INFLUENCE ANALYSIS OF NEUTRAL PLANE ON VENTILATION IN WORKSHOP

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ABSTRACT

This paper analyzed the influence of neutral plane on natural ventilation in workshop. For several typical heights of neutral plane of a molding workshop, its influence on ventilation was simulated by means of CFD. In designing natural ventilation, to coordinate the dimensions between the inlet and outlet openings and to play down the neutral plane properly may be the effective measures to increase ventilation efficiency. In supervising ventilation, the cooperation should be intensified between the inlet windows, the secondary windows and clerestories in order that airflow short-circuits may be avoided.

KEYWORDS

Neutral plane, Stack ventilation, Airflow short-circuit, CFD

INTRODUCTION

Workshop environment is immediately related to workers' health and product quality. Ventilation is one of effective measures to improve environment, and air distribution is the key to improve ventilation efficiency. Natural ventilation is driven by wind and thermal pressures. Designing natural ventilation is concerned with harnessing these forces by the careful sizing and positioning of openings (Liddament 2000, Luo et al. 2005). According to design criterions, thermal pressure is treated as the only driving force, but wind pressure may be an auxiliary factor because of its diversification in designing natural ventilation of a workshop, especially for a thermally machining or processing workshop (Li 2002，Feng et al. 2004). The neutral plane is immediately related to air distribution, and ventilation efficiency (Chen et al. 2000). In this paper, the influence of neutral plane on natural ventilation in workshop was simulated and analyzed. The outcomes and conclusions are of constructive meaning for optimizing ventilation of analogous workshops and improving indoor environment.

COORDINATING DIMENSIONS BETWEEN INLET AND OUTLET OPENINGS

Effective ventilation is a necessary measure to improve environment in a thermally processing workshop, because large numbers of heat, dust, smoke and poisonous gas are generated during processing work pieces. For a certain height of a workshop and heat elimination, to coordinate the sizes between the inlet and outlet openings may be the key to increase ventilation efficiency.

Figure1 illustrated the stack ventilation in a workshop, F_1, F_2 are areas of inlet and outlet openings respectively, and Δp_1, Δp_2 are intake and exhaust pressures, h_1, h_2 are heights of inlet and outlet openings, while H is the height between midlines of inlet and outlet.

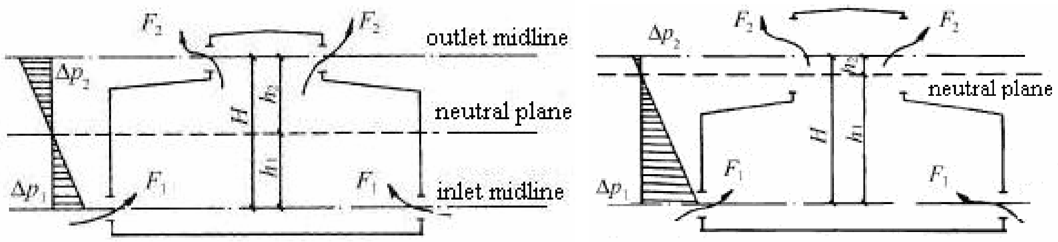
As illustrated in Figure 1, In order to make most or all fresh air flow across working region, the neutral plane should be played down as soon as possible. On the other hand, the lower neutral plane may increase the height of exhaust zone h_2, ant it means a larger exhaust pressure Δp_2, which can decrease the area of exhaust openings (clerestories), and further decreases the construction investment.

Ventilation openings must be provided to meet all anticipated ventilation needs. The area of inlet openings should be not less than that of outlet openings, which is a key step to play down neutral plane, and to improve the ventilation effect further. If mechanical ventilation not considered, according to the condition that the rate of supply air equals that of exhaust air, following formulas can be educed:

$$h_1 = \left(HF_2^2\right)/\left(F_1^2 + F_2^2\right) \qquad (1)$$

$$h_2 = \left(HF_1^2\right)/\left(F_1^2 + F_2^2\right) \qquad (2)$$

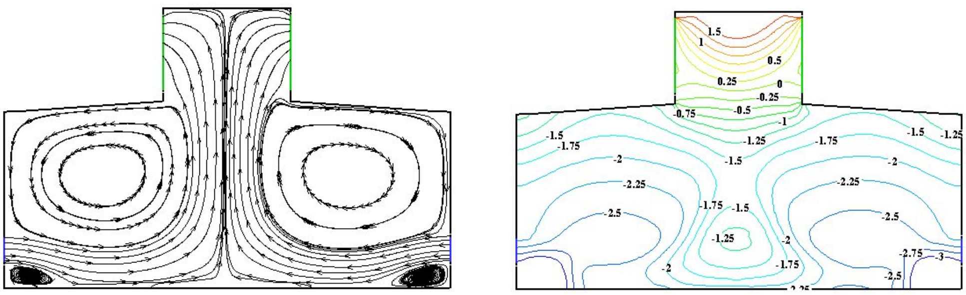
Several typical situations can be deduced: (i) if the inlet area equals outlet area, namely F_1 = F_2, neutral plane lies at midline of H, namely h_1 = h_2, as illustrated in Figure 1(a); (ii) if F_1 =F_2/2, neutral plane rise upper, h_1 =4H/5; (iii) if F_1 =F_2/3, neutral plane may locate in the clerestory, h_1 =4H/5, as illustrated in Figure 1(b). In such situation, exhaust pressure Δp_2 become less, partial clerestory(outlet) is negative pressure, clerestory size and investment may be quite large, however, neutral plane is quite high, ventilation efficiency and IAQ in the working region are poor.



(*a*) F_1=F_2 (*b*) F_1=F_2/3

Figure 1 Schematic diagram of stack ventilation in a workshop

The dimensions of a moulding workshop are following: total length is 54 m, width 21 m, height 13.2 m; and the height of clerestory (outlet) is 3.9 m, the width of clerestory throat is 6.0 m. the elevation of inlet sills is 1.2 m, and that of outlet sills is 9.3 m. The mean rate of heat-elimination is about 420 W/m^2 on the workshop floor. If the inlet height was 1.2 m, the outlet height was 3.6 m, and wind pressure wasn't considered, the air-distribution in the workshop was simulated, and illustrated in Figure 2. The neutral plane is higher than the outlet sills, air-distribution is very poor in the workshop, and ventilation didn't contribute to improving working environment efficiently.



(*a*) *Stream trace* (*b*) *pressure distribution*

Figure 2 The airflow simulation and pressure distribution (F_1 =F_2/3)

In order to make most fresh air flow across working region, the neutral plane should be played down as soon as possible. The dimensions between the inlet and outlet openings should be coordinated, and the inlet area can't be less than outlet area, which is a key step to improve the ventilation effect and decrease project investment. If the inlet area couldn't satisfy fresh air requirement, the secondary windows should be set. Which could be treated as inlet openings in cold season, and the elevation is usually higher than 4.0 m. However, such means may induce airflow short-circuit, so secondary windows would be set only in the situation that heat-elimination is quite large. For multi-span workshops with large heat-elimination, cold-span and hot-span workshop should be alternated as soon as possible, and clerestories of cold-span can be set as inlet openings also.

PLAYING DOWN INLET OPENINGS

If the inlet area was increased, the neutral section might be fall down properly. However, with inlet area (or height) increased, both intake pressure and velocity may be decreased. And the effective inlet air might be also reduced in working region. In such situations, heat, dust, smoke and poisonous gas may not be removed efficiently. On the other hand, the larger inlet area (or height) makes the project investment increased.

The thermal pressure in a workshop can be calculated as following expressions, ρ_i and ρ_o are air densities of indoor and outdoor air respectively（kg/ m^3）.

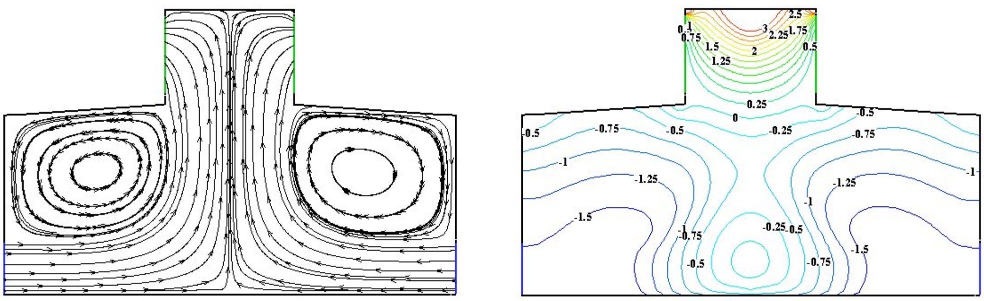
$$|P_1| + |P_2| = H\cdot(\rho_o - \rho_i) \quad (3)$$

Obviously, stack ventilation is affected mainly by two factors: the elevation difference between inlets and outlets, the density difference between indoor and outdoor air. The later is usually restricted by the technology process and environment factors. So, the elevation difference is the key to improve the stack ventilation. Under the permission of technology, illumination and sanitation criterions, to play inlets down means to increase the elevation difference and to fall the neutral plane, and the ventilation pressure and velocity were increased. As a result, the effective ventilation rate and efficiency may be increased.

If inlet openings can't be play down, shutters can be added under inlet openings. Shutters actually increase the elevation difference between inlets and outlets. Thermal pressure, ventilation rate and velocity are increased accordingly in working region. The investment of such measure is quite less than that of playing down inlet openings; moreover, it is convenient for regulating balance between inlets and outlets in different seasons.

However, the inlet openings of main workshop may be obstructed by auxiliary buildings (such as tool house, temporary storehouse, retiring room and so on.), because layout is unreasonable in some practical project. Sometimes, the design of natural ventilation is restricted by building layout, and the height of clerestories may be increased passively and even reached to 8 m or so. In such situation, the inlet area may be less than one third of outlet area, and air distribution is quite poor in workshop as shown in Figure2. Because of obstruction of auxiliary buildings, the upper auxiliary openings (secondary windows) may be treated as main inlets. The investment may be increased remarkably in such way; however, the ventilation may be not efficiently, namely, the game is not worth the candle.

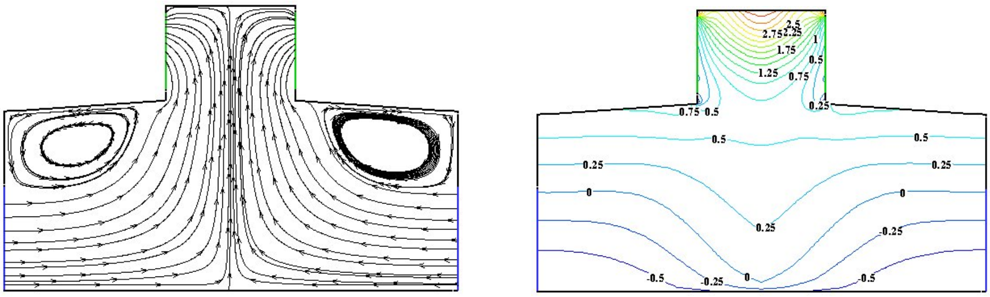
As for the situation of Figure 2, if the elevation of inlet sills was reduced to 0 m, and its height was 2.4 m, the indoor air-distribution was simulated and shown in Figure 3. Compared with Figure 2, though the inlet area was still less than outlet area, namely F_1=2F_2/3, air-distribution was improved in the whole workshop, and the improvement was especially obvious in the working region. The vortexes were eliminated under windowsill, and the elevation of neutral plane was reduced by 0.9 m or so, and under the outlet sills. The ventilation efficiency was increased remarkably, and airflow control was strengthened on indoor heat elimination.



(*a*) *Stream trace* (*b*) *pressure distribution*

Figure 3 The situation of playing down inlet openings (F_1 =2F_2/3)

However, if the elevation of inlet sills was 0 m, and its height was 4.8 m, namely F_1 =4F_2/3, the indoor air-distribution was simulated and shown in Figure 4. Compared with Figure 2 and Figure 3, the neutral plane fell to top sill of inlets. Air-distribution was improved fatherly in the whole workshop. There were no vortexes in working region. Such situation was satisfying.



(*a*) *Stream trace* (*b*) *pressure distribution*

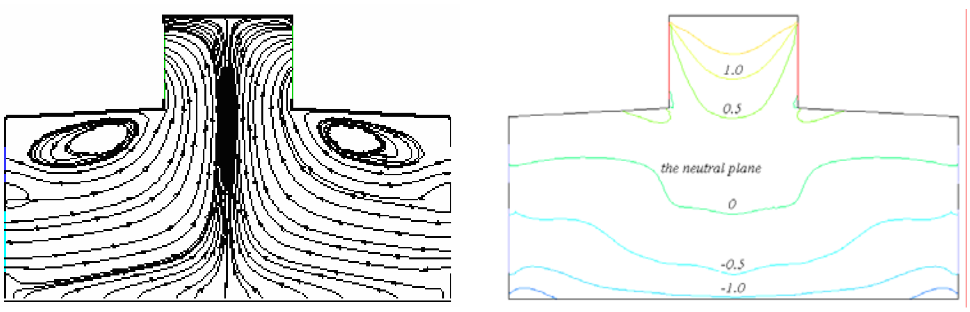
Figure 4 Another situation of playing down inlet openings ($F_1 = 4F_2/3$)

While designing natural ventilation of a workshop, reasonable layout is indispensable, and auxiliary buildings can't obstruct the inlet openings of main workshop. Otherwise, the auxiliary buildings should be built on stilts in order that the inlet openings are unblocked. Such measure is economical and helpful to improving workshop environment. If inlet openings blocked, neutral plane rises, clerestories had to be greatly heightened, and the investment is increased consequentially. The adding cost of heightening clerestories may be larger than that of former. However, most fresh air can't across the working region, and air distribution and heat control are unsuccessful, as shown in Figure 2.

AVOIDING AIRFLOW SHORT-CIRCUITS

The airflow short-circuits is the phenomenon that fresh air is directly exhausted outdoor and not flow across working region. As for the formerly mentioned case of the secondary windows, the ventilation may be quite unstable. When wind pressure is larger than thermal pressure, the secondary windows become inlets. Because the neutral plane is excessively high, the air flow in through the secondary windows, and directly exhaust out by clerestories, namely the airflow short-circuits. If wind pressure is less than thermal pressure, the secondary windows become outlets. The later situation is beneficial for reducing ventilation resistance and enhancing effective ventilation. Because pressure of the secondary windows is changing all the time, its cooperation with inlet windows and clerestories should be strengthen for improving the working environment. Their on-off state should be managed effectively.

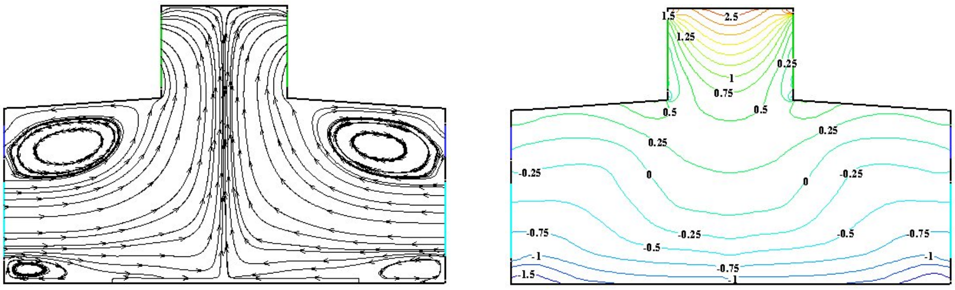
As for the mentioned moulding workshop, the secondary windows near traveling crane are originally designed as compensating illumination and ventilation. Its sill elevation was 5.4 m, the height was 1.8 m; the elevation of inlet sills was 1.2 m, height was 3.0 m. Taking no account of wind pressure, when the clerestories (outlets), inlet openings and secondary windows were all open, the simulation of stack ventilation was shown in Figure 5. The inlet air through secondary windows was directly exhausted by clerestories. Such airflow is ineffectual for improving working environment. However, the inlet area (with height of 3.0 m) is slightly less than that of outlets (3.6 m), and neutral plane fall considerably, as a result, air distribution is improved in the whole workshop.



(*a*) *Stream trace* (*b*) *pressure distribution*

Figure 5 The situation with secondary windows

As for another situation, the sill elevation of the secondary windows was 6.0 m, the height was 1.5 m; the elevation of inlet sills was 1.2 m, height was 3.6 m. Taking no account of wind pressure, when the outlets (clerestories), inlets and secondary windows were also all open, the simulation of stack ventilation was shown in Figure 6. The secondary windows were turn into exhaust openings, and vortexes became remarkable. The secondary windows were no significant to improving stack ventilation in workshop in such situations.



(*a*) *Stream trace* (*b*) *pressure distribution*

Figure 6 Another situation with secondary windows

Airflow short-circuits should be avoided as soon as possible. The secondary windows are not always open, and it's appropriate to adopt cheap fixed lighting strap. But every some distance, breather holes must be installed to supply fresh air for crane operator or repairer. In some cases, the secondary windows are designed as outlets, then, wind-shields should be fit for the avoiding inverse irrigation when the wind pressure is larger than thermal pressure, it is like the case of wind-shield clerestory.

There may be various factors for airflow short-circuits; corresponding measures should be adopted to avoid the phenomena. For example, when the heat source is close to outside wall, the airflow short-circuit must happen. The best measure is certainly changing technology layout, if unfeasible, more and big windows must be fit near heat source. The main heat source should be laid just under clerestory as soon as possible. The clerestory throat sizes and height difference between inlets and outlets should be increased properly to reduce ventilation resistance. For some workshops with large spans, clerestories with wind-shields should be fit to avoid air reverse irrigation.

However, when the outdoor temperature is above 36℃, the high temperature in working region can't be cooled down by only natural ventilation. Other measures should be adopted to lower local temperature at working spot, and air velocity should be increased properly to improve thermal comfort.

CONCLUSIONS

For certain indoor height and heat elimination in a workshop, the neutral plane is a key factor to improve ventilation effect and indoor environment.

In designing natural ventilation, to coordinate the dimensions between the inlet and outlet openings and to play down the neutral plane may be the effective measures to increase ventilation efficiency and to improve working environment. In supervising ventilation, the cooperation should be intensified between the inlet windows, the secondary windows and clerestories in order that airflow short-circuits may be avoid, because ventilation pressures are changing all the time.

The simulation outcomes and analysis conclusions are of constructive meaning for optimizing ventilation design of analogous workshops and improving indoor environment. Another significance of designing neutral plane rightly is to optimize workshop structure and to save project investment.

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