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Research Paper

# Evaluation on indoor thermal comfort improvement of Baffle Natural Ventilation System for rural overhead building in Hot-summer and Cold-winter zone

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**ABSTRACT**

The rapid growth in urbanization and economy activities has led to an increase in energy consumption, which hastens the depletion of available energy resources and causing the traditional villages to lose regional characteristics in China. The building sector is one of the major end-users of energy. And On the other hand, the air conditioning system is viewed as an important tool to sustain and improve the thermal comfort of occupants （Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review）, that seriously enhanced the energy and environment risks, especially in Hot-Summer and Cold-Winter (HSCW) zone. Therefore, it is vital to find a green and sustainable way to construct. The problems of rural public buildings in Hot-summer and Cold-winter Zone were analyzed and summarized. The rural overhead public building which authors involved in was selected to be the research object, as its' avoid hardening of the land and reducing the heat island effect.

## 1. Introduction

With the increase in population and the improvement of living standards, the demand for energy in China is steadily increasing. Urbanization and economic development are causing the traditional villages to lose regional characteristics in China, also consuming a large number of mineral and land resources [1]. With the urban rapidly expanding in recent decades, the annual energy has been increasing dramatically. Meanwhile, the urban environment and pollution problems have become increasingly prominent. With network communication development, remote activities are generalizing, and people's living standards rising, rural public building is gradually becoming a hot topic recently.

"Public Building" refers to "the buildings for people to carry out various public activities [2], including office buildings, commercial buildings, tourist buildings, science and education buildings, communications buildings, Transportation buildings and others (police stations, warehouses, detention centers). But this is defined from the perspective of the city, so in this paper, "Rural public building" drawing on this definition can include modern public buildings what are non-productive and different form residential buildings. The scale and function of rural public buildings are often matched with the nature and grading of rural settlements. At the same time, it represents the modernization of rural construction, influenced by the cultural life standards of the villagers.

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*Note :* Discussion on this paper is open until June 2021

· Comprehensive. Although the rural public building is usually on a small scale, the villagers always combine the buildings with similar properties.

· Versatility. In order to improve the utilization of space, rural public building often includes a variety of functions, such as culture, technology, commerce, and education.

· Regional. The rural public building must serve the local residents as well as play the regional role of economic activities within its scope.

The large-scale construction of rural public building began in 2005 in China. Although there are so many advantages to a rural public building, there are also many problems in the construction process.

The villagers usually occupy basic farmland to build during the construction process, which makes most of the ground hardened, leading to many new rural environmental problems. Besides, they only think about the practicality of buildings, without culture and climatic conditions. So, they always pursue modernization, lacking the excavation of regional characteristics, making rural villages become assimilated in China. Due to the lack of passive technology and the poor performance of traditional ecological technology, the villagers choose to use air condition massively, which has led to a significant increase in energy consumption. What's more, the natural ventilation is poor, and the thermal comfort is bad, with improper location and size of windows. This paper attempts to evaluate and verify the feasibility of passive sustainable technology in rural public buildings in Hot-summer and Cold-winter Zone, taking natural ventilation optimization as an example.

## 2. Selection of location

The climate condition varies greatly from region to region in China, leading to different regional characteristics of building energy consumption. The Chinese national regulation "Thermal Design Code for Civil Building"[3] defined five climate zones in China according to the mean temperature of the coldest month and the hottest month, as shown in Fig.1.

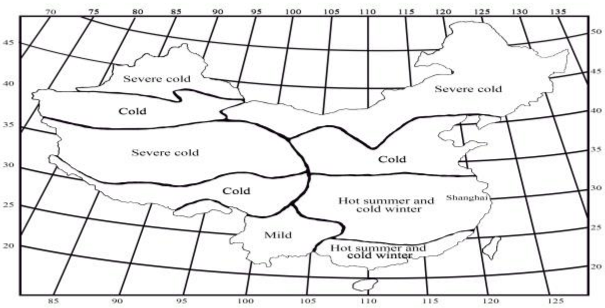



**Fig.1.** Layout of five climatic zones in China

Compared with other climate zones, the Hot-Summer and Cold-Winter (HSCW) Zone showed special significance in energy conservation task of China due to the following reasons:

· This area covers 16 provinces, which is nearly half of the nation's entire provinces; more than 40% of the Chinese population lives in this area, which is less than 20% of the total Chinese area, leading to much higher population density than other regions.

· The economy growth is more rapid than other regions and takes up 48% of the gross domestic product (GDP).

The weather data of Typical Meteorological Year [4] showed that the average outdoor temperature is 0–10 ℃ in the coldest month and 25–30 ℃ in the hottest month. The relative humidity is 70%–80% or even higher all over the year. Together with the long period of summer and winter (summer: from early May to late September, winter: from mid- December to mid-February next year), the building energy consumption in HSCW Zone takes about 45% of the whole country [5]. According to China's design regulation [3] and traditional local habits, no central heating system was designed for buildings in the HSCW zone. The meteorological situation of Tonglu town was shown as following Fig.2 and Fig.3. The dry bulb temperature in August is 32 ℃, and the relative humidity is 71.5%.

To sum up, in order to adapt to such climate conditions and reduce the energy issue, it's necessary to achieve cooling in summer, with good proper ventilation.

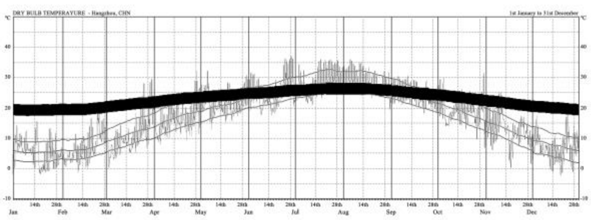


**Fig.2.** The daily dry bulb temperature situation

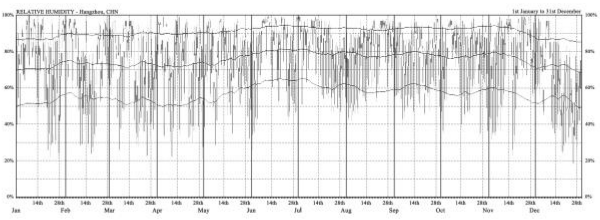


**Fig.3.** The daily relative humidity situation

## 3. Method

Investigation and simulation were conducted in an overhead public building of Tonglu town in HSCW zone, the model was shown in Fig.5 and Fig.6. Field measurement were carried out for collecting physical parameters and climatic conditions "point-in-time", so that

In this study, the time-dependent PMV, which is a complex mathematical expression involving activity, clothing, and the four environmental parameters, was generated from Fanger's expression [6]:

PMV=[0.303$e^{-0.036M}$+0.028]{（M-W）-3.96$E^{-8}$fcl[（$t_{cl}$+273$t_r$+273）$^4$] -$f_{cl}h_c$（$t_{cl}$-$t_a$）-3.05[5.73-0.007（M-W）-$p_a$]-0.42[（M-W）-58.15]-0.0173M （5.87-$p_a$）-0.0014M（34-$t_a$）}　　　　　（1）

With,

$$f_{cl}=\frac{1.0+0.2I_{cl}}{1.05+0.1I_{cl}}$$

$t_{cl}$=35.7-0.0275（M-W）-$R_{cl}${（M-W）-3.05[5.73-0.007（M-W）-$p_a$]

-0.42[（M-W）-58.15]-0.0173M（5.87-$p_a$）-0.0014M（34-$t_a$）}

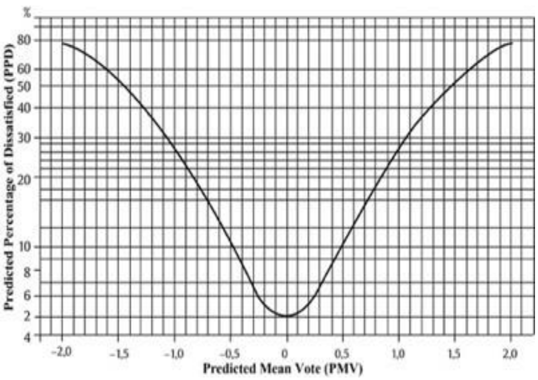
$R_{cl}$=0.155$I_{cl}$

$h_c$=12.1（V）$^{1/2}$

Where

e =Euler's number (2.718)　　$R_{cl}$ =clothing thermal
$f_{cl}$ =clothing factor　　$t_a$ =air temperature [℃]
$h_c$ =convective heat transfer　　$t_{cl}$ =surface temperature
$I_{cl}$ =clothing insulation [clo]　　$t_r$ = mean radiant
M =metabolic rate [W/m$^2$]　　V = air velocity [m/s]
$p_a$ =vapor pressure of air　　W = external work

In addition, another index calculated through PMV is also developed by Fanger, which is called Predicted Percentage Dissatisfied (PPD) and expresses the expected percentage of people who are thermally uncomfortable in the subjected environment. The relationship between PPD and PMV is shown in Fig.4.




*Data source: E.N.I.S.O.7730,*

**Fig.4.** PPD as function of PMV

Since PPD is a function of PMV, it can be defined as:

PPD=100-95 $e^{[-(0.3353PMV^4+0.2179PMV^2)]}$　　（2）

As shown in Table 1, to express the quality of the thermal environment as a quantitative prediction of the percentage of thermally dissatisfied (i.e, people who feel too cold or too hot) the PPD-index (predicted percentage of dissatisfied) is also used. The PPD correlates to the PMV value by mean of Eq. (2) whose mathematical structure reveals that a little percentage of dissatisfied (5%) can be expected under thermal neutrality conditions (i.e, PMV = 0).

**Table 1.** 7-points ASHRAE thermal sensation scale

| | |
|---|---|
| +3 | Hot |
| +2 | Warm |
| +1 | Slightly Warm |
| 0 | Neutral |
| -1 | Slightly Cool |
| -2 | Cool |
| -3 | Cold |

## 4. Calculation and analysis

### *4.1 Simulation program PHOENICS*

The CFD code development group at Imperial College headed by D.B. Spalding began multiphase flow modeling in the mid- and late 1970s. Spalding developed the interphase slip algorithm (IPSA) to solve the PDEs contained in the PHOENICS code, debuting in 1978, which Runchal claims "…was the first commercially available tool in CFD." Runchel makes extensive reference to the influence of the Group T-3 at LANL on multiphase flow but does not mention the SLOOP code development work at ANC. This is in spite of the fact Spalding was quite aware of it, as evidenced by his consulting at ANC in the early 1970s and his participation in Dimitri's 1976 NSF workshop and the 1979 EPRI workshop. The Web site for the PHOENICS code is http://www.cham.co.uk.

The PHOENICS CFD code solves the time-averaged conservation equations of mass, momentum, energy, and chemical species in steady three-dimensional flows：

$$\frac{\partial}{\partial_t}(\rho\Phi)+div\{(\rho v\Phi-\Gamma_\Phi grad_\Phi)\}=S_\Phi$$

where ρ; υ; ΓΦ; and SΦ are density, velocity vector, "effective exchange coefficient of Φ," and source rate per unit volume, respectively, for a solved-for variable Φ. The discretization of the domain is followed by the reduction of the previous equations to their finite domain form using the "hybrid formulation of the coefficients," and the solution technique employs the SIMPLEST algorithm (an improved version of the well-known SIMPLE algorithm). The standard k–ε turbulence model is applied, while buoyancy effects are considered. To improve convergence, under relaxation techniques were used.

*4.2 Base case model*

The base case(case A) is a one-floor typical overhead building. The total area is 324m$^2$. As shown in Fig.5 and Fig.6, the building has a 2.5m stilt floor to avoid the hardening of the land and to reduce the heat island effect. As the limit of site condition, the angle between orientation and summer wind direction are incompatible. That led to a bad indoor thermal condition, especially in summer.

According to the local meteorological data of Tonglu town from Energyplus Weather Data, the average dry bulb temperature in the hottest month is 32℃, the relative humidity is 71.5%, the PMV value is 2.51, and the PPD is 94%, most people have to face the hot situation without cooling equipment, as case A.

Even open the window to identify the feasibility of applying natural draft ventilation, according to the ASHRAE-55, the indoor PMV value is 1.12, in a "slightly warm" level, and the PPD is 0.31, as case B.

In addition, as shown in Fig.7 and Fig.8, the Baffle Natural Ventilation System contains ten parts, including outside pipe, ring slot, ball bearing, plate, baffle, regulating valve, rotating shaft, branch, and filter. There is an air-duct designed inside, with a special air baffle installed at the bottom. Then the inner ring of the ball bearing is connected with the plate so that the plate can drive the baffle to rotate. Lastly, the wind could be blown into the air-duct in any direction by the baffle rotated to the windward side when blown by the wind, making ventilation improved inside, as case C.

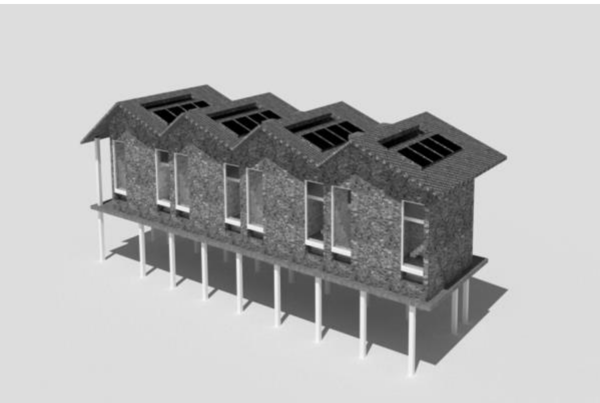
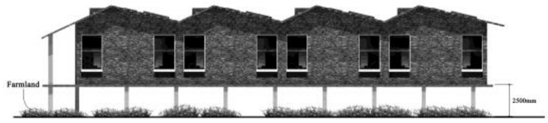


**Fig.5.** The rendering of the overhead building



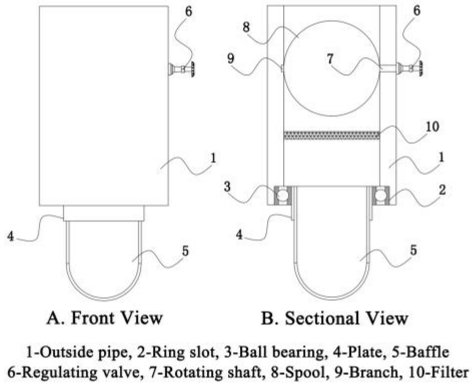




**Fig.7.** Schematic diagram of the wind baffle

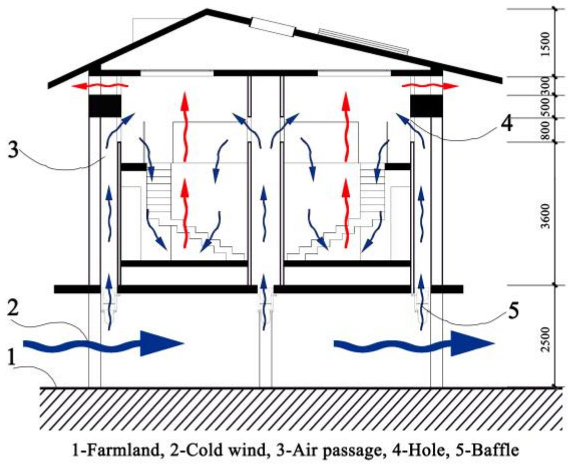



**Fig.8.** Sketch of the baffle natural ventilation system

Then three situations were conducted, they are opening closed, opening open, and opening open with baffle natural ventilation system, were defined as situation A, B and C. Next, for the identified people, the metabolic rate and the clothing level were defined as the same value when simulated by CFD. Lastly, according to the three cases above, there are three natural ventilation situations followed, shown in Table 2.

**Table 2.** Boundary condition of calculation

| Case / Boundry Condition | Dry Bulb Temperature (℃) | Mean Radiation Temperature (℃) | Air Speed (m/s) | Relative Humidity (%) | Metabolic Rate | Clothing Level |
|---|---|---|---|---|---|---|
| A | 32 | 32 | 0 | 71.5 | 1.2 | 0.5 |
| B | 30 | 30 | 0.5 | 80.0 | 1.2 | 0.5 |
| C | 28 | 28 | 0.8 | 89.5 | 1.2 | 0.5 |

For case A, the dry-bulb temperature, respectively calculated was 32℃, and the air velocity was 0m/s, with the opening closed. Its indoor environment will be very hot and dry, which makes people feel uncomfortable. And the case B as the basal natural ventilation situation, shown in Fig.9, the dry-bulb temperature was 30℃, and the air velocity was 0.5m/s, so that it will be light warm indoor. But as case C, the dry-bulb temperature dropped to 28℃, and the air velocity increased to 0.8m/s due to the baffle natural ventilation system, improving the indoor thermal comfort, shown in Fig.10. Especially, the fastest air velocity reached 1.62m/s by the Baffle Natural Ventilation System shown in Fig.11, accelerating the airflow in the room and improving the indoor thermal comfort.

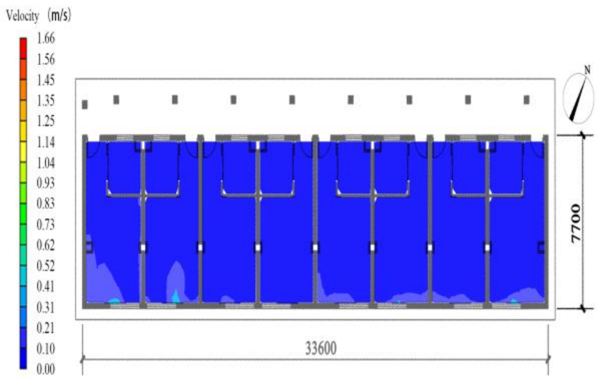



**Fig.9.** The ventilation situation of the case B

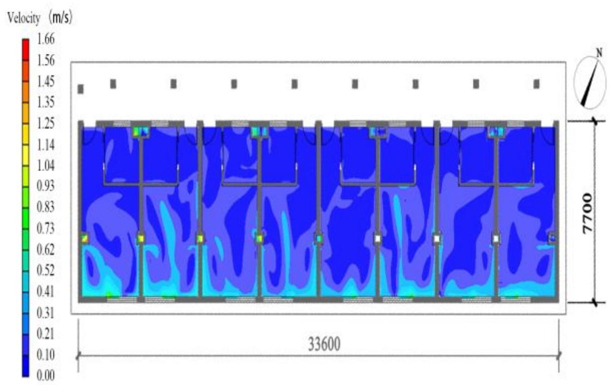



**Fig.10.** The ventilation distribution of the case C

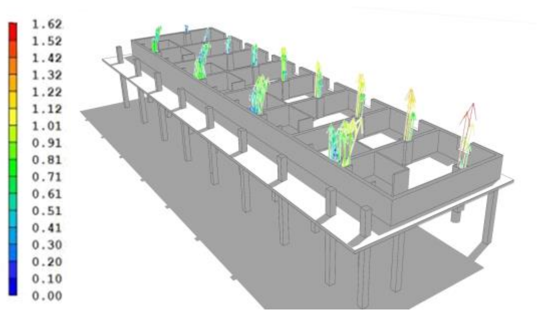



**Fig.11.** Diagrammatic drawing of case C vertical ventilation

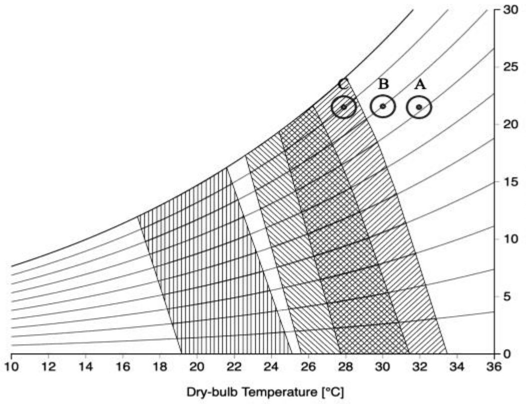



**Fig.12.** Relationship between the thermal situation and comfort zone for each case

To sum up, as shown in Fig.12, for case A, the PMV value is much higher than the comfort zone, and case B as the ventilation situation, the PMV value is better than case A because of the natural ventilation. But still in the uncomfortable zone area. As case C, the inlet temperature is lower than case A and case B. Also, the velocity speed is enhanced only 0.3m/s, but the apparent temperature was reduced a lot.

## 5. Conclusion

Applying the optimum indoor human thermal environment in a rural overhead building in Hot-summer and Cold-winter zone, the economic benefit of ventilation can be well improved. In this study, the determination of the Baffle Natural Ventilation System is analyzed, which considers the effect of the inlet air temperature in the hot season. Three typical cases A, B, C, are selected to represent no ventilation, ventilation, and ventilation with a baffle system, respectively. The result shows that the Baffle Natural Ventilation not only reached the air velocity and increased the relative humidity to improve the indoor thermal comfort but reduce the mechanical energy for cooling ventilation

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## References

J.Y. Liu. Research on Incremental Renewal Strategy of The Rural Public Architecture in The Context of New Urbanization---Taking South Regions of

Yangtze River As Case Study. Southeast University;2016

“Code for Design of Civil Buildings” （GB50352-2005，2005）

“Thermal Design Code for Civil Building”（GB 50176-93, 1993）

Meteorological information center of China meteorological administration and Tsinghua meteorological administration and Tsinghua University, 2005

Yu J, Yang L, Tian L, Liao D. A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China. Applied Energy 2009；86（1）Pages 2520–2529.

P. O. Fanger, Thermal comfort. Copenhagen: Danish Technical Press, 1970

**Symbols and abbreviations**

| | |
|---|---|
| A, B | Constants of integration |
| b | Outer radius of the plastic zone during loading |
| c | Internal cohesion of the ground |
| D | Depth of footing |
| d | Pile tip diameter |
| F | Skin friction of pile |
| $f_s$ | Unit skin friction |
| $F_c$ | Percent fines |
| $I_D$ | Relative density of soil |
| $I_R$ | Function of relative density |
| $I_r$ | Rigidity index |
| $I_{rr}$ | Reduced rigidity index |
| N | Standard penetration resistance value |
| n | Integer from zero to infinity |
| $P_B$ | Total end bearing resistance |
| $P_S$ | Total skin friction |
| $P_T$ | Total bearing capacity |
| $p_0$ | Initial cavity pressure |
| $p'$ | Mean effective stress |
| $p_u$ | Cavity expansion pressure |
| $q_a$ | Net allowable bearing pressure |
| $q_{pcal}$ | Ultimate end bearing capacity |
| $r_0$ | Radius of material point at initial state |
| R | Cavity pressure ratio |
| Y | Function of cohesion and friction angle |
| $\beta$ | Function of dilation angle |
| $\gamma$ | Function of material properties |
| $\delta$ | Function of material properties |
| $\eta$ | Function of material properties |
| $\Lambda$ | Infinite power series |
| $\xi$ | Function of material properties |
| $\varsigma$ | Auxiliary variables |
| $\rho_s$ | Density of particles |
| $\kappa$ | Material constant |
| $\sigma$ | Radial stress of ground at interface |
| $\sigma_0$ | Initial radial stress |
| $\sigma_r$ | Radial stress |
| $\tau_0$ | Initial yield stress of interface |
| $\psi$ | Dilation angle for ground |
| $\phi$ | Internal friction angle of ground |