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The Study on Numerical Simulation of Classrooms Using Hybrid Ventilation Under Different Solar Chimney Radiation

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Abstract

Based on the known geometric model of classrooms using hybrid ventilation with solar chimney, the solar radiation intensity of the solar chimney's effect on indoor air temperature and velocity is simulated and analyzed based on the Fluent software. Combined with the numerical simulation analysis, it can be seen that ventilation quantity increases with the increase of solar radiation and the variation of average temperature with a series of room heights under different solar radiation can be available. Study and Research on the solar chimney can provide the theoretical evidence for the ventilation effect of classrooms, however, a more accurate conclusion will be required for further study on the numerical simulation and experimental verification.

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Keywords: Fluent, airflow; solar chimney; numerical simulation

1. Introduction

Hybrid ventilation is the organic combination of natural ventilation and mechanical ventilation in different seasons or during different periods of a day, and it can take the maximum use of the outdoor climate, reduce energy consumption and create acceptable thermal comfort conditions for rooms [1]. Since 1999, many countries have collaboratively researched the mechanisms and control mode of hybrid ventilation [1], research shows that the mechanical ventilation of hybrid ventilation have a greater impact on the hot pressure of natural ventilation: the gain or suppression. Li, etc takes the theoretical analysis of hybrid ventilation, and use the Fr number to describe the

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impact of mechanical ventilation on natural ventilation driven by hot pressure [2]. David researches the numerical analysis of a single residential house using the control strategy of hybrid ventilation [3]. Hybrid ventilation technology has obtained more and more attention and application in all aspects, however, how to increase the maximum intensity of natural ventilation in hybrid ventilation systems is very important for the use of hybrid ventilation.

Solar chimney is a great way to improve the hot pressure effect, and many scholars have taken a lot of research on the strengthening effect of solar energy on natural ventilation. Afonso and Oliveira compare solar chimneys to ordinary chimneys, proving that solar chimneys can significantly increase the ventilation rate than ordinary chimneys and it can be more effective increasing the width of the solar chimney rather than height [4]. Chen proves the methodologies used nowadays predict the ventilation rate highly [5].

At present, many scholars have carried out experiments and simulation studies focusing on the variation of air velocity and temperature inside the channel of solar chimney flows. Taking energy efficiency, thermal comfort and indoor air quality comprehensively into account to improve the classroom ventilation can not only meet the need of fresh air for rooms, but also conduct to the realization of energy-saving ventilation system [6]. Therefore based on the existed structure model of the solar chimney and the Fluent software, this paper researches the effects of natural ventilation driven by hot pressure under different solar radiation on the indoor thermal environment.

2. Research model and boundary conditions

2.1. Physical model

The classroom model is shown in Figure 1, and the size is 9m×6m×4.2m (L×W×H). A volume heat source of 5m×4m×1m is laid in the middle of the room bottom, while 2 mechanical air distributors of 1m×0.4m are put in the the front wall of the classroom with a symmetric layout and the outlet margin is 1.5m away from the side wall. The exhaust outlet with a size of 1m×0.3m is on the roof near the back wall, and the solar chimney with a height of 4m is on the exhaust outlet.

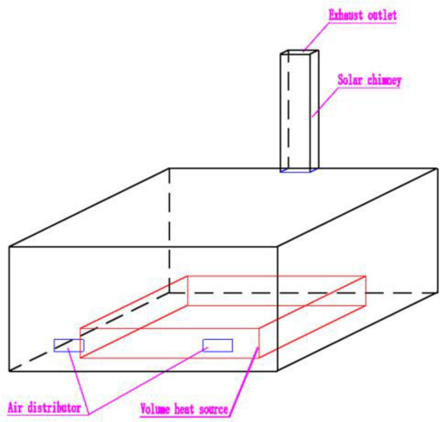


Fig. 1. Geometric model of the classroom.

2.2. Numerical model

A mathematical model is established based on Figure 1, making following assumptions for the model air: normal temperature, low-speed, incompressible fluid, following ideal gas state equation, indoor gas meeting the Boussinesq hypothesis. Natural convection and forced convection air flow coexist in the classroom. The air flow in the classroom follows the incompressible visco-fluid control equation, the continuity equation, and energy equations, as is seen in equation (1) ~ (3):

$$\frac{\partial \rho U_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial \rho U_i}{\partial t} + \frac{\partial \rho U_i U_j}{\partial x_i} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + \rho\beta g_i\left(T_{ref} - T\right) \tag{2}$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho H U_j}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\lambda}{c_p}\frac{\partial H}{\partial x_j}\right) + S_H \tag{3}$$

Where U_i is the speed of x-direction, i=1, 2, 3 and x_i is the coordinate of three vertical axises, U_j is the speed of y-direction and P is the atmospheric pressure, μ is the kinetic viscosity of air flow, and β is the coefficient of air thermal expansion, T_{ref} is the reference temperature and T is the air temperature, g_i is the acceleration of gravity for i-direction and H is the specific enthalpy of the air with constant pressure, S_H is the source and λ is the coefficient of air thermal conductivity, c_p is the specific heat capacity of the air with constant pressure.

The k-ε model is used as the turbulence model, in which the turbulent eddy viscosity coefficient is as follows:

$$\mu_t = \upsilon C_\mu \frac{k^2}{\varepsilon} \tag{4}$$

Where C_μ =0.09.

The k-equation is:

$$\rho\frac{\partial k}{\partial t} + \rho U_j\frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \mu_t\frac{\partial U_j}{\partial x_i}\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) - \rho\varepsilon \tag{5}$$

The ε-equation is:

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho U_j\frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{C_1}{k}\mu_t\frac{\partial U_j}{\partial x_i}\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) - C_2\rho\frac{\varepsilon^2}{k} \tag{6}$$

Where C_1=1.44, C_2 =1.92.

2.3. Boundary condition and simulating conditions

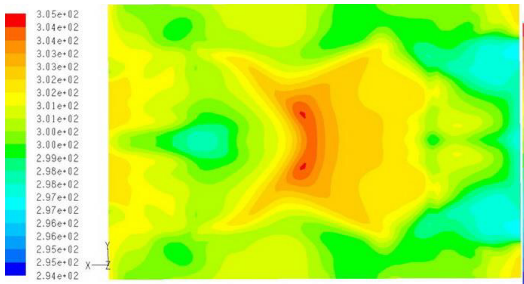
Boundary conditions include: classroom walls with insulation, air distributors with velocity inlets, supply air temperature of 294K, exhaust outlets with pressure outlets, pressure differences of the outlets with 2 Pa.

Table 1. Simulating Conditions of the classroom

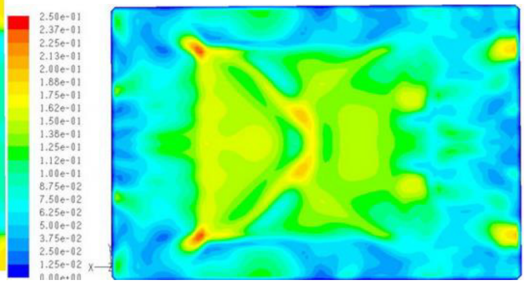
Air Supply Velocity *v* (m/s)	Height of Air Distributors *h*（mm）	Intensity of the Heat Source *Q*（W）	Solar Heat Gain of the Chimney *q*（W/m^2）
0.5	100	4000	100，200 300，500，700

3. Results and discussion

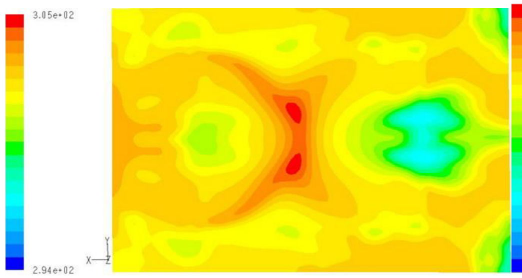
Due to the sitting position for classroom staff, the work area is defined as the height which is 1.3m below. Considering that the three-dimensional field distribution is difficult to be clearly shown in quantity and the space of this paper is limited, various distributions of the velocity field and temperature field in the room will be analyzed for the work area in following text (Fig. 2a-j).



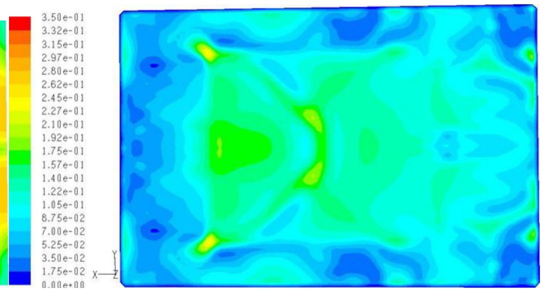
a. Temperature field of 100W



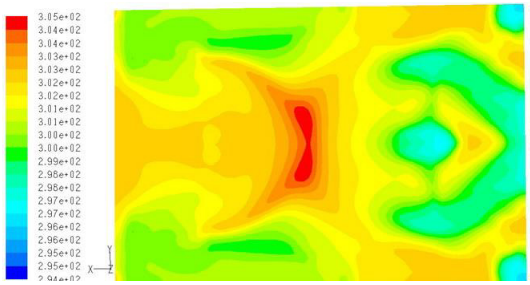
b. Velocity field of 100W.



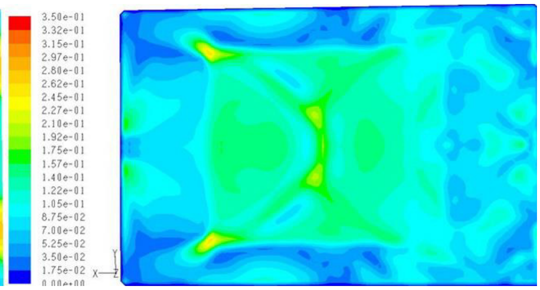
c. Temperature field of 200W



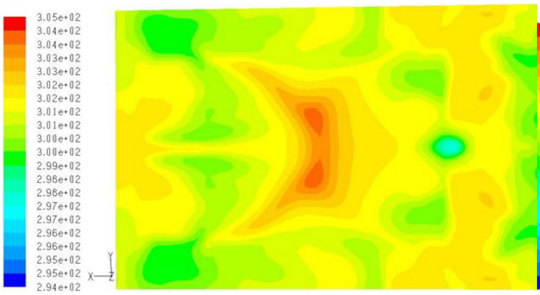
d. Velocity field of 200W.



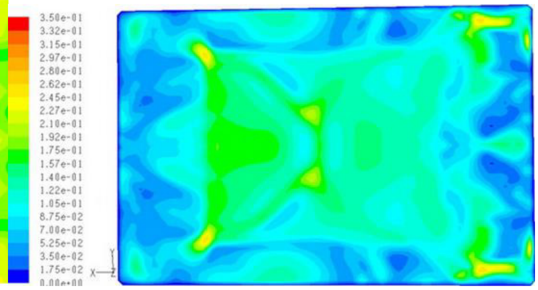
e. Temperature field of 300W



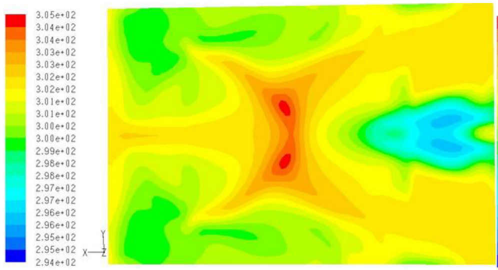
d. Velocity field of 300W.



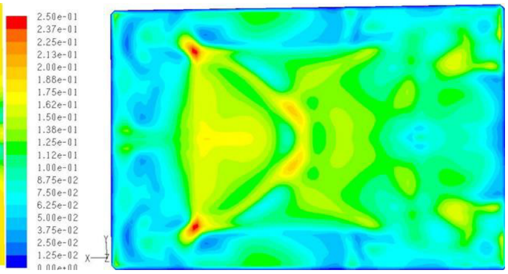
g. Temperature field of 500W



h. Velocity field of 500W.



i. Temperature field of 700W



j. Velocity field of700W.

Fig. 2. a-j Various distributions of the velocity field and temperature field under different solar radiation

The average temperature distribution following the increase of the z-axis height under different solar radiation is shown in Figure 3.

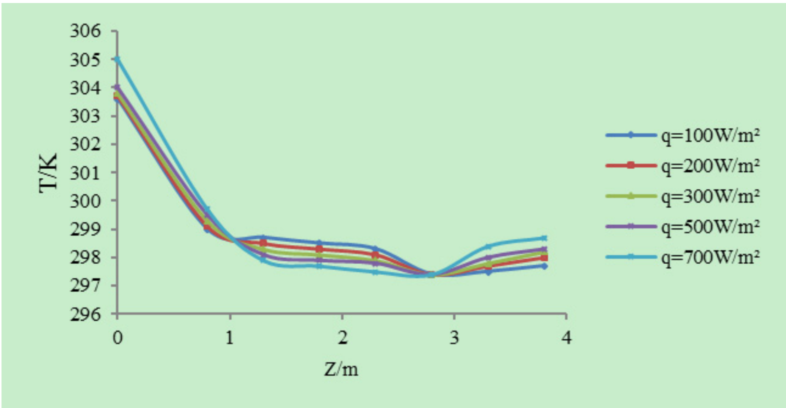


Fig. 3. The Indoor Average Temperature Variation Following the Z-axis Height under Different Solar Radiation.

From Figure Fig. 2. a-j ， it can be seen that the temperature above the heat source gradually decreases with the increase of solar radiation, the air velocity below the chimney continuously increases and finally stabilizes and the outlet rate increases. It is because that with the increase of the hot pressure the air near the heat source is quickly pumped outside, however, it cannot result in a more favorable effect on the distribution of the temperature and speed with the excessive pressing of solar radiation. Once the hot pressure increases to a certain extent, the indoor air cannot be pumped outside with sufficient heat exchange. It is available when it comes to the preferable choose of radioactive materials, and it is of great significance to enhance the heat exchange successfully.

As can be seen from Figure 7, with the increase of solar radiation, sectional average temperature T reduces when $Z < 2.8$m and T begins to increase when $Z \geq 2.8$m. Thus, the average temperature T of the work area will reduce and the temperature of the upper space will increase when increasing the solar radiation, it will be more conducive to the discharge of hot air.

4. Conclusions

Based on the various indoor air distribution under different solar radiation, the following conclusions can be drawn:

1. The average temperature of the work area will reduce and the temperature of the upper space will increase when increasing the solar radiation, it will be more conducive to the discharge of hot air.

2. Once the hot pressure increases to a certain extent, the indoor air cannot be pumped outside with sufficient heat exchange.
3. The solar radiation researched is still limited, and there is no validated test to obtain a more accurate conclusion, so it is crucial adjective with a further research.

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