Research on Technology of Creating Natural Ventilation in Huizhou Traditional Dwellings

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Abstract. In the long-term adaptation of Huizhou traditional dwellings to the local environment, a variety of climatic creating techniques have been formed, and natural ventilation creating technology is one of them. Three methods, i.e. theoretical analysis, simulation and actual measurement are combined to study the natural ventilation creating technology of Huizhou buildings. Natural ventilation design of Huizhou traditional dwelling can be summarized into four types: basic ventilation mode, reinforce of natural ventilation, passive cooling and control strategies. Natural ventilation performance is indicated by field measurement, and the hall and the bedroom both meet the minimum number of air changes per hour. The influencing mechanism of patio on natural ventilation of Huizhou traditional dwelling is studied by CFD software, flow rate is similar between the dwelling with patio and without patio. The wind speed range of the hall is 0.3–1.4 m / s, and the bedroom is 0.1–0.5 m / s. Cross ventilation of the hall is restrained and flow direction of each opening is changed by the patio, and chimney effect makes the inflow and outflow of patio simultaneously.

1. Introduction

The purpose of natural ventilation is to control indoor air quality and solve the indoor thermal comfort problem in summer or transition season, then replace or partially replace air conditioning. Natural ventilation creating techniques with local characteristics is formed in ancient Chinese traditional dwellings, so, many scholars in China have studied the natural ventilation of ancient dwellings. Chen[1] explored the natural ventilation optimization design method of Huizhou traditional dwelling by means of CFD simulation. It was found that the best natural ventilation performance is the vertical length of the patio. The slightly increased windward opening area can significantly reduce air age. The leeward opening can produce cross ventilation, and its location has little influence on indoor air age. CFD numerical simulation was conducted by Li [2] on the basis of the natural ventilation measurement of a typical patio-style dwelling in Xinye Village, airflow direction of the ancient building in summer was obtained, and the patio plays the role of organization ventilation. Gao[3] takes the traditional bamboo house in Lingnan village as the research object, and natural ventilation mode is analyzed by CFD numerical simulation, focusing on the variation of indoor ventilation performance with the size of the patio. As a result of that, there are few studies on the natural ventilation of traditional dwellings, and research on technology of creating natural ventilation is absent.

2. Investigated Dwelling
A traditional dwelling, named Yuqing House, located in Zhaji village of Jingxian county in Anhui province. The building faces south and has a sloping roof on the second floor, as shown in Figure 1. The main zone of Huizhou traditional dwellings is the patio, the bedroom, the hall and the attic. The patio is the transitional space connecting outside and inside the dwelling. The bedroom is used for sleeping and resting. The hall is used to entertain guests, and the attic is used to storage because of the poor thermal environment of the second floor.

The symbols that appear in the formula below are as follows:
(1) Zone description: \( in \) is indoor, \( out \) is outdoor, \( P \) is patio, \( h \) is hall, \( b \) is bedroom;
(2) Opening description: \( h_2 \) is back door, \( h_1 \) is hall opening, \( b_2 \) is bedroom door, \( b_1 \) is bedroom window (two windows combined), \( p_2 \) is front door, \( p_1 \) is patio opening.

3. Natural Ventilation Design

3.1. Basic Ventilation Model

3.1.1. Wind-Driven Ventilation The wind-driven ventilation mode mainly occurs in the openings opened during daytime, as shown in Figure 2. Two-sided openings mode is applied to simplification of hall, where it has two openings, i.e. the backdoor and the hall opening situated on the interface between hall and patio. The hall has large inlet and small outlet, which can promise ventilation performance of small velocity and uniform flow fields. When prevailing wind in summer is southwest in the region of dwelling, cross ventilation is generated in the hall with outdoor wind from the front door into the bottom of patio and then out of backdoor. The hall and the patio are regarded as a whole to calculate ventilation rate of hall. The outdoor wind entering from the front door, part of which flows out from the opening of the patio, part of which flows to the hall, and that are the ventilation rates of the hall \( Q_h \).
\[ Q_h = B_{hl} A_{hl} v \sqrt{C_{in} - C_{hl}} \]
\[ B_{p2} A_{p2} \sqrt{C_{p2} - C_{in}} = B_{hl} A_{hl} \sqrt{C_{in} - C_{hl}} + B_{p1} A_{p1} \sqrt{C_{in} - C_{p1}} \]

Where \( Q \) is ventilation rate \( m^3 \), \( B \) is discharge coefficient, \( A \) is area, \( m^2 \), \( v \) is wind speed in the height of building, \( m/s \). Ventilation performance is poor in the single-side opening of bedroom due to only turbulent wind when wind-driven ventilation, and its ventilation rates are almost nearly zero [4]. The patio is similar to atriums, and “suction effect” is produced at the patio opening when the outdoor wind flow into. The ventilation rate of the patio opening consists of two parts, one is the chimney effect of the outdoor wind on the opening of the patio, and the other part is the outflow of patio resulting from the front door. The net outflow rates of the patio opening are

\[ Q_p = B_{p1} A_{p1} v \sqrt{C_{p1} - C_{in}} \]

3.1.2. Buoyancy-Driven Ventilation

The dwelling buoyancy-driven ventilation mode occurs at night (Figure 3). During summer, the indoor temperature is higher than patio, outdoor respectively. Therefore, the bedroom and the hall are heat sources, the patio is a cold source, and the patio is also a heat source relative to the outdoor. Cross ventilation mode transforms into single-side and single opening mode in Hall for the closing of the front door and the back door. Lose heat rapidly above patio at night, so its temperature is lower. After the cold air sinks to the bottom of the patio, it flows through the lower part of the hall to the hall. After taking the heat of the hall, it flows out from the upper part of the hall (under the eaves) and then flows directly to the outside through the patio opening. The ventilation rate of the hall is approximately.

\[ Q_h = B_{hl} A_{hl} \frac{3}{3} \sqrt{\frac{(T_{in} - T_{out}) g H_{hl}}{T_{out}}} \]

Where \( T \) is temperature, °C, \( H \) is opening height or height difference between openings, m. Depth of bedroom \( D=2*H \), interior space of the bedroom is in effective area of single-side natural ventilation \( (D \leq 2.5*H) \). Lattice window and lattice door are decorated with large opening area and big height difference to the benefit of single-side thermal pressure ventilation. Vents of bedroom are lattice door and lattice window, so the bedroom can be simplified to single-side and double opening mode, and its ventilation rate is

\[ Q_o = C_{h1-h2} (A_{h1} + A_{h2}) \left[ \frac{\sqrt{2} A_{h1}/A_{h2}}{\sqrt{(1+ A_{h1}/A_{h2})(1+ A_{h1}^2/A_{h2}^2)}} \right] \sqrt{\frac{(T_{in} - T_{out}) g H}{T_{out}}} \]
Where \( B_{b12} \) is flow coefficient for the opening \( b1 \) and \( b2 \), \( H_{b12} \) is the height difference of \( h1 \) and \( h2 \), m. Bedroom can be simplified to single-side and one opening mode with closing lattice door and lattice window, and ventilation rates can refer to equation (3).

3.2. Reinforce Of Natural Ventilation
The basic ventilation mode of the dwellings is to ensure natural ventilation performance, that is, to improve indoor air quality. However, at some time, the outdoor wind speed is too small, and the indoor and outdoor temperature difference is small, the basic natural ventilation effect of the residential houses may not be guaranteed, measure of reinforcing natural ventilation is required.

The double pitch roof has a good diversion effect and can guide the airflow from the eaves to the ridge, especially in wind-pressure ventilation. The roof is a tiling structure, and the airtightness between the tiles and the tiles is insufficient, which exacerbates gas exchange between indoor and outdoor. The patio is an important vent for residential buildings, which can guide wind pressure ventilation and guide thermal driven ventilation. In a sense, residential ventilation depends on the patio.

3.3. Passive Cooling
When outdoor temperature is high at high noon in hot summer, natural ventilation has an adverse impact on indoor thermal environment (expect for high wind speed can improve human thermal comfort). Expect to restrain appropriately natural ventilation and cool wind can reduce negative influence to thermal environment.

The mountain, vegetation and water system around the village are the first step of pre-cooling the wind. The buffer space of the patio, cold alley and ground bamboo can be used to heat the wind in the second step. The vegetation and water in the patio and courtyard for the wind entering the room is pre-cooled in the third step. After a series of precooling measures, people who are in doors in hot summer can feel “cool breeze”

3.4. Control Strategy
Greatest ventilation effect must be ensured by controlled natural ventilation. The local dwellers have experienced control strategy to adjust natural ventilation, of course, this is human control.

The most effective means of controlling natural ventilation performance is to regulate opening area. Natural ventilation performance of the bedroom controlled by lattice window with a lot of gaps. Closing lattice window not only pledge to adequate ventilation rate indoor, but also can uniform the airflow distribution.

Screen, named “stop wind”, has a fundamental role of separation and decoration, and restraining wind is more important. Cross ventilation of the hall is controlled by screen, opening scree for the benefit of formation of cross ventilation and closing screen to restrain cross ventilation.

In hot summer daytime, the local villages in Huizhou change their use of the patio from passive to active. The patio opening is covered by mat, which has influence on shading and also restraining ventilation simultaneously. At night, the mat was removed to promote indoor ventilation for removing indoor heat.

4. Influence Factor Of Natural Ventilation
There are many factors that affect the natural ventilation of a building, including external factors and internal factors. The style and location of windows are the key factors affecting the efficiency of natural ventilation in buildings. The patio is not only the most distinctive architectural form in Huizhou traditional dwellings, but also an important ventilation opening.

CFD, the most common and effective research method of natural ventilation[5], is to solve the flow field model from the microscopic point of view, using a basic equation such as mass, energy and momentum conservation to analyze the airflow condition of a zone and room.
4.1. NATURAL VENTILATION PERFORMANCE

The tracer gas method applied in testing air change rate of rooms is continuing to mature. The tracer gas drop method is currently the most widely used method, and its advantage is control easily, and the amount of tracer gas required is relatively small. A certain amount of tracer gas is injected into the test room. The concentration of the tracer gas decays with the tracer gas spreading in the test room, which can be used to predict the natural ventilation[6].

![Carbon dioxide concentration reduction in closing doors and windows of bedroom.](image)

The Figure 4 shows carbon dioxide concentration reduction in closing doors and windows of bedroom, and the air change is calculated according to the fitted curve of CO2 concentration in the figure. According to the test results, the number of air exchanges of the bedroom in closing doors and windows and opening doors and windows is calculated, their value is 5.93 h-1, 8.6 h-1, respectively. The air change of hall in the closing doors and opening doors is 7.83 h-1, 14.9 h-1[7], respectively. According to the relevant literature, the minimum number of air changes for Chinese residential buildings to meet the fresh air volume should be 0.45 h-1. So, it can be calculated that Huizhou traditional dwellings meet the minimum number of fresh air exchanges under different working conditions and different functional areas.

4.2. SIMULATION SCHEME SETTING

![SolidWorks model of dwelling](image)

(a) With patio (b) Without patio

**Figure 5.** SolidWorks model of dwelling
The actual building of the dwelling as shown in Figure 5(a), having patio model as a contrast to study the impact of the patio to dwellings ventilation, which the front door is used to replace the hall opening. The wind pressure driving force is only considered, while the thermal force is ignored in this ventilation simulation. The wind environment of indoor and outdoor is simultaneously simulated in order to increase the accuracy. The wind speed of the outer field shows a gradient distribution with height change. According to weather data of wind in summer in Zhaji reference the literature[8], the wind speed at a height of 10 m is 1.6 m/s.

4.3. RESULT AND ANALYSIS

(a) Without patio

(b) With patio

Figure 6. 1.5 m pedestrian height wind speed vector on the first floor of the dwelling.

Compare the wind speed vector of 1.5 m pedestrian height on the 1st floor of the dwelling with patio and without patio (Figure 6). There is little difference in wind speed between the indoor and outdoor of the dwelling with patios or without patio. The wind speed range of the hall is 0.3~1.4 m/s, the wind speed of the bedroom is 0.1~0.5 m/s, the flow velocity of the bedroom and hall is relatively uniform, but the internal flow velocity of the bedroom is too small, its value is only 0.1 m/s. The wind speed of the patio is about 0.4~2.0 m/s. The wind speed at the opening is up to 2 m/s, the wind speed in the bedroom is significantly smaller than that in the hall, and the wind speed in the patio is slightly larger than that in the hall and the bedroom. For the dwelling without patio, there is not much different in the indoor airflow of west bedroom and east bedroom, and the obvious cross ventilation is formed in the hall. But, the wind speed of the east bedroom is obviously larger than that of the west bedroom, cross ventilation is not formed in the hall.
Comparing vertical section speed vector of the bedroom and the attic with patio and without patio (Figure 7), when there is no patio, the flow field of bedroom and attic is similar, and the flow rate of attic is smaller than that of the bedroom because of patio. Both the bedroom and the attic are single-sided ventilation areas. Except for the large wind speed at the opening, the internal area has a small flow velocity and a uniform flow field.

Compared with section speed vector of hall with patio and without patio (Figure 8), when there is no patio, the outdoor southwest wind flows directly from the front door into the hall and flows out from the back door. When there is a patio, the hall opening, the back door, the patio opening is inlet and outlet simultaneously except the front door which only wind flow into. In general, the inlet is the back door, and the outlet is the hall opening and patio. The airflow flows into the patio from the front door, and a part of the airflow flows directly from the patio opening. The other part of the airflow flows to the hall opening and then flows to the hall, and then flows out from the back door.

5. Conclusion
There are four main types of natural ventilation design techniques in Huizhou traditional dwelling: The dwelling natural ventilation performance is assured by wind pressure and thermal pressure. Ventilation rates are ensured by reinforce of natural ventilation. Thermal comfort is promoted by passive pre-cooling ensures comfort, and stability of ventilation is ensured by stable ventilation controlling strategy.

Actual measurement of air change rates shows that the natural ventilation of the dwelling is good, and the halls and the bedrooms can meet the minimum ventilation requirements when the doors and windows are closed. There is little difference in the flow rate of each area between the dwelling with patio and without patio. The wind speed range of the hall is 0.3~1.4 m / s, and the wind speed of the...
bedroom is 0.1~0.5 m / s. The bedroom and attic are characterized by a single-sided ventilation flow field, and uniform flow field and small flow rate in the internal bedroom and attic except for the opening. The obvious cross ventilation is formed in the hall without patio, but cross ventilation is restrained by patio which can change the flow direction of the hall, the suction effect of the patio makes the inflow and outflow of the patio opening simultaneously and inflow rates is smaller than outflow rates.

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