ground height 1.5 meters under the different ground surface reflectivity. As can be seen from the figure, with the increase of the ground reflectivity, the wind speed at the surface 1.5 meters is almost unchanged, but the location of the air temperature has decreased. The reason is that as the ground reflectivity increases, the absorption rate will be correspondingly reduced, which leads to lower surface temperature, and affects the ambient air temperature, so that the surface temperature has decreased in the area near the ground. In the inlet direction of wind speed on campus (around the upwind side of building), the temperature is lower, while in the export direction (on the leeward side of building), it's higher. The reason is that large air velocity takes away more heat in the windward of the building, while when wind speed is smaller, air heat is hardly reduced in the leeward. By comparing Fig.4(1)-Fig.4(3), it can be found that improving the pavement reflectivity to some extent makes the temperature (the line height of 1.5 meters decrease, thus improves the degree to the comfort of outdoor activities of teachers and students, but the effect is not obvious in the area around the leeward side of some buildings. Improving the surface reflectivity only reduces the air temperature near the earth's surface, while for the higher area of the ground; the average radiation temperature of the air will be improved with the increase of the ground reflectivity. Therefore, we can not improve the comfort of outdoor thermal environment by only a single increase of the ground surface reflectivity. For regions with high local temperature, it can be achieved through reasonable change of underlying surface reflectivity, such as planting trees and lawns, arrangement of water or other measures to fundamentally solve the problem of high temperature, creating a safe and comfortable indoor/outdoor living environment for teachers and students.

CONCLUSIONS

In this paper, the outdoor thermal environment has been simulated in a university campus in the summer. It is found that the increase of the surface reflectivity has little effect on the wind speed of 1.5 meters,
but the air temperature in 1.5m height decreased. Improving the surface reflectivity only reduces the air temperature near the earth's surface, while for the area far off over the ground; the average radiation temperature of the air can be improved with the increase of the ground reflectivity. It should be combined with the way of green to create a good learning and living environment for teachers and students.

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REFERENCES