Research Article
Optimized Design of Outlets Layout in Thermal Pressure Naturally Ventilated Rooms

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Abstract: Using thermal pressure ventilation principles to achieve passive ventilation in buildings is an important way to promote green and low consumption building strategy. The reasonable vents layout design can fully tap the potential of thermal pressure ventilation. Aimed to civil buildings with internal heating source, using Computational Fluid Dynamics (CFD) technology, the effects of outlets layout on thermal natural ventilation in rooms were studied. Three types of typical air outlets distribution patterns were considered and the airflow distribution of thermal natural ventilation in rooms was simulated. The ventilation rates and the average workspace temperatures of different simulated conditions were given. The velocity and temperature fields of different simulated conditions were analyzed and the indoor thermal stratification characteristics were discussed. In addition, the effective heat coefficients of different simulated conditions were analyzed and compared. The results show that the strategy of dispersed outlets on ceiling can achieve the optimal natural ventilation effect. The results can provide theoretical references for the design of natural ventilation system in civil buildings.

Keywords: Optimized design, outlets layout, temperature field, thermal natural ventilation

INTRODUCTION

Passive induced ventilation technology in architectural design is an important way to promote green and low consumption building strategy (Stephen and Andrew, 2006; Liu *et al*., 2011). Passive induced ventilation can be divided into two modes including wind pressure ventilation and thermal pressure ventilation (Hazim, 2003). Outdoor air flow can create a positive-pressure zone at the windward side of buildings and create a negative-pressure zone at the leeward side. The pressure difference of these two zones is the driving force of wind pressure ventilation. Thermal pressure ventilation is an air flow phenomena that the hot air exhausts from the top vent of building and the cold air inpours at the bottom of the building. When the outdoor wind pressure is instable, or that ventilation across building is difficult to achieve because of the complex environment around the building as well as its complex body, bad orientation, deep depth and other factors, thermal pressure ventilation is the dominant factor of natural ventilation (Xue, 2005).

Thermal pressure natural ventilation is mainly affected by the concentration degree and the arrangement of heating sources, as well as building geometry, vents layout and its characteristic parameters (Sun, 1994). Regulation of natural ventilation can not be undertaken in isolation. It needs the support of

building performance and must be in conjunction with the entire building. The vent configuration directly affects air flow in buildings as well as ventilation effect. The relative position of the vents plays a decisive role for airflow route. Reasonable vents layout design can fully tap the potential of thermal pressure natural ventilation. This study aims to study the affect on the thermal natural ventilation characteristics of outlets layout.

Using CFD technology, the natural ventilation flow field was simulated in civil buildings with general geometric characteristics. Three typical air vents layout were considered. Indoor velocity field and temperature field under different conditions were studied and indoor thermal stratification characteristics were also discussed. The affect of outlets layout on some characteristic parameters such as ventilation rate, work area temperature, thermal stratification height and effective thermal coefficient, was analyzed. The optimized design of outlets layout was given. The conclusion can provide a theoretical reference for the application of passive induced ventilation technology in architectural design.

PHYSICAL MODEL AND NUMERICAL METHOD

Physical model: The study takes a domestic building as the research object with representative geometrical size

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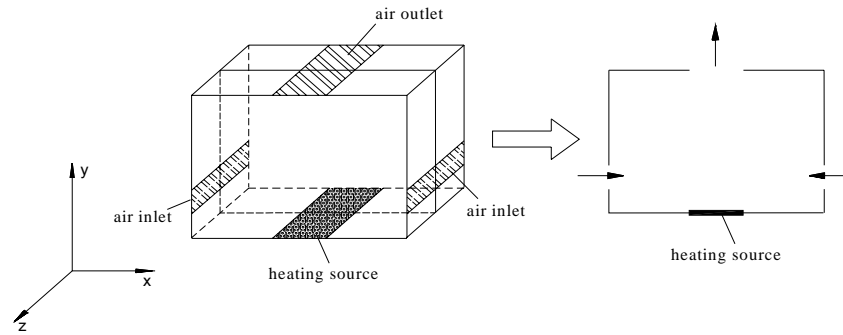
Fig. 1: Physical model

Fig. 2: Simulation conditions

Table 1: Numerical simulation results of different outlets layouts

Simulation condition	A	B	C
Ventilation rate G/(kg/s)	0.27494	0.27412	0.2724
Average temperature of exhaust air tp/K	291.842	291.841	291.979
Average temperature of intake air to/K	290.033	290.029	290.148
Average temperature of work area tn/K	291.046	290.952	291.125
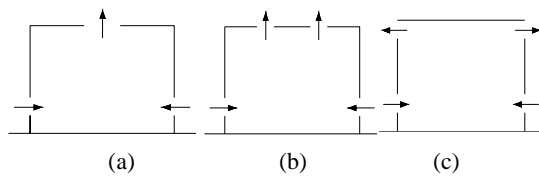
(4 m×3 m×3 m), such as Fig. 1 shows. In the 3D model, the central cross section at the z direction is the symmetry side of the room, so the simulation model can be simplified as a 2D model and the symmetry side of the room is made as the simulation object. The outdoor environment temperature is 290 k and the outdoor environmental pressure is the standard atmospheric pressure. The distribution of air outlets can be summarized into three kinds of typical layout. As is shown in Fig. 2, condition A is the air outlet in the ceiling at the top of the room distributed intensively, but condition B is scattered distribution and condition C is the air outlets in the side wall of the room distributed dispersedly. The redundant quantity of indoor heat is 500W. In the two-dimension model, the heat source width is 1.0 m, the air inlet height is 0.5 m and the total width of air outlets is 1.0 m. The height difference between air inlet and air outlet in the ceiling decorated air outlet condition is 2.25 m, while the height difference is 2.0 m in condition C.

Numerical calculation methods: Taking much simulation and analysis, the writer choosed RNG model as the calculation model which considering the influence of buoyancy and used the standard wall function method and the Boussinesq assumption (Tao, 2001). Taking much trial calculation, the calculation district was fixed: The length and height is 30 and 50 times of room's length and height, form the infinite far boundary.

RESULTS AND DISCUSSION

**Ventilation rate and exhaust air temperature:** Under the condition of invariable room geometry size and indoor residual heat, three working conditions were simulated respectively. Thermal natural ventilation rate, inlet air temperature, outlet air temperature and average temperature of workspace were given, which were shown in Table 1. As shown in the table, condition A (the single outlet on ceiling) has the maximum amount of exhaust air rate and condition C (two outlets are distributed on the both sides of the external wall) has the minimum amount of exhaust air rate, but the difference is only 0.00254 kg/s, which shows that the changing of outlets layout has little influence on exhaust air rate. Conditions A and B (dispersed outlets on ceiling) almost have the same exhaust air temperature, condition C has the highest. The workplace of Condition C (two meters height below room area) has the highest average temperature and condition B has the lowest one and relatively large difference exists. The results show that the strategy of dispersed outlets on ceiling can achieve the optimal natural ventilation effect.

Velocity distribution: Indoor velocity field distribution of three simulated conditions are shown in Fig. 3. It shows that there are obvious thermal plumes above the heat source of three conditions. However, due to the changing of outlets layout, flow field distribution patterns are different. Condition A's hot plume is concentrated, while conditions B and C are scattered because of dispersed outlets layout. Recirculating air zone in condition A's upper space is the largest and condition C's is the smallest. Updraft above heat source of condition A is the largest with the speed of 0.397 m/s and condition C's is the smallest with the speed of 0.373 m/s.
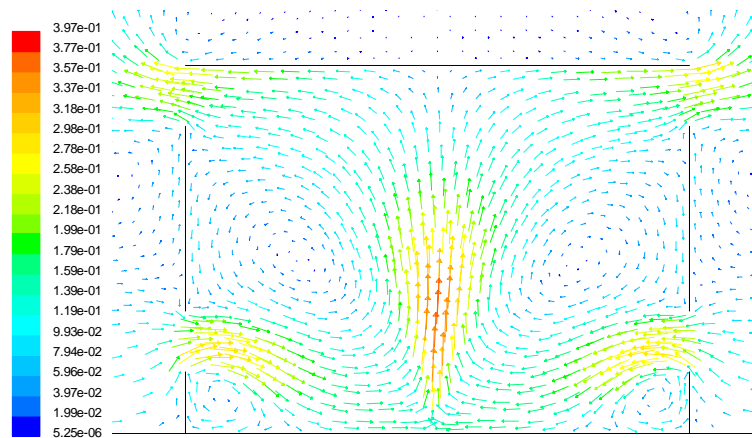
Temperature distribution: The temperature distribution of three simulated conditions is clarified in
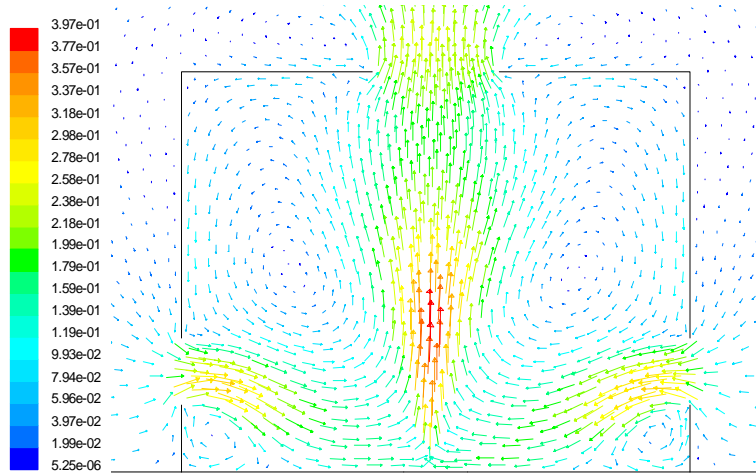
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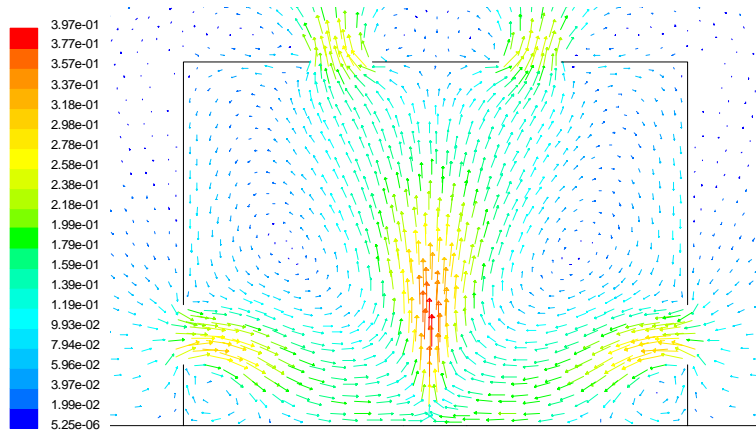
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Fig. 3: Velocity distribution in room of different outlets layouts

the Fig. 4. We can see that beyond the heat source of this three simulated conditions, high temperature zone forms obviously because of the buoyancy of hot plume. The stratified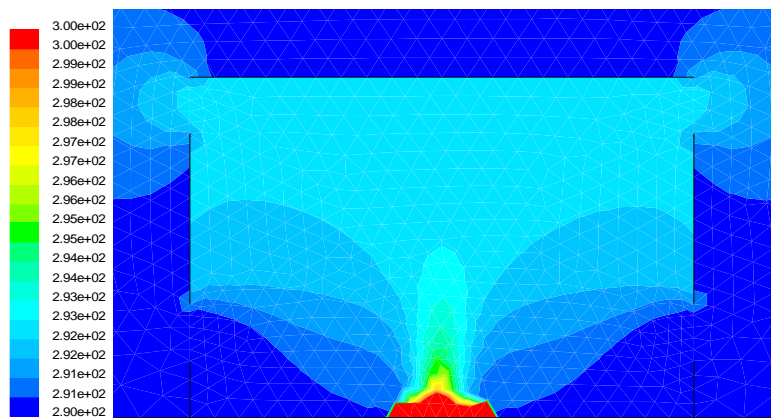 phenomenon of indoor temperature distribution is obvious and there is high and low temperature zone obviously. Thermal stratification is familiar of conditions A and B. Low temperature zone is in zonal distribution below 1.2 m of the room while
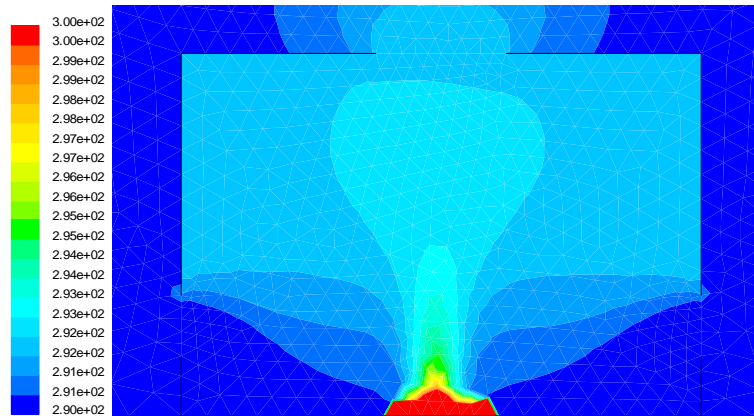
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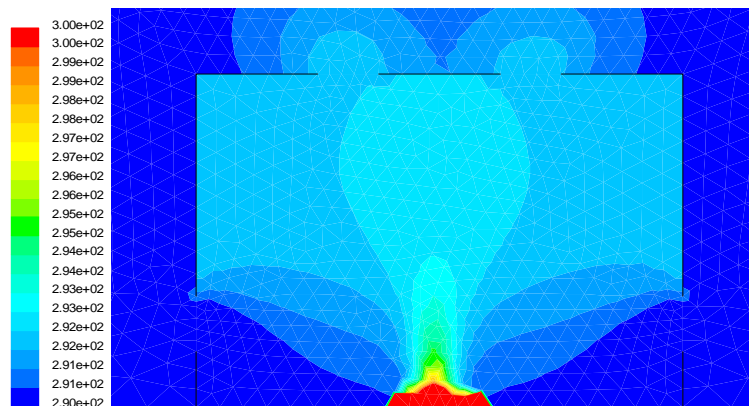
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Fig. 4: Temperature distribution in room of different outlets layouts

there is certain thickness of the hot air layer beyond 1.2 m. Condition C has the highest thermal stratification height. The dividing line of high and low temperature zone is at about 1.5 meters. Besides, air temperature of the upper region of condition C is higher than A and B conditions obviously. It is because when the air outlets are distributed on both sides, thermal updraft offsets

after it reaches the roof of the room and discharges through the air vents. As a result, the diffusion area of upper hot air increases, therefore the temperature of the upper region increases.

Temperature distribution of x = 0.5 m and x = 1.0 m section along the direction of height of three simulated conditions are shown in Fig. 5. We can see
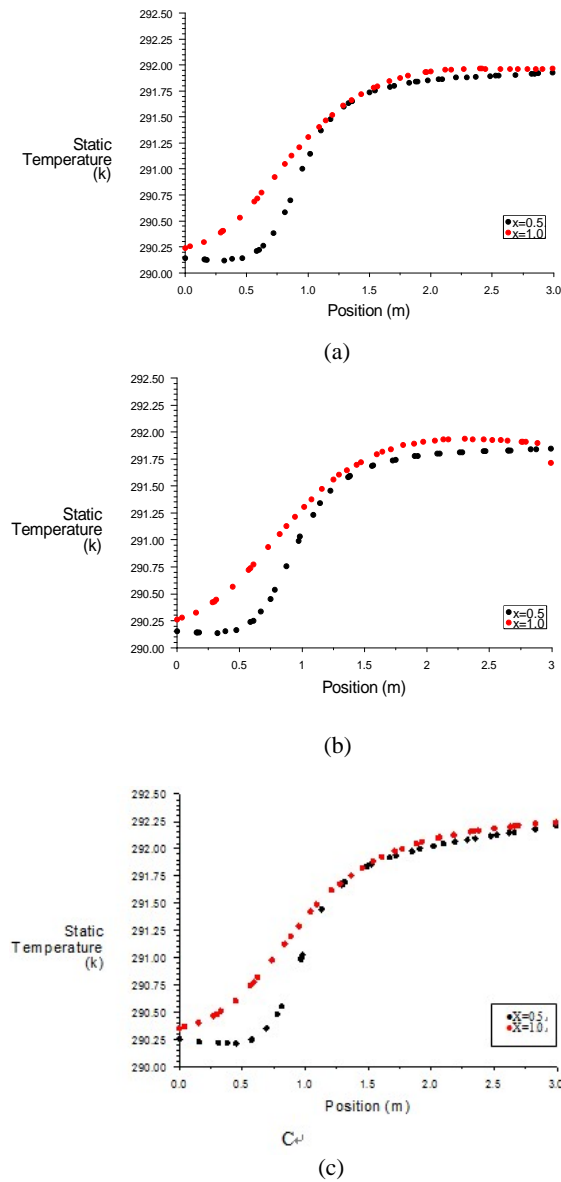
(a)

(b)

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Fig. 5: Temperature distribution of x = 0.5 m and x = 1.0 m section along the direction of height of different outlets layouts

(a)

(b)

(c)

Fig. 6: Temperature distribution of y = 0.5 m, y = 1.5 m, y = 2.0 m and y = 2.5m section along the horizontal direction of different outlets layouts

that conditions A and B have similar temperature distribution along the direction of height. Below 1.2 m, there is a large low-temperature transition zone with larger temperature gradient. Above 1.2 m, the temperature is higher and it is almost consistent. The dividing line of temperature change of condition C rises to 1.5 m.

Temperature distribution of y = 0.5 m, y = 1.5 m, y = 2.0 m and y = 2.5 m sections along the horizontal direction of three simulated conditions are clarified in Fig. 6 From the figure we can see that the uniformity of temperature distribution along the direction of three calculated conditions is not very different. Temperature is h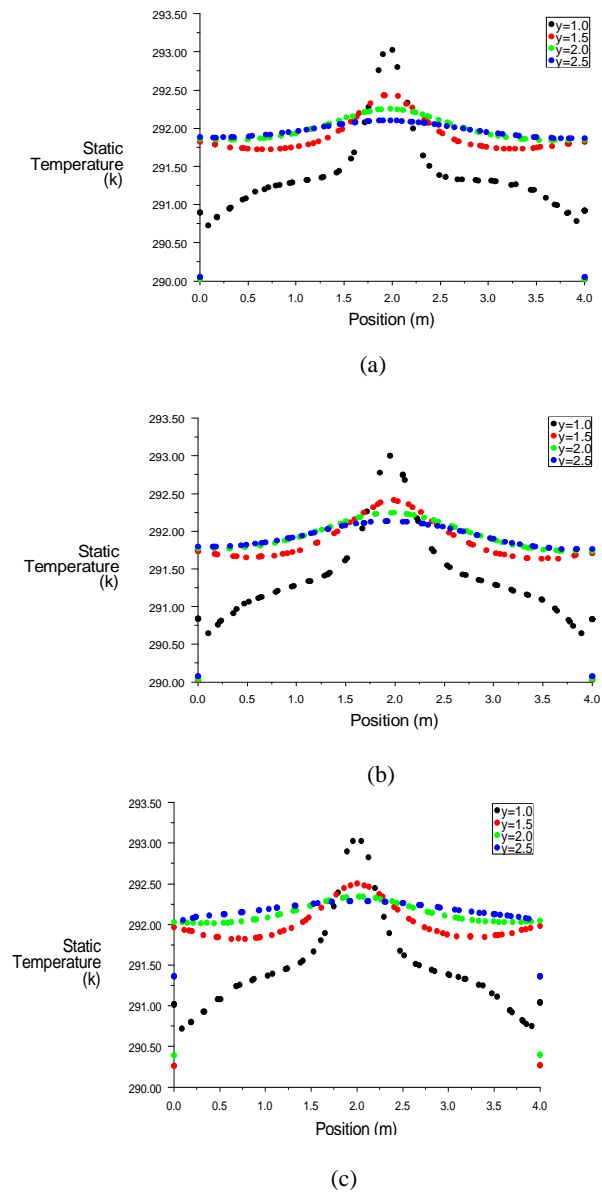igher in the center area of room with the influence of heated plumes and the uniformity of temperature distribution is better on both sides of the room.

The effective thermal coefficient m: Effective thermal coefficient is also called thermal distribution coefficient, which is one of the important indicators to evaluate the ventilation efficiency. It indicates that part of the heat directly scattered into the work area accounted for the number of the indoor heat dissipation, the formula is:

$$m = \frac{t_n - t_o}{t_p - t_o} \qquad (1)$$

Table 2: Effective thermal coefficients of different outlets layouts

Condition	A	B	C
m	0.5545	0.5096	0.5334

where,

m = Effective thermal coefficient
t_p = Exhaust air temperature, °C
t_n = Workplace temperature, °C
t_o = Inlet air temperature, °C

According to the results of numerical simulation, we can calculate the value of the effective thermal coefficient m of different simulated conditions by formula (1), shown in the Table 2. Condition B has the minimum value of m, which shows that when air outlets are on ceiling and arranged dispersedly, the quantity of heat scattered into the work area is the least and thermal ventilation effect is the best.

CONCLUSION

When the geometric dimension of the air inlet is must, the center height difference of air inlet and air outlet is not very different and the total area of air outlet is unchanged, the change of air outlets distribution patterns does not have a big influence on air output. When air outlets are on ceiling and arranged dispersedly, the workplace's temperature of room is the lowest and the effective thermal coefficient is the smallest. It shows that when air outlets are arranged dispersedly, the quantity of heat scattered into the work area is the least and thermal natural ventilation effect is the best. When the geometric dimensions of buildings and internal heating sources are fixed, the strategy of dispersed outlets on ceiling can achieve the optimal natural ventilation effect.

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