Construction strategy on outdoor environment of ecological community in dry region–Lanzhou, China

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Abstract. In order to improve the human thermal comfort of the ecological community, aiming at the characteristics of low humidity and large wind and sand in northwest areas such as Lanzhou, the method was proposed to improve the human thermal comfort by water evaporation from porous pavement. Firstly, the outdoor environmental model of the ecological community was established and the environmental parameters of a community are simulated by using the model in Lanzhou. The simulation results are compared with the experimental results, and the relative error is less than 15%. Secondly, the change law of outdoor thermal and humid environment is simulated and analysed when porous pavement and ordinary pavement are used in ecological community, respectively. The results show that the humid environment of the community has changed significantly and the maximum change is about 7% after considering the water evaporation from porous pavement. Meanwhile, the amount of single water sprayed onto the porous pavement should meet the water evaporation requirement of 1.67h under the climatic conditions at that time. The above research results provide theoretical guidance for improving the outdoor thermal comfort of residential buildings in dry region.

1 Introduction

The main form of modern Chinese urban architectural complex is the building community. At the same time, the human comfort of the pedestrian area has attracted more and more attention in the building community. However, more and more underlying surfaces are replaced by buildings in cities, which makes the problem of urban heat island more and more serious[1-3]. Unplanned urbanization directly affects people's comfort to a great extent[2,4]. At present, the slogan of green, ecology and health has been put forward by many real estate developers. However, the coordination and unity of buildings, people and outdoor environment has not been realized under various actual conditions.

Water evaporation[5,6], plant transpiration[7,8]and architectural form[9,10] have been studied by many scholars as the important factors to improve outdoor environment. For example, Chen et al.[11] used the method of simulating the block surface temperature to evaluate the impact of urban geometry on the surface temperature of various components (roof, street and four-way wall) under different scenarios. The result shows that the building height plays a leading role in the surface temperature and can reduce the solar radiation reaching the surface when the distance is fixed. Then, Mana et al.[12] studied the relationship between urban surface temperature and radiation flux density by measuring the short wave and long wave radiation flux density in six different directions. This shows that the architectural form and environmental radiation have great influence on the outdoor ambient temperature. Meanwhile, vegetation was considered as a tool for cooling the ambient environment. For example, Wang et al.[13] used a new numerical model to study the cooling effect of different vegetation types. The results showed that the shading and cooling effect of trees was obviously more important than the evaporation lawn. In the research of using water and greening to improve outdoor human thermal comfort, according to the current research status, it is also in a relatively mature stage. In fact, in arid areas such as Lanzhou, it is also a good choice to use the water evaporation of porous pavement to improve the thermal comfort of outdoor human body.

Therefore, in view of the above problems, a coupling model of outdoor environment is established in dry regions based on the water evaporation from porous pavement and plant transpiration in the community. The influence law of water evaporation from porous pavement on outdoor thermal comfort is explored by the model. This provides a theoretical basis for residential building planning.

2 Model research

2.1 Physical Model

In this paper, the physical model is established according to literature[14], as shown in Fig.1. The size of the geometric model is 365m×150m×50m (X×Z×Y),

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and the calculation area is 865m×900m×300m (X×Z×Y).

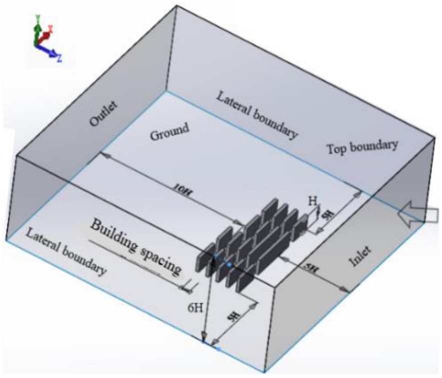


Fig.1. The physical model.

2.2 Mathematic Model

2.2.1 Governing Equations

For the study of outdoor environment, the governing equation is mainly composed of continuity, energy, momentum and composition equation. They can be expressed as follows.
Continuity equation:

$$\frac{\partial u_i}{\partial x_i}=0 \tag{1}$$

Energy equation:

$$\frac{\partial T}{\partial t}+\frac{(\partial u_i T)}{\partial x_i}=a\nabla^2 T \tag{2}$$

Momentum equation:

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial(\rho u_i u_j)}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left[(\mu+\mu_t)\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\frac{\partial u_l}{\partial x_l}\delta_{ij}\right)\right]+F_i \tag{3}$$

The turbulent viscosity in Eq.(3), μ_t, can be expressed as

$$\mu_t=\rho C_\mu\frac{k^2}{\varepsilon} \tag{4}$$

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k-\rho\varepsilon \tag{5}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}G_k-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{6}$$

Where G_k can be calculated by Eq. (7).

$$G_k=\mu_t\left\{2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2\right\} \tag{7}$$

Composition equation:

$$\frac{\partial(\rho c_s)}{\partial t}+div(\rho u_i c_s)=D_s div(grad\,\rho c_s) \tag{8}$$

Where u is the velocity, m/s; T is the temperature, K; a is the thermal diffusivity, m^2/s; t is the time, s. ρ is the density of humid air, kg/m^3; P is the static pressure, Pa; μ is the dynamic viscosity, N·s/m^2; μ_t is the turbulent viscosity, m^2/s; F is external force due to vegetation, N; c_s is the volume concentration of a component, mol/L; D_s is the diffusion coefficient of a component.

2.2.2 Boundary Condition

The boundary conditions need to be added to have a unique solution. Therefore, this section mainly analyses its boundary conditions. The boundary conditions are set as shown in Table 1.

Tab.1 The boundary condition setting

The boundary condition	The boundary condition setting
The inlet boundary	Speed inlet
The outflow boundary	Free export
The above and on both sides of the building boundary	Free sliding boundary
The boundary of building wall	The wall function method is used to modify the turbulence model

2.3 Mesh generation and Model verification

As shown in Fig.2, the grid around the building is encrypted with a grid transition ratio of 1.3 and the final number of grids is 3.85 million. At the same time, a field experiment is carried out on the environmental parameters of the four locations in Fig.3, and the experimental results are compared with the simulation results.

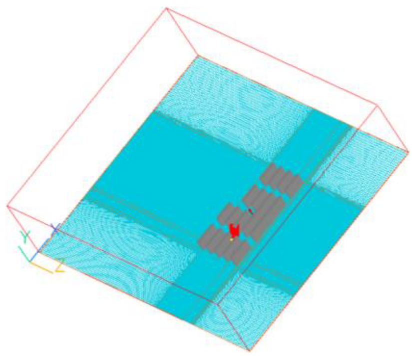


Fig.2. Computing area meshing

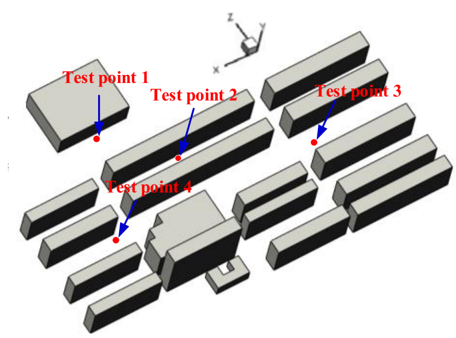
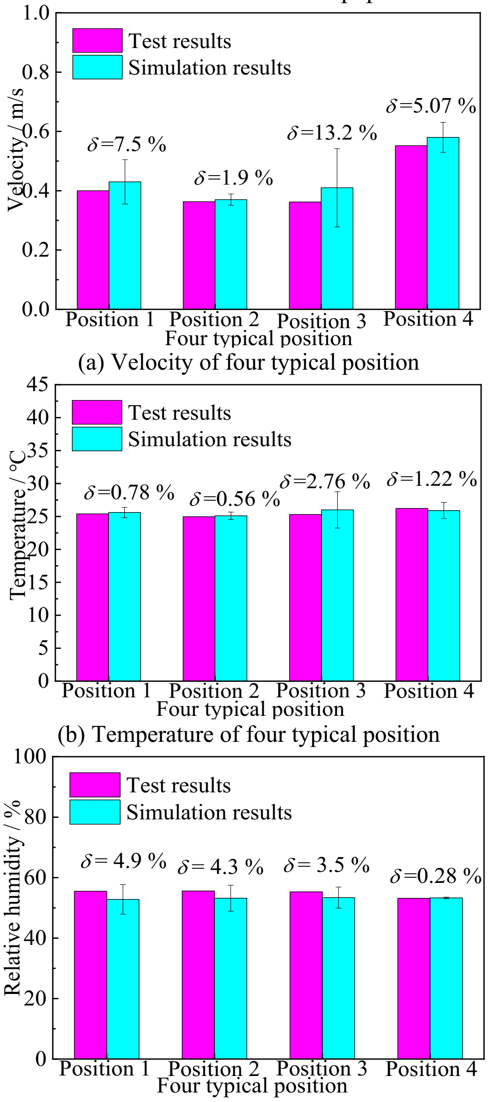


Fig.3. Location of experimental test point

Fig.4 shows the relationship between measured and simulated values. The results show that the simulated value is generally larger than the measured value. The relative errors of temperature and relative humidity are relatively small. The relative error of wind speed is large, the maximum value is 13.2%, but the overall relative error is less than 15%. Therefore, this shows that the simulation method is reliable in this paper.



(a) Velocity of four typical position

(b) Temperature of four typical position

(c) Relative humidity of four typical position

Fig.4. The comparison results between measured value and simulated value

3 Result and Analysis

Fig.5 is the comparison of the simulation results of relative humidity at pedestrian height between water evaporation from porous pavement and ordinary pavement. The results show that the relative humidity has changed significantly after considering the water evaporation from porous pavement, which can be changed by about 7%. Therefore, the water evaporation rate of porous pavement will be higher and the improvement of environment will be greater when the temperature is higher and the relative humidity is lower in dry region such as Lanzhou. Thus, the relative humidity of environment is improved in dry region, the formation of dust weather is restrained, and the thermal comfort of outdoor human body is further improved.

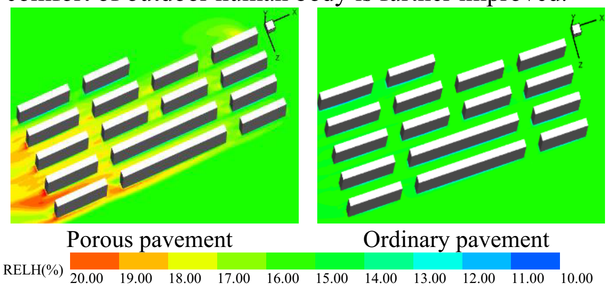


Fig.5. The effect of water evaporation on environmental relative humidity

4 Discussion

The water storage capacity of porous pavement is limited and water cannot evaporate all the time. Therefore, the effective watering strategies should be implemented. Fig.6 and Fig.7 show the results of ambient temperature, relative humidity and UTCI under the conditions of ambient temperature 18.3℃, relative humidity 21% and wind speed 1.2m/s, respectively. The results show that the influence of water evaporation from porous pavement is not obvious for the change of ambient temperature, but it mainly improves the relative humidity. At the same time, due to the dry environmental and climatic characteristics in Lanzhou, the relative humidity of the environment is difficult to reach the saturation state. The longer the duration of water evaporation from porous pavement, the more obvious the change of environmental relative humidity. The UTCI decreases first and then increases with time when there is no water evaporation on porous pavement, reaching the minimum value of 17.08℃ in about 2.5h. There is water evaporation on the porous pavement, the minimum value appears after watering for about 2.5h, but the minimum value increases from 17.08 ℃ to 18.178 ℃. At the same time, the change of UTCI increases with the duration that water evaporation from porous pavement.

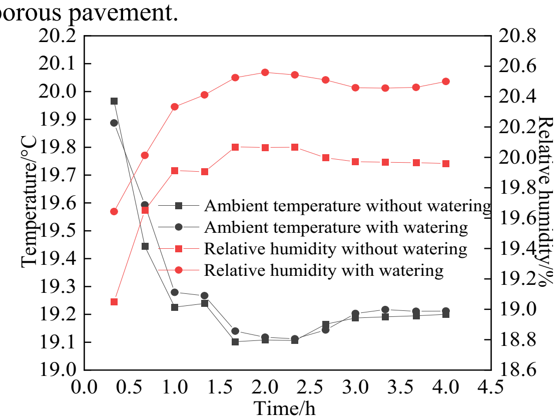


Fig.6. The variation law of ambient temperature and humidity with time

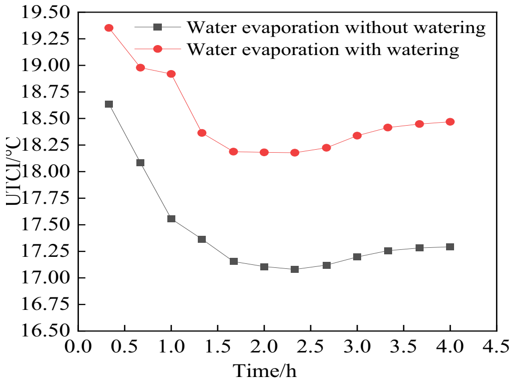


Fig.7. The variation law of UTCI with time

It can be found from Fig.6 that the change of relative humidity caused by water evaporation from porous pavement increases with the continuous water evaporation from porous pavement, and tends to be stable after 1.67h. Similarly, the same change law can be clearly found from Fig.7. Therefore, the amount of single water sprayed onto the porous pavement shall meet the water evaporation requirement of 1.67h at least under such climatic condition when watering on porous pavement.

5 Conclusion

A coupled model of outdoor environment was established based on water evaporation from porous pavement and plant transpiration in this paper. The influence law of porous pavement and ordinary road was simulated and analyzed by the model for the outdoor hot and humid environment of ecological community. The conclusions are as follows:

(1) Lanzhou and other arid areas in northwest China, the environmental relative humidity can increase about 7% when water evaporates from porous pavement in ecological communities. It can effectively improve the outdoor thermal and humid environment, so as to improve the thermal comfort level of outdoor human body.

(2) The influence of water evaporation from porous pavement is not obvious for the change of ambient temperature, but it mainly improves the relative humidity of environment.

(3) The amount of single water sprayed onto the porous pavement shall meet the amount of water evaporation for 1.67h at least under such climatic condition when watering on porous pavement.

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