Numerical investigations of Stilt houses natural ventilation and Thermal Comfort Evaluation in Southern Yunnan Province
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Keywords: Stilt houses; Natural ventilation; Thermal comfort evaluation; Optimization schemes

Abstract. For the purpose of improving the effect of natural ventilation and thermal comfort of a traditional stilt houses located in Southern Yunnan Province. The indoor and outdoor wind environment of the existing Stilt houses were simulated by Airpark software, the factors of indoor ventilation effect and thermal comfort were analyzed, and the effects of the size and location of the windows and vents on natural ventilation were analyzed. The results indicated that the size and location of the windows could improve the indoor natural ventilation effect, and the indoor air temperature reduced of 2.4°C in summer, while the role of the vent is not obvious. Furthermore, the design suggestions and strategies for enhancing the thermal comfort of a traditional stilt house located in the Southern Yunnan Province were presented.

1. Introduction
In recent years, along with strengthening of energy saving and environmental protection awareness, Architects paid more attention to the role of natural ventilation in saving building energy, a lot of scholars had also done related research of natural ventilation. Potential of natural ventilation in temperate countries was proved to be enormous; there was a reduction of 90% of hours of a possible use of mechanical ventilation [1]. By using CFD software to simulate a typical architecture of Thailand, the results indicated that approximately 2700 kWh of air conditioning energy savings could be achieved in the room by employing the proposed ventilation shaft [2]. The natural ventilation effect and thermal comfort of atrium buildings had also been widely researched [3-5]. There was a lot of research about the influence of building orientation, shape coefficient, opening size and location on indoor ventilation effect, and many new methods have been proposed to optimize ventilation [6-8]. Studies was shown that rational setup of courtyards’ size and walls’ height could increase the natural ventilation effect of courtyards [9]. But the above researches were not involved in the natural ventilation of the Stilt houses.

Stilt houses—i.e. houses raised on piles over the surface of the soil or a body of water. Stilt houses were built primarily as a protection against flooding, but also served to keep out vermin. The shady space under the house could be used for work or storage [10]. The houses were made of bamboo and thatch and included one or two fireplace. The fireplaces were usually used to cook the meals, and it also was the traditional customs of the local residents.

2. CFD Simulation
2.1 Simulation Methods
In this paper, the indoor and outdoor wind environments of the Stilt houses were simulated by the CFD software. The simulation was divided into two parts: Firstly, the outdoor model were established to research the wind field around buildings; Secondly, the indoor model were established based on the simulation results of the outdoor model to research the indoor air temperature, relative humidity and wind speed.
2.2 CFD Model

2.2.1 Outdoor Model
The computational domain shown in Fig.1 was 130m (L) × 60m (W) × 28m (H), the discretization grid consists of 625.3 thousand hexahedral cells. The RNG $\kappa$-$\varepsilon$ model and discrete ordered rendition model were used in the model. The inflow boundary was gradient wind, the wind speed was 2.4m/s and the direction was North East which based on the local weather data. The outflow boundary was zero static pressure. At the ground and building surfaces, the standard wall functions were used in conjunction with the sand-grain based roughness modification. The lateral side of the domain was symmetry boundary condition.

![Fig.1 outdoor model](image1)

![Fig.2 Indoor model](image2)

2.2.2 Indoor Model
The computational domain of indoor model is the interior space surrounded by building envelope, the size is 8.15 (L) × 5.4 (W) × 5.6 (H) m$^3$ (shown in Fig.2). The “velocity inlet” boundary was temperature of 28.6°C, relative humidity of 66%. For the outlet of the flow, the “pressure outlet” was taken. The wall temperatures were based on, the thermal parameters of other heat sources were shown in Tab1. According to the calculation results of outdoor model, the inlet and outlet boundary were shown in Table2.

<table>
<thead>
<tr>
<th>Internal heat source</th>
<th>Tab1. Thermal parameters of internal thermal loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person (W/m$^2$)</td>
<td>58×2</td>
</tr>
<tr>
<td>Lamp (W/m$^2$)</td>
<td>34</td>
</tr>
<tr>
<td>Television (W/m$^2$)</td>
<td>120</td>
</tr>
<tr>
<td>Fireplace (°C)</td>
<td>600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tab2. Boundary conditions of inlet and outlet of indoor model</th>
</tr>
</thead>
<tbody>
<tr>
<td>North window</td>
</tr>
<tr>
<td>average wind pressure (Pa)</td>
</tr>
</tbody>
</table>

2.3 Simulation Results Analysis
The simulation results of outdoor model were shown in Fig.3 and 4, the average building surface pressure of windward and leeward was 0.465Pa and -0.619Pa. The average wind speed around the building is 0.351m/s. The results showed that the outdoor wind environment was adverse for indoor natural ventilation.
The simulation results of indoor model were shown in Fig.5 and 6. It showed that the air velocity near the windows was larger, while the air velocity of other regions was small or even clam. The average velocity and temperature of the indoor region at 1.2m above the floor was 0.11m/s and 31.1°C, respectively.

3. Optimization Schemes

There were many factors influenced the effect of indoor ventilation and thermal environment, such as orientation, shape coefficient, opening size and location, etc. But only the opening size and location were analyzed and the other factor was default in this paper. Then three optimization schemes were put forward based on the mechanism of natural ventilation. Details are shown in Table 3.

In case A, cross-ventilation would appear when the outdoor wind speed was favorable, while the effect of buoyancy-driven natural ventilation could not be considered. In case B, the buoyancy-driven natural ventilation was considered, while the cross-ventilation was adverse. In case C, the wind pressure and buoyancy-driven natural ventilation were taken into the model.

Table 3 Optimization scheme of ventilation

<table>
<thead>
<tr>
<th>Case</th>
<th>Optimization measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>Add a window on the south and north wall respectively, the size of window is 0.9 × 0.6m²; add two windows on the south and north side roof respectively, the size of window is 0.6 × 0.45m²</td>
</tr>
<tr>
<td>Case B</td>
<td>Add four vents on the floor, size is 0.6 × 0.4 m²</td>
</tr>
<tr>
<td>Case C</td>
<td>Add a window on the south and north wall respectively, the size of window is 0.9 × 0.6m²; Add two windows on the south and north side roof respectively, the size of window is 0.6 × 0.45m²; Add four vents on the floor, size is 0.6 × 0.4 m²</td>
</tr>
</tbody>
</table>

4. Results and discussions

The accurate opening boundary conditions of each model were obtained by using the CFD software to
simulate the outdoor wind environment of each case. According to the simulation results, the wind speed and wind pressure of each opening as the boundary conditions of the indoor wind environmentsimulation are obtained while the conditions of all internal thermal loads were default. The simulation results of average wind speed and air temperature were shown in Fig.7 and 8.

![Fig.7 average wind speed of each case](image)

![Fig.8 average air temperature of each case](image)

It could be seen from Fig.7 and 8 that the wind speed of the case C was large, followed by case A, and the case B is minimal. The reason was that the role of buoyancy-driven natural ventilation was little when the temperature variations between the indoor and outdoor environment was small.

The comparison of the effect of indoor ventilation and thermal comfort of case A and C was shown in Fig.9. It can be seen that the CFD predictions of the indoor air velocity of case C was better than case A, and at the same time the calm wind area of case C was smaller than case A. The vertical air temperature difference of 3°C is recommended in ISO 7730 standard, while the vertical air temperature difference of case A is 3.2°C which beyond the standard recommended values. Therefore, from the angle of thermal comfort, the Case C was the best optimization scheme.

![Fig.9-a velocity contours of case A(z=1.2)](image)

![Fig.9-b velocity contours of case C(z=1.2)](image)

![Fig.9-c Temperature contours of case A(z=1.2)](image)

![Fig.9-d Temperature contours of case C(z=1.2)](image)

5. Conclusions

In this study, a traditional stilt houses was modeled and the effect of cross-ventilation and buoyancy-driven natural ventilation is investigated using a validated CFD model. Steady-state CFD simulations of the natural ventilation airflow and temperature distributions in the building were carried out utilizing the RNG κ-ε turbulence model. Furthermore, three optimization schemes were put forward and simulated in terms of the mechanism of natural ventilation. The following main
conclusions were drawn from this study.

1. From the analysis of the results obtained for various optimization schemes, it was found that the cross-ventilation strategy was favorable to improve the effect of natural ventilation in hot summer, but the effect of natural ventilation was adverse when only used the buoyancy-driven natural ventilation.

2. It was observed that the Case C was the best optimization scheme as the effect of cross-ventilation and buoyancy-driven natural ventilation were taken account into this model. This case was effective to improve the indoor ventilation effect and thermal environment with the velocity of air increased by 1.95 times and the temperature reduced of 2.4°C.

3. Overall, the results indicated that rationally setting the size and location of the windows and vents could improve the indoor natural ventilation effect in hot summer, the relative location of openings should make full use of the effect of cross-ventilation and buoyancy-driven natural ventilation.

Acknowledgements

This work was financially supported by:

(1) National Natural Science Foundation of China, under Grant No.51268020.
(2) Key Projects in the National Science & Technology Pillar Program, under Grant No.2013 BAJ07B01.

References