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Performance-based Design of Smoke Extraction for the Basketball Gymnasium of Wukesong Culture and Sports Center

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Abstract
By using performance-based design, a smoke extraction system employing hyperboloidal smoking shaft technology in the basketball gymnasium of Wukesong Culture and Sports Center is studied through numerical simulations. The results show that hyperboloidal smoking shaft is efficient for smoke extraction. From the simulations, it is found that the most important factor to smoke extraction is the temperature in the smoking shaft, and a reasonable control of opening and closing of the hyperboloidal smoking shaft can avoid the smoke to regorge
Keywords: super-high-rise apartment; location; view; Common institution; plan

1. Introduction

Recently, With the progress of society and the development of architecture technology, there are more and more buildings that have areas larger than thousands of square meters and heights higher than three hundred meters. It's a necessary current that these special buildings will increase. Traditionally, the design of building fire safety had relied on prescriptive-based codes; however there are some extra problems such as compartmentation can't be resolved efficiently by the traditional prescriptive-based codes. Wukesong Culture and Sports Center is such a typical example.

Wukesong Culture and Sports Center locates on west of Beijing city, and will be a special basketball gymnasium for the 29th Olympic Games. It consists of the Culture and Sports Center and the Multi-function gymnasium. The multi-functional gymnasium can accommodate 18,000 audiences, and its area is 58,980 m^2.

Compartmentation is a basic measure to prevent smoke movement, and the poisonous smoke can be hold up and life safety can be ensured by it. The main method for compartmentation is that the inner space of a building is divided into some limited smoke compartments by using smoke curtains and fire curtains. In prescriptive-based codes the area of compartment must be less than 500 m^2. However, because of the integrated function of Wukesong Culture and Sports Center, its inner space can't be divided. Evidently, prescriptive-based codes are incompatible with the integrated function of the center [1][2].So performance-based design is used to solve this problem.

Using analytical engineering tools, the development and impact of fire in a building can be assessed. In this paper, a design of hyperboloidal smoking shafts located on top of the gym is introduced for the spirit of green Olympic and a model, called the NIST Fire Dynamics Simulator (FDS), Version 3., has been demonstrated to predict the thermal conditions resulting from this compartment fire [8,9].

2. Description on Smoke Management System Design

The section of the basketball gym is shown in figure 1. The principle of the hyperboloidal smoking shafts is natural ventilation by stack effect. The smoking shafts are similar to external wall vents, except that smoke from the fire floor is vented through a shaft. The venting is aided by buoyancy forces codes; specific engineering data regarding sizing of smoking shafts is available from Tamura and Shaw[3].

On smoke management system design, a phenomenon is considered that the smoke perhaps flows backwards into the inner space of the gym

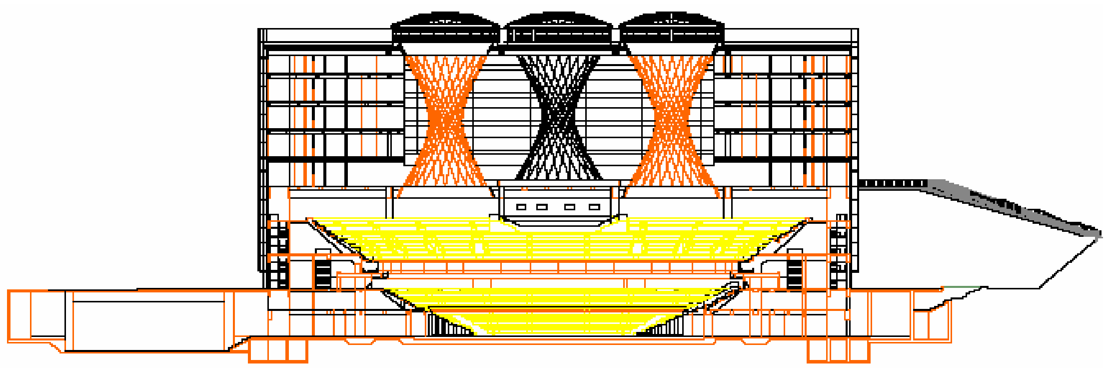

Fig. 1. section of the basketball gym

through the smoking shafts which are far from the fire source. The reasons are discussed:

1. From the Alpert ceiling jet model[4] and the Heskestad model[5], if the heat release rate of the fire source is constant, the smoke temperature in the smoking shaft that is far from the fire source is lower than that is in the near one . And from the Epstein model[6] we can also find that if temperature is low, the acceleration by buoyancy forces is reduced. When the acceleration reaches zero, the dynamic pressure will not mount up despite that the height of hyperboloidal smoking shaft can be increased. If the environment resistance is larger than this dynamic pressure, the smoke perhaps flows backwards into the inner space.

2. If fire develops rapidly and the heat release rate is high, the natural vents (such as windows and doors) can't provide sufficient oxygen. So the smoking shafts which are far from the fire source perhaps become another supply vents.

Table 1. Results of simulation

conditions			the average velocity of the smoke of the sites that are near the fire source(m/s)	the average velocity of the smoke of the sites that are far from the fire source (m/s)	Figure
Mode of ventilation	Heat release rate of fire source (MW)	Mode and quantity of air supply			
natural ventilation system	3	Natural air supply	0.087	0.009	Figure 2
smoking shaft system	3	Natural air supply	1.703	0.134	Figure 3
smoking shaft system	10	Natural air supply	1.948	0.058	Figure 4-1
smoking shaft system	10	200,000m^3/h mechanical air supply	1.722	0.607	Figure 4-2
smoking shaft system	10	900,000m^3/h mechanical air supply	1.797	0.183	Figure 4-3
smoking shaft system with partial shafts	10	200,000m^3/h mechanical air supply	1.776	-	Figure 5

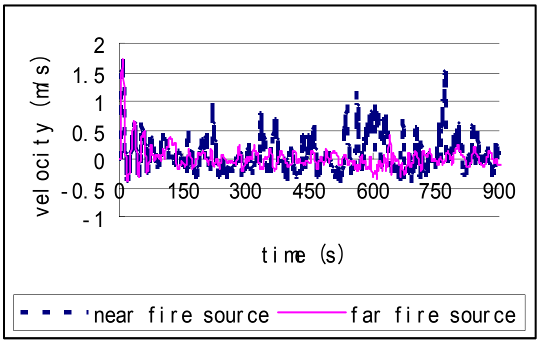

Fig. 2. flow velocity versus time in natural ventilation system

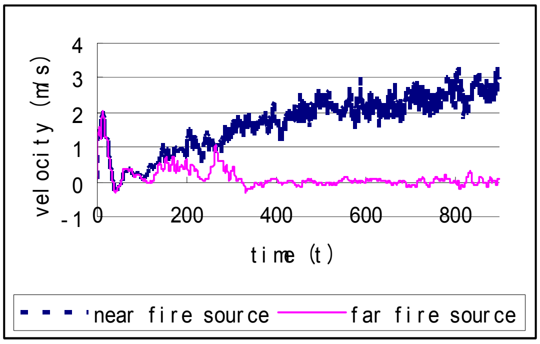

Fig. 3. flow velocity versus time in smoking shaft system with low HRR

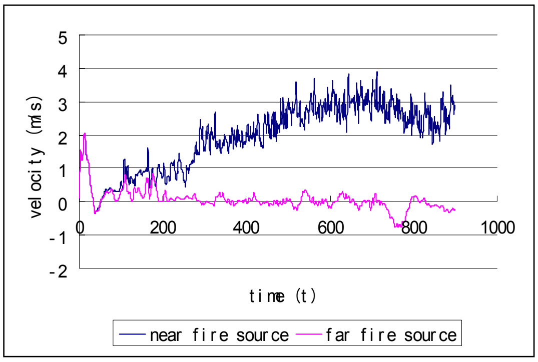

Fig. 4-1. flow velocity versus time in smoking shaft system with high HRR

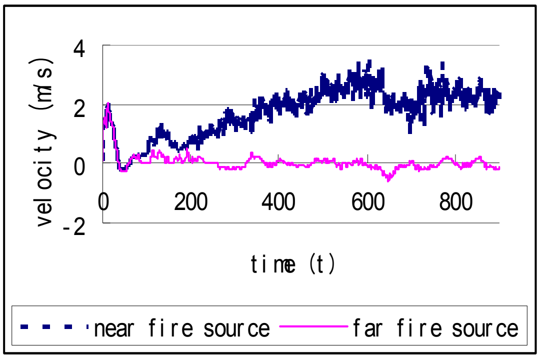

Fig. 4-2. flow velocity versus time in smoking shaft system with 200,000m^3/h mechanical air supply and high HRR

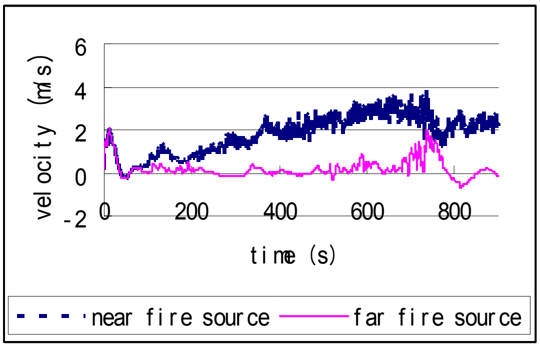

Fig. 4-3. flow velocity versus time in natural ventilation with 900,000m^3/h mechanical air supply and high HRR

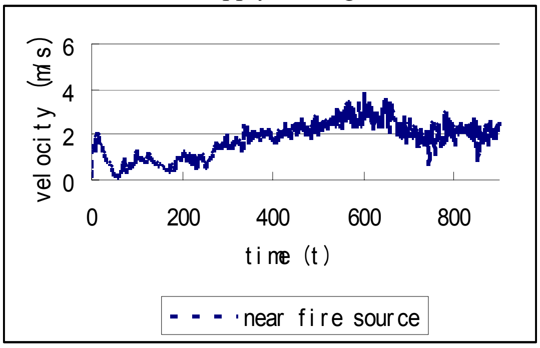

Fig. 5. flow velocity versus time in partial smoking shaft which are near the fire source when far smoking shafts are closed

3. Numerical Simulation of the Smoking Shaft System

NIST has developed a computational fluid dynamics (CFD) fire model using large eddy simulation (LES) techniques [7], which is called the Fire Dynamics Simulator (FDS). This model (Version 3) has been demonstrated to predict the thermal conditions resulting from this compartment fire [8, 9]. A CFD model requires that the room or building of interest be divided into small three-dimensional rectangular control volumes or computational cells. The CFD model calculates the density, velocity, temperature, pressure and species concentration of the gas in each cell. Based on the laws of conservation of mass, momentum, species and energy the model tracks the generation and movement of fire gases.

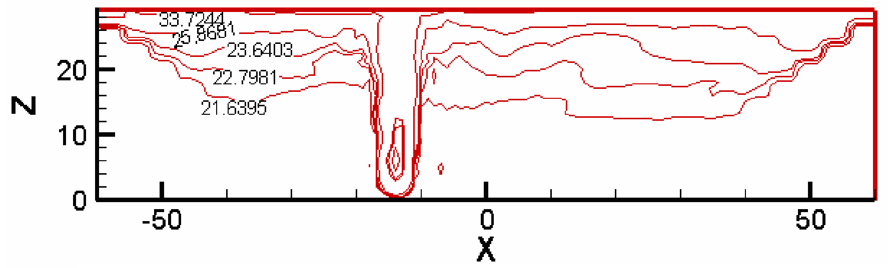

Fig. 6-1. Distribution of temperature in natural ventilation at 480s

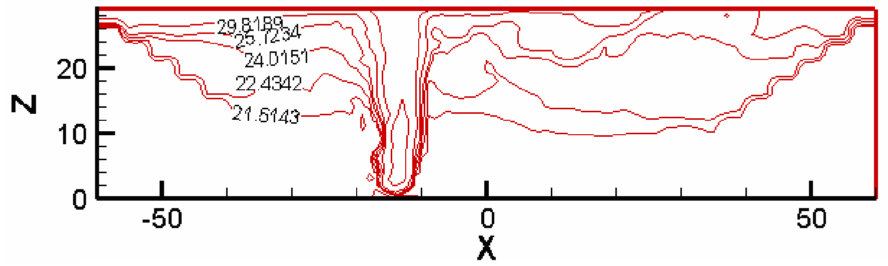

Fig. 6-2. Distribution of temperature in smoking shaft at 480s

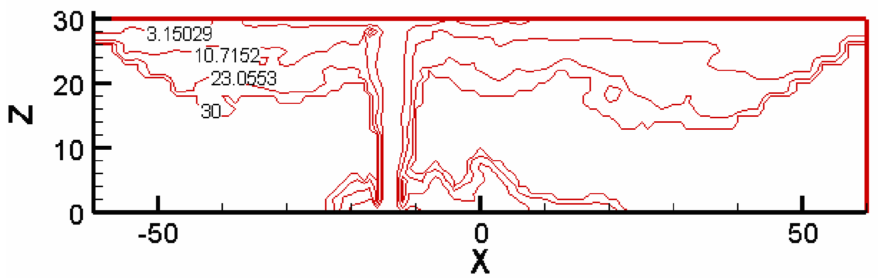

Fig. 6-3. Distribution of visibility in natural ventilation at 480s

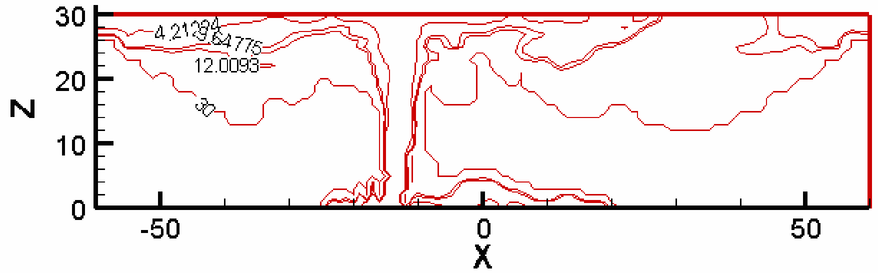

Fig. 6-4. Distribution of visibility in smoking shaft at 480s

FDS utilizes material properties of the furnishings, walls, floors, and ceilings to compute fire growth and spread. A complete description of the FDS model is given in reference [7].

The size of the basketball of Wukesong Culture and Sports Center is about 50m×50m at bottom and 120m×120m at top respectively. The height of the gym is 30m. The position of the fire source is located on the stand with a height of 15m. Two kinds of fire scenario are designed. One is that the heat release rate of the fire is assumed to grow fast, reaching a peak of approximately 3MW at 253s. The other is that the heat release rate of the fire is assumed to grow fast, reaching a peak of approximately 10 MW at 462s. To predigest the model, the four filling ventilations are located on the bottom and its size is 3m×3m each.

In order to obtain a comparison between natural ventilation and the smoking shaft system, the natural ventilation simulation is also studied. In natural ventilation system**,** four natural vents whose size is 8m wide and 8m deep are studied and four smoking shafts whose size is 8m wide, 8m deep and 38m high are used to evacuate the smoke in the smoking shaft system. Some of the author's findings are listed in table 1.

From table 1, the results are shown as follows:

1. The effect of natural ventilation is very unstable and smoke volume flux is small.

2. With the increase of the heat release rate of fire source, the average velocity of smoke in smoking shaft is increased obviously. However, sometimes the average velocity of smoke in the smoking shaft which is far from the fire source is little and negative.

3. Though mechanical air supply system is set up, the average velocity of smoke in the smoking shaft which is far from the fire source isn't improved. So the temperature in smoking shaft is regards as the most important factor to affect smoke extraction.

4. For obtaining more stable effect, the theory that only near smoking shaft is opened is studied in figure 5. The result shows that the effect of smoke extraction is perfect.

3.3. Risk analysis of the inner space

From figure 6-1 to chart 6-4, the difference of visibility and temperature between natural ventilation and smoking shaft are shown. As a result of our analysis, we concluded that the smoking shaft system is better than natural ventilation.

4. Conclusions

A smoke extraction system employing hyperboloidal smoking shaft technology in the basketball gymnasium of Wukesong Culture and Sports Center is studied through simulation. The results show that the hyperboloidal smoking shaft can be efficient to smoke extraction if it is designed reasonably. By using this model, much fund is saved and green Olympic spirit is embodied. But if the design of smoke extraction is unreasonable, the smoke layer will be disturbed and the people in gym are threatened.

We also find some problems which should be improved in the future in traditional theories:

1. It is supposed that the temperature is average in smoking shaft. But there is much difference between the top and the bottom of the smoking shafts. In Epstein model, the velocity of smoke is determined by the smoke temperature in the smoking shafts and the velocity is the main factor to affect the dynamic pressure, so the measure to temperature is an important work in the future.

2. Heat conduction on the wall of smoking shafts is an important boundary condition, it can influence the smoke temperature.

Finally, it is noticed that outside wind isn't considered in this paper and it's an important future work.

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