Study on ventilation performance of inclined solar chimney coupled with indoor heat source

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Abstract. The study of ventilation air distribution of the building with built-in heat source and set inclined solar chimney is carried out through 3D numerical simulation. The synergistic effect of thermal plume formed by internal heat source and solar chimney effect is analyzed. The effects of different solar radiation intensity *I*, heat flow density *W* at the surface of the internal heat source and structural parameters (including the height of the internal heat source from the ground *h* and the mezzanine inlet spacing *b*) on the indoor natural ventilation performance of the building are investigated.

Keywords: solar chimney, indoor heat source, natural ventilation, numerical simulation, air distribution

1 Introduction

Energy is an important material basis for economic and social development. Coal, crude oil, natural gas and other non-renewable energy reserves are declining year by year. Building energy consumption is a key issue facing the construction industry around the world, therefore, reduce building energy consumption, the implementation of renewable energy alternatives, accelerate the construction of a clean, low-carbon, safe and efficient energy system is an important task at this stage in China. Solar chimneys use solar energy as the main source of energy, and as a simple and practical bioclimatic design method, and can use the chimney effect to enhance the natural ventilation of energy-saving ventilation technology, so in the reduction of heat gain has received a lot of attention.

In recent years, domestic and foreign scholars have conducted some studies on architectural solar chimneys. Kong [1] developed a two-dimensional model of an inclined solar chimney and numerically simulated the model for inclination angles from 30° to 90° by using computational fluid dynamics software CFD and found that the optimal inclination angle of the solar chimney varied from 45° to 60° depending on the latitude and season of operation. Imran [2] presented an experimental and numerical model of a solar chimney with natural convection inside the inclined solar chimney forming a steady two-dimensional turbulent flow. Zamora [3] investigated the ventilation performance of a solar chimney under the combined effect of wind and thermal pressure and the variation of the average *Nu* with *Ra* by numerical simulation. Zhang [4] found that increasing the chimney height from 3.0 m to 5.0 m increased the ventilation capacity by about 90 %, moving the inlet upward increased the ventilation capacity by 57.28 %, and increasing the window area increased the volumetric flow rate by 14.98 %. Ren [5-6] found a relationship between *Ra* and *Nu* with solar chimneys and investigated the effect of discrete heat sources on backflow suppression. Kebabsa [7] also found that the inclination angle of the heat absorbing wall depends on the inclination distance and remains almost the same for different *Ra*. Duan [8] proposed a new model for predicting the airflow rate in a typical solar chimney. The airflow rate is explicitly expressed as a function of the incident solar radiation intensity, the intensity of the internal heat source, the emissivity of the glass cover, and geometric parameters, and it is convenient to estimate the ventilation performance of a solar chimney based on the incident solar radiation intensity.

The above studies mainly focus on the effects of structural and operational parameters on the performance of tilting or roof-mounted solar energy and the effects of internal heat sources on the ventilation performance inside the building, while there is less research on the internal heat sources in enhancing the ventilation performance of tilting solar chimneys. In this paper, we conduct a study on the ventilation airflow organization of buildings with built-in heat sources and set tilting solar chimneys through three-dimensional numerical simulation. The synergistic effect of the heat plume formed by the internal heat source and the solar chimney effect is analyzed to realize the gain of natural indoor ventilation. The interaction of the thermal plume generated between the internal heat sources and its effect on the airflow organization of the indoor space is studied to explore the coupling effect between multiple physical fields. Using the orthogonal method, the natural ventilation performance of the tilted solar chimney is investigated under different solar radiation intensity, heat flow density on the surface of the internal heat source and structural parameters.

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2 Physical Model

Fig. 1. shows the physical model of a tilted solar chimney with an indoor heat source, mainly consisting of a glass cover, an air flow channel, a heat absorbing plate, a sandwich layer, and an indoor heat source. x-axis is the width direction of the room, y-axis is the length direction of the room, and z-axis is the height direction of the room. The room length AB=4000mm, width AD=3000mm, height AE=3300mm; the indoor heat source is placed in the center of the room with the geometry size of 500×500mm, the height of the heat source from the ground is h; the height of the mezzanine HL=300mm, the mezzanine entrance 1 is fixed in the center on the side of the south wall with the size of 200mm×1000mm, the mezzanine entrance 2 and the mezzanine entrance 1 have the same size. The length of the solar chimney is MQ=2000mm, the width of the chimney runner is MN=200mm, the angle between the inclined chimney section and the horizontal direction is 45°; the fresh air inlet UVWX is located at the north side of the building, the center height from the ground is 300mm, the size is 400mm×200mm, the size of the chimney inlet MNOP and the chimney outlet QRST are both 200mm×1000mm ×1000mm.

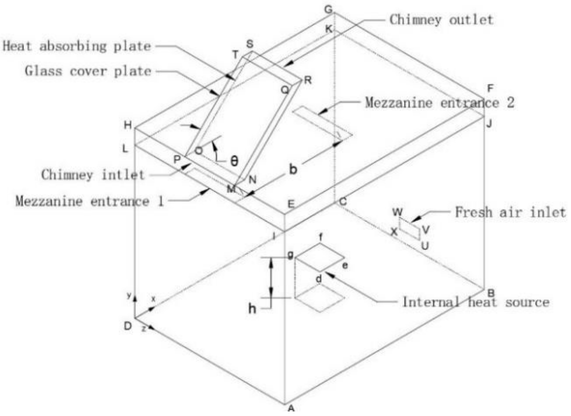


Fig. 1. Tilting solar chimney with indoor heat source

3 Numerical simulation methods

3.1 Control equations and calculation methods

The control equations for the numerical simulation include continuity equation, momentum equation, energy equation, k equation, ε equation, which are given in reference [9].

Boussinesq assumption is used in the numerical calculation, and all solid wall velocities are slip-free conditions; the finite volume method is used to discretize the control equations, the turbulence model is RNG-*k*- ε model, the velocity-pressure coupling is SIMPLE algorithm, and the convective term discretization format is second-order windward format with sub-relaxed TDMA algorithm.

3.2 Boundary Conditions

The solar radiation intensity is set to a constant value, the absorption rate and transmittance of the glass cover and the heat-absorbing plate are also kept constant, the absorption rate is taken as 0.06 and 0.95, and the transmittance of the glass cover is taken as 0.84, so that the heat flow density values of both can be obtained. The outdoor ambient temperature is set to 300K.

3.3 Calculation grid

The overall grid type of the model is unstructured. Local encryption is performed for the interior of the solar chimney, near the indoor heat source, fresh air inlet and chimney outlet to ensure the accuracy of the calculation results. The grid independence assessment was carried out during the simulation calculation, and six sets of grids were generated, with the numbers of 630743, 803923, 902588, 1039947, 1205420, 1376601, and the mass flow rates under different grid numbers are shown in Fig. 2. The error of calculation results between the 2nd set and the 3rd set of grids is found to be less than 1% by comparison, and the 3rd set of grids is the final chosen grid in order to obtain accurate simulation results with limited computational resources.

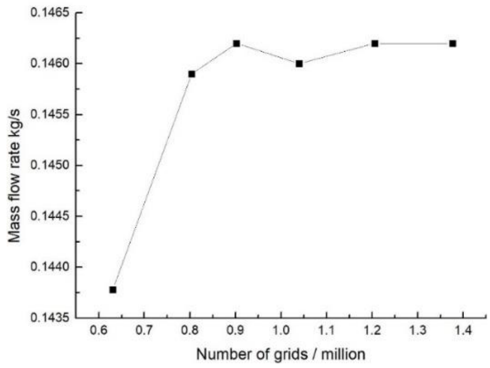


Fig. 2. Mass flow rate under different grid numbers

3.4 Model Validation

In this calculation, a solar chimney with the same structure and boundary conditions as in the literature [10] is simulated numerically, and the ventilation capacity is used as the main comparison parameter. The height of the solar chimney is 1025 mm, the length is 925 mm, the heat flow density is 800 W/m2, and the widths are 20, 40, 60, 80, 100, and 110 mm, respectively. Fig. 3. shows the comparison between the numerical simulation and the experimental results.

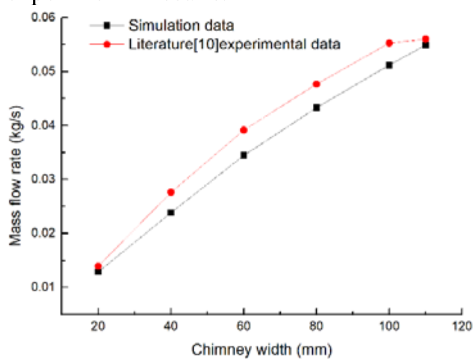


Fig. 3. Comparison of simulation in this paper and experimental ［10］ values

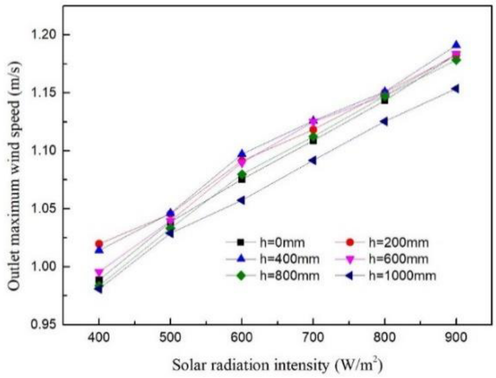
4 Results and Analysis

4.1 Effect of solar radiation intensity I on the maximum wind speed at the exit of a solar chimney

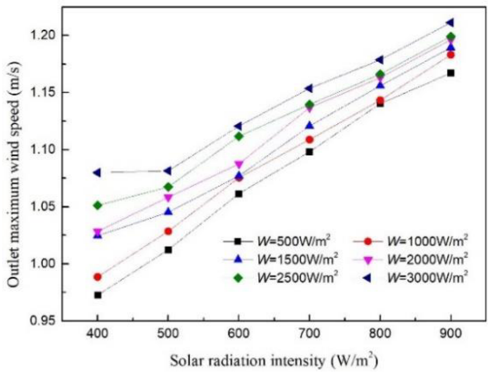
Fig. 4a. and Fig. 4b. show the variation curves of the maximum wind speed *v* at the exit of the inclined solar chimney with the solar radiation intensity *I* for different internal heat source surface heat flow density *W* and different internal heat source height *h*, respectively. The variation range of solar radiation intensity *I* is 400 W/m²~900W/m², the variation range of heat flow density *W* on the surface of the internal heat source is 500~3000 W/m², the height of the internal heat source from the ground *h* is 0~1000 mm, and the surface emissivity of the internal heat source is *ε*=0.8, where the interlayer inlet spacing *b*=0 mm.

Fig. 4a. shows that the maximum wind speed at the outlet varies with the increase of solar radiation intensity and the different heat flow densities at the surface of the internal heat source. With the increase of solar radiation intensity, the maximum wind speed at the exit of the chimney shows an increasing trend. When the heat flow density *W* on the surface of the internal heat source was 500 W/m², the maximum wind speed at the solar chimney outlet increased from 0.973 m/s to 1.167 m/s with the increase of solar radiation intensity *I* from 400 W/m² to 900 W/m², with a maximum increase of 19.9%. When the heat flow density *W* on the surface of the internal heat source was 3000 W/m², the maximum wind speed at the solar chimney outlet at different solar The maximum increase of 12.2% at different solar radiation intensities. The results surface: with the increase of heat flow density *W* on the surface of the internal heat source, the effect of solar radiation intensity *I* on the maximum wind speed at the outlet gradually decreases. With the increase of solar radiation intensity, the heat collecting wall absorbs more heat, which makes the air in the chimney channel gain heat, the temperature increases, the density difference increases, and the airflow float driving force generated by the density difference gradually increases, which in turn drives the maximum wind speed at the exit of the chimney to increase. With the increase of heat flow density on the surface of the internal heat source, the heat plume generated on the surface of the heat source carries out natural convection heat exchange with the indoor air.

Fig. 4b. shows that the maximum wind speed at the exit of the chimney increases with the increase of solar radiation intensity when the heat flow density at the surface of the internal heat source is 1000 W/ m² and the emissivity at the surface of the internal heat source is *ε*=0.8, and increases and then decreases with the increase of the height of the internal heat source from the ground, and the maximum wind speed at the exit reaches the maximum when *h*=400 mm. When the height of the internal heat source from the ground *h* is 0 mm, the maximum wind speed at the exit of the solar chimney increases from 0.989m/s to 1.183m/s. When *h* is 400mm, the relative increase of the maximum wind speed at the exit of the solar chimney under different solar radiation intensity is 17.4%, which shows that the height of the internal heat source from the ground has less influence on the ventilation volume. It can be seen from the figure that the maximum wind speed at the exit of the chimney is most influenced when the height of the internal heat source is 200mm and 400mm from the ground, because the center of the fresh air inlet is 300mm from the ground, the air enters the room from the outside, and the air rises under the driving force of thermal buoyancy, and when passing through the internal heat source, the air is closer to the heat source with *h* of 400mm, and the degree of heat gain is the highest, and the airflow generated by the density difference The floating driving force gradually increases, which in turn leads to an increase in the maximum wind speed at the exit of the chimney.



a. *h*=0mm



b. *W*=1000W/m²

Fig. 4. Variation of maximum wind speed at the outlet for different solar radiation intensities

4.2 Effect of mezzanine inlet pitch *b* on the maximum wind speed at the exit of the solar chimney

Fig. 5. shows the variation curves of the maximum wind speed *v* at the exit of the inclined solar chimney with the heat flow density *W* on the surface of different internal heat sources with the inlet spacing *b* of the mezzanine. The variation range of the mezzanine inlet spacing *b* is 0~2000mm, the variation range of the heat flow density *W* on the surface of the internal heat source is 500~3000 W/m², the height of the internal heat source from the ground *h* is 0mm, the surface emissivity of the

internal heat source is ε=0.8, and the solar radiation intensity I=400 W/m².

The calculation results show that when the solar radiation intensity is a constant value. With the increase of the interlayer inlet spacing b, the maximum wind speed at the exit of the chimney shows a trend of first decrease, then increase and then decrease. When the interlayer inlet spacing b is 0mm, the maximum wind speed at the outlet reaches the maximum. The maximum wind velocity at the exit of the chimney increases from 0.973m/s to 1.080m/s. When the interlayer inlet spacing *b* is 400 mm, the relative increase of the maximum air velocity at the chimney exit is 9.1% for different heat flow densities at the surface of the internal heat source, which shows that the interlayer inlet spacing *b* is 0 mm can provide the maximum chimney exit air velocity. When the interlayer inlet spacing *b* increases from 0mm to 400mm, because the separation of inlets causes part of the airflow to pass through the interlayer inlet 2, which in turn generates backflow and loses part of the airflow. With the gradual increase of the interlayer inlet spacing *b*, the distance of the interlayer inlet 2 from the internal heat source gradually decreases, and the heat plume generated by the internal heat source can be better induced into the interlayer through the interlayer inlet 2, which promotes indoor ventilation circulation and increases the maximum wind speed at the chimney outlet; when *b* increases to 2000 mm, the inhibiting effect of the return flow is greater than the promoting effect of the internal heat source, and the maximum wind speed at the chimney outlet appears to drop steeply.

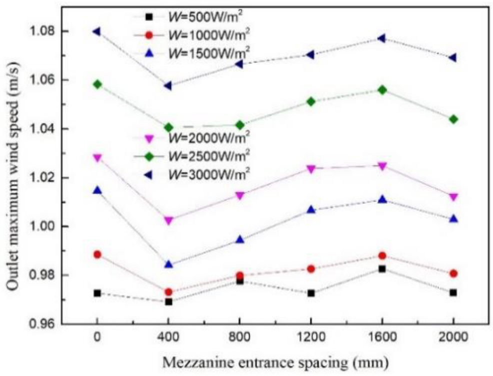


Fig. 5. Variation of maximum wind speed at the outlet for different Mezzanine entrance spacing

5 Conclusion

In this paper, through three-dimensional numerical simulation, the ventilation and airflow organization of built-in heat source and inclined solar chimney building is studied. The main conclusions are as follows.

1) Within the scope of this study, the surface heat flux and solar radiation intensity of the internal heat source have a gain effect on the ventilation performance. With the increase of solar radiation intensity, the maximum wind speed at the outlet of solar chimney gradually increases by the maximum increase of 19.9 %. the influence of solar radiation intensity on the maximum wind speed at the outlet of chimney is more obvious.

2) With the increase of solar radiation intensity, the maximum wind speed at the outlet increases at different heights of the inner heat source, and the maximum increase is 19.6 % when the height of the inner heat source is 0. With the increase of the height of the inner heat source from the ground, the maximum wind speed at the chimney outlet increases first and then decreases, and reaches the maximum when h = 400 mm.

3) When the solar radiation intensity is constant, with the increase of interlayer inlet spacing, the maximum wind speed at the outlet decreases first, then increases and then decreases. When the heat flux of the internal heat source increases from 500 W / m^2 to 3000 W / m^2, the maximum wind speed at the outlet increases from 0.973 m / s to 1.080 m / s.

Acknowledgments

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