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Influence of site selection on natural ventilation in Chinese traditional folk house

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Abstract: The relationship between the site selection of a hilly terrain and the natural ventilation of the Dangdamen building complex, which is a traditional folk house, is revealed by a computational fluid dynamics (CFD) simulation. The wind press and speed distributions around the building in four cases with different weather conditions and topographies are simulated. The simulation results show that a hill can reduce the absolute values of the wind pressure at the windward and leeward sides of the building. The encouraging effect of the patio on the natural ventilation in a terrain with a hill is greater than that without a hill. The same situation occurs when comparing the patio effects between summer and winter. The wind speed around the building can be reduced by the hill as it is an obstacle and the degrees of the influence of the hill in summer and in winter are quite different because of different wind directions. The analysis results show that this kind of site selection, with the hill to the north, is a suitable way to settle the conflict of the natural ventilation requirements in summer and in winter under subtropical climate conditions, especially in houses with patios.

Key words: site selection; traditional folk house; natural ventilation; computational fluid dynamics simulation

Buildings originate from the need for human beings to protect themselves from adverse impacts of climate. The site selection of traditional folk houses in China is profoundly influenced by Feng Shui. Lee[1] suggested that Feng Shui is a traditional Chinese architectural theory for selecting a favourable site for dwellings. The natural ventilation and topographic features are two important considerations in Feng Shui. Because of various and complicated influential factors and methodological limitations[2-5], the influence of topographic features on natural ventilation was ignored in the past[6-11]. So, the study on the relationships between the topographic features and the natural ventilation systems of traditional folk houses is worthy of valuable consideration for improving modern residential building design in the countryside.

1 Methodology

1.1 Simulation house

Zhangguying village is located in the northern part of Hunan Province, China, under a subtropical climate. As shown in Fig. 1, Zhangguying village lies in a small basin at the foot of a hill to the north and faces south. The site selection of this village is obviously influenced by Feng Shui[12]. The village is divided into three parts. The first part, referred to as the Dangdamen building complex, was constructed in 1562. The second and third parts were constructed at the beginning of the 18th century. The simulation house is the main part of the Dangdamen building complex, and the plane of the main building is illustrated in Fig. 2.

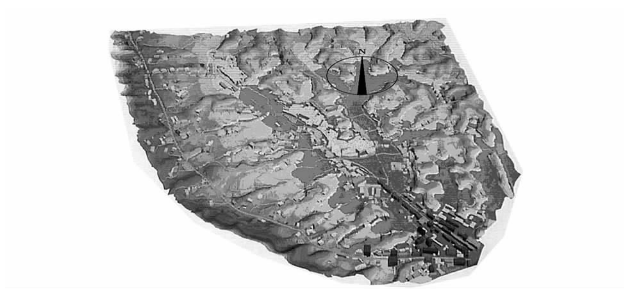

Fig. 1 Landform of Zhangguying village

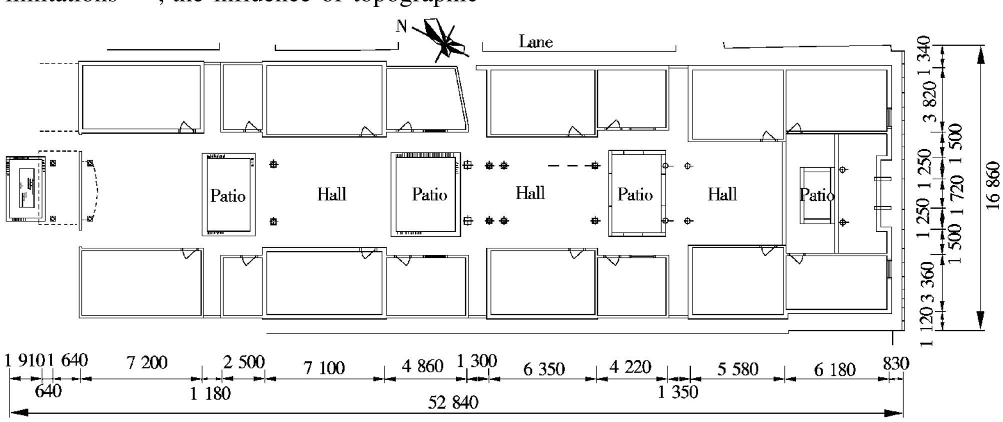

Fig. 2 Plane of main building in Dangdamen building complex (unit: mm)

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1.2 Model and simulation cases

Through simplification, a regional 3D model, including the northern hill and the Dangdamen building complex, are established by AutoCAD based on the real situation, as shown in Fig. 3.

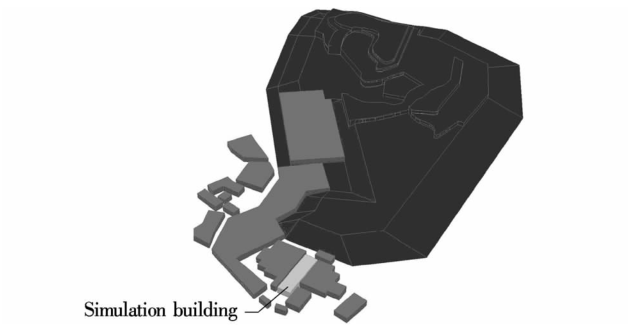

Fig. 3 The regional 3D-model

In this study, numerical simulation is carried out in four cases to investigate the wind environment around the main building based on the FLUENT software. Cases 1 and 2 are the ones with a hill in summer and in winter, respectively, and the size of the computational domain is 1 200 m × 700 m × 80 m. Cases 3 and 4 are the ones without the hill in summer and winter, respectively, and the size of the computational domain is 800 m × 700 m × 80 m. The meshes of the geometric model in all cases are generated based on the Gambit software. Tab. 1 shows the detailed conditions of all cases.

1.3 Outside boundary conditions

1.3.1 Freestream conditions

For the speed distribution, the exponential distribution function can be calculated by

$$U_h = U_m \left(\frac{d_m}{H_m}\right)^{\alpha_m} \left(\frac{h}{d}\right)^{\alpha} \tag{1}$$

where U_h is the wind speed at the height of h, m/s; U_m is the wind speed measured by a portable weather station, m/s; H_m is the height of the weather station, m; d_m is the boundary layer thickness of the location of the weather station, m; α_m is the surface roughness of the location of the weather station; d is the boundary layer thickness under different topographic conditions, m; α is the surface roughness under different topographic conditions. The values of α and d can be determined based on the national standard (GB50009—2001).

Tab. 1 Conditions of all cases

Case	Season	Topography	Type of meshes	Number of meshes
1	Summer	With the hill	Tetrahedron	2 364 952
2	Winter	With the hill	Tetrahedron	2 364 952
3	Summer	Without the hill	Hexahedron/Triangular prism	1 845 999
4	Winter	Without the hill	Hexahedron/Triangular prism	1 845 999

In the turbulence modeling, the turbulent kinetic k_h and the dissipation rating of the turbulent kinetic ε_h can be calculated by[13]

$$k_h = 1.5(U_h I_h)^2 \tag{2}$$

$$\varepsilon_h = \frac{u_*^3}{\kappa h} \tag{3}$$

$$\kappa = \frac{u_*^2}{\sqrt{C_\mu}} \tag{4}$$

where κ is the Karman constant and is equal to 0.04; u_* is the rubbing speed, m/s; I_h is the intensity of turbulence at the height of h; C_μ is the momentum coefficient and equals 0.09. The intensity of turbulence in this paper is determined based on the Japanese national standard[13].

1.3.2 Boundary conditions of side, top and outflow surfaces

Because of the large computational domain, the long distance and the horizontal incoming flow, a hypothesis can be drawn as follows: the velocity gradient of the top and side surfaces along the tangential direction is zero and the speed along the normal direction is zero. The gradient of other scalars along the normal direction, such as κ and ε, are zero. The outflow surface can be regarded as fully developed, and the gradients of all variables along the normal direction are zero.

1.3.3 Boundary conditions in winter

Because the wind direction in winter is not perpendicular to the boundary surface of the geometric model, the method of velocity resolution is adopted. The inflow speed is supposed to be U; the angle between the inflow direction and the X axis of the model is set to θ. Then, the inflow speed can be divided into two parts: $u = U\cos\theta$ and $v = U\sin\theta$. These two components can be regarded as the boundary conditions of the windward side. Other boundary conditions are the same as those mentioned above. The simulation is carried out twice, and the simulation results are superimposed by the user-defined function method.

2 Results and Discussion

The wind pressure distributions of the building in four cases are illustrated in Fig. 4. In cases 1 and 3, the windward sides are barotropic fields and other sides are negative pressure regions. In case 1, the minimum negative pressure is at the right side of the building while it is at the leeside in case 3. The same situation occurs in cases 2 and 4. Most of the top surfaces in cases 1 and 3 are in the negative pressure region, but the absolute value in case 1 is greater than that in case 3. In case 2, the area of the negative pressure zone in the top surface is almost the same as that of the barotropic field. Most of the top surface in case 4 is in the barotropic field. The absolute values in cases 2 and 4 are much less than those in cases 1 and 3. The simulation results show that the hill can reduce the absolute values of the wind pressure at the windward and leeward sides of the building. Furthermore, the encouraging effect of the natural ventilation of the patio with the hill is greater than that of the ventilation without the hill. The same situation occurs when comparing the patio effects between summer and winter.

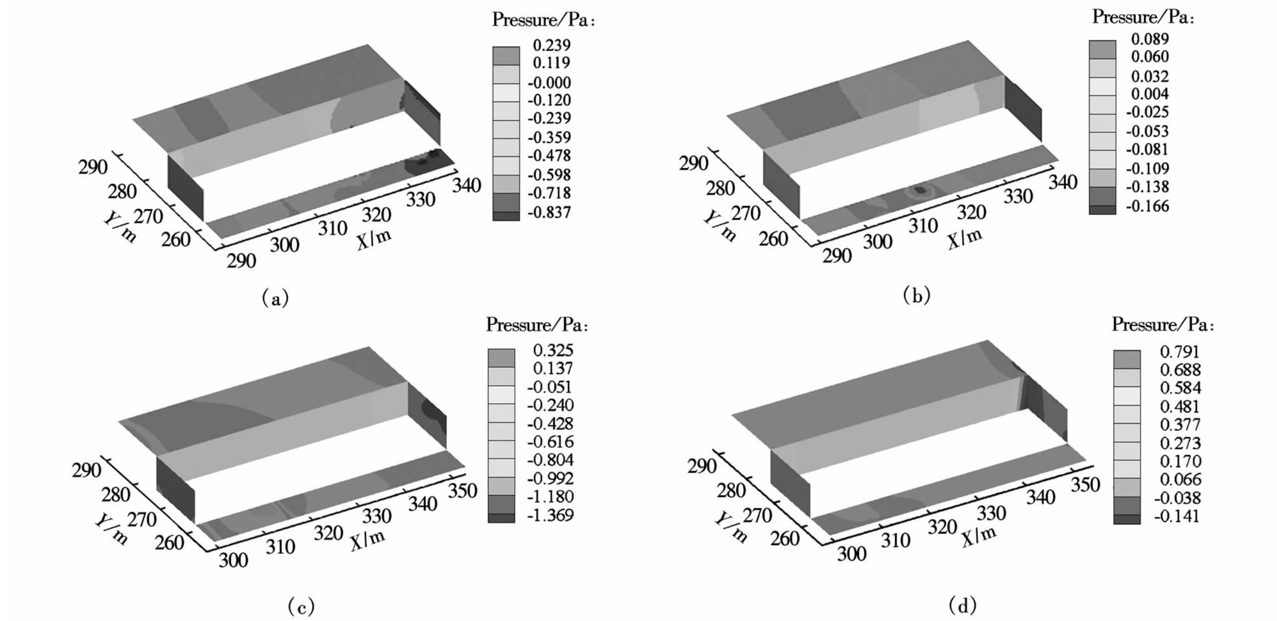

Fig. 4 Wind pressure distributions of the building. (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4

The wind speed distributions around the building at the height of 1.5 m in all cases are illustrated in Fig 5. As shown in Fig 5, the wind speeds around the building in cases 1 and 2 are less than those in cases 3 and 4. This phenomenon is obviously in the zone near the hill. The speed of the building area in case 2, which is less than 0.25 m/s, is less than that in case 1. And the average wind speed in case 2 is less than that in case 1. The simulation results show that the wind speed around the building can be reduced by the hill. The influence degrees of the hill in summer and in winter are quite different because of different wind directions. Without the hill, the natural ventilation can be increased. But a suitable ventilation design should minimize the ventilation in winter and maximize it in summer. As shown in the results, this kind of site selection can satisfy the requirements mentioned above and is worth being used in modern building design. Furthermore, the results also prove the scientificity of Feng Shui in a way.

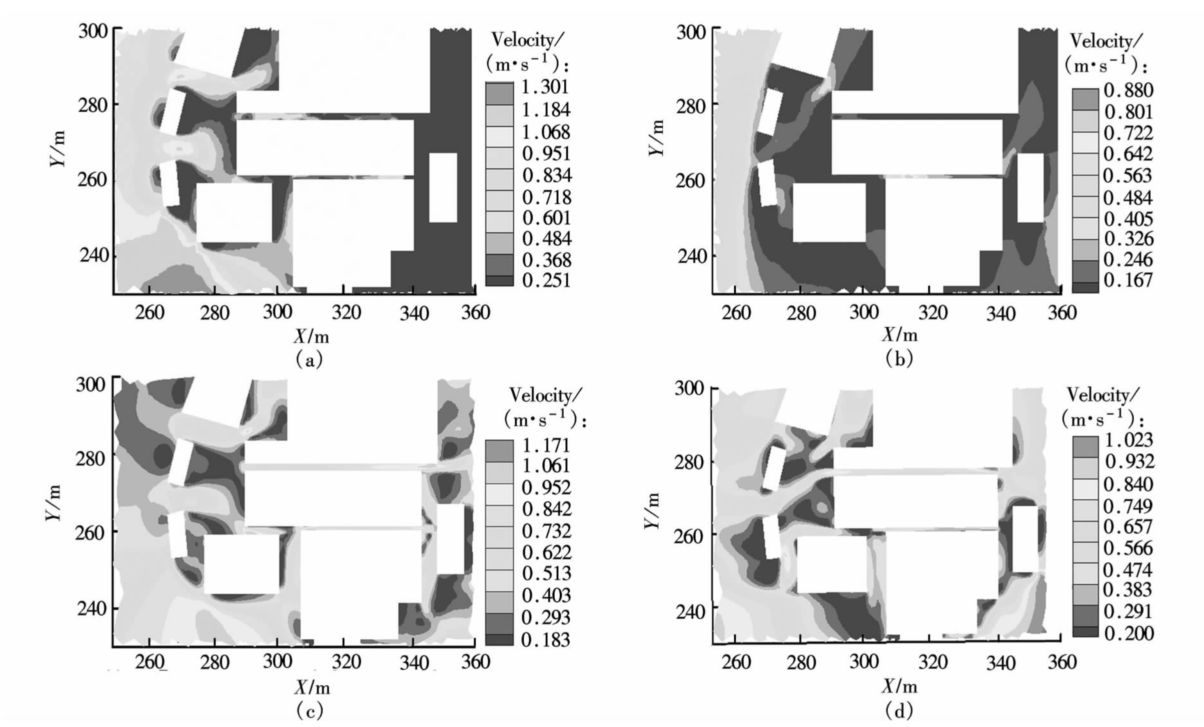

Fig. 5 Wind speed distributions around the building at the height of 1.5 m. (a) Case 1; (b) Case 2; (c) Case 3; (d) Case 4

3 Conclusions

In this paper, the wind pressure distributions of the building and the wind speed distributions around the building are simulated in four cases with different weather conditions and the topographies. The results show that the site selection and the topographic features can obviously influence the natural ventilation. Some valuable conclusions can be drawn as follows:

1) The hill can reduce the absolute values of the wind pressures at the windward and the leeward sides of the building. And it can affect the natural ventilation both in summer and in winter.

2) The patio with the hill can encourage the natural ventilation, and the encouragement effect is greater than that of the patio without the hill. The same situation occurs comparing the patio effects between summer and winter. Therefore, with this kind of site selection, the patio is a useful design to improve the natural ventilation in summer.

3) The wind speed around the building can be reduced by the hill in both summer and winter. But the effects in winter are much greater than those in summer.

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中国某传统民居选址对自然通风的影响

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摘要:利用计算流体动力学模拟了传统民居当大门建筑群丘陵地形下选址与自然通风的关系. 该模拟包括不同气候与地形下的 4 个案例及其建筑周边风压与风速分布. 模拟结果显示:山体能够降低建筑迎风面和背风面的风压绝对值;在有山体的地形中天井对自然通风的促进效果大于没有山体的地形,对比冬季与夏季天井效果时也可得到同样结论;作为障碍物,山体还能降低建筑周边的风速,且由于冬夏季风向不同,山体的影响程度呈现出较大区别. 分析结果表明,丘陵位于建筑北向的选址方式可以解决亚热带气候条件下住宅冬夏 2 季不同的自然通风需求而造成的矛盾,尤其在含天井的住宅中最为显著.

关键词:选址;传统民居;自然通风;CFD 模拟
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