Journal of Theoretical and Applied Information Technology
31st December 2012. Vol. 46 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

OPTIMIZATION OF VENTILATION MODE OF SMOKE CONTROL SYSTEM IN HIGH-RISE BUILDING FIRE

[1]RU ZHOU, [2]WEI ZHANG

[1]School of Urban Construction and Safety Engineering, Nanjing University of Technology, Nanjing 210009 Jiangsu, China

[2]73677 PLA troops, Nanjing, 210016, Jiangsu, China

ABSTRACT

In high-rise building fire, a large amount of fresh air will be pressurized into the fire floor when smoke ventilation and prevention system is used. The fresh air dilutes the smoke, but it also reduces the efficiency of mechanical exhaust. The assumption that vertical composition smoke control model (air curtain combined with pressurization and exhaust fan) is put forward. The mathematic model of smoke flow in high-rise building and κ-ε three-dimension turbulence model with two equations are used, and the influences of smoke exhaust effect with different smoke control modes are analyzed. The simulation and experiments results show that: in strip corridor, air curtain can effectively prevents the smoke moving into the atria, but the smoke control time is short relatively. While using air curtain combined with positive pressure, the smoke control time at least has an increase of 60s, and the vertical composition smoke control model has the same effect as atria pressurization model, but the volume of fresh air has decreased by 1/3.

Keywords: *High-Rise Building, Fire Smoke, Vertical Composition Model*

1. INTRODUCTION

In past few decades, high-rise buildings have developed rapidly, and the fires become the biggest threaten of the high-rise building because of the dense population, flammable material and fewer safe exits relatively. Poisoning and asphyxia by smoke are primary reasons for the casualty. From 2009 to 2011, in China, there were 37725 fires in high-rise buildings, which caused 1195 casualties and about 414 million Yuan of the directly economic loss. In these fires, there were about 12 large fires, which caused 63 casualties and about 48 million Yuan of direct economic losses [1, 2].

Now the traditional smoke control model includes ventilation and prevention systems in high-rise building, which the positive pressure air is introduced in the staircase and elevator atria, the corridor and other areas with natural or mechanical smoke extraction. In some time this model can help people escape [3], the smoke is push back by the pressure air leaking form the atria when the door is open with this model. But there is a lot of fresh air which could easily enlarge the fire and make the exhaust efficiency lower. Some contents for getting more efficiency smoke control model have been studied: a network model was accounted for all of the complex interactions among the variables that affect the movement of smoke via an elevator shaft, the COSMO-Software was developed to research the modified and improved differential smoke control model for the conditions in the floor spaces, the fire behavior in the compartment of high-rise buildings in wind environment was considered for exploring some effective methods used for evaluation of compartment fire smoke movement and control system, and so on.

After analyzing the traditional model, a new method called vertical composition smoke control model was proposed in order to solve these problems of the traditional smoke control model, which make the pushing the smoke back change into vertical cutting off. The vertical combination control model was organized like this: some airflow was set in front of the atria door, keeping a lower positive pressure in the atria which pressurized less air comparing the traditional model at the same time. By the model the smoke could be prevented to flow to the atria, which cut off the smoke and make people evacuation safely. So three cases were done to make sure the composition of this new model.

2. MATHEMATIC MODELS

2.1 Basal Assumption and Simplification

In the high-rise building fires, the smoke flow is a highly complex three-dimensional no steady state and rotation irregular flow. The various physical

Journal of Theoretical and Applied Information Technology
31st December 2012. Vol. 46 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

parameters of fluid such as speed, pressure, temperature and so on changes with time and space. κ-ε three-dimension turbulence model with two equations are used in this paper. Turbulent flow in fire can be described by energy equation, momentum equation, continuity equation, component equation and κ-ε equation. These equations have the same form [4]:

$$\frac{\partial}{\partial t}(\rho\phi)+div(\rho u\phi)=div(\Gamma grad\phi)+S_\phi \quad (1)$$

Four parts of the equation are time, convection, diffusion and source terms with φ generic variable and Γ diffusion coefficient.

Solving Reynolds-averaged Navier Stokes equations by SIMPLEC arithmetic in the simulation and κ-ε model with two equations were used to turbulent flow calculation [5, 6].

1.2 Boundary Condition of Entrance and Outlet

Neutral plane position of high building can be calculated though mass balance. Pressure inlet and pressure outlet boundary condition were used. Static pressure was set for pressure outlet [7].

3. DESIGN OF FULL-SCALE CORRIDOR TEST

2.1 Test Design

A physical model of a high-rise building was built in this paper as shown in Fig.1 and Fig.2. The physic model was 33m×8.5m×54m, and the building was seventeen-story, the height of every standard floor was 3.3m. The corridor was 30m×1.5m×2.5m, and the single-chamber depth was 3.6m. The fire was located on the 3rd floor. In the end of the wind tunnel, a standard fire room with 3.6m×2.4m×2.4m was set, in which a oil pan was in the middle with 0.8m×0.6m. The carbinol with trace gas was chosen as fuel, and the fire power was 338kW from the reference 1. The thermocouples were set in the horizontal center of wind tunnel as shown in Fig.3-5, which include 13 groups and the interval of each group was 2m. Each group has two thermocouples, one was in the top of the corridor, the other was 1.6m. In order to study the exhaust efficiency in the corridor, the vertical composition smoke-control model, the pressurization, the smoke screen and mechanical exhausting were combined, and three typical full-scale corridor fire smoke control experiments were carried out. In model 1, only the air curtain was set, in model 2 the air curtain and exhaust fan(EF) were set, in model 3, the air curtain, exhaust fan and pressurization in corridor were all set [8, 9].

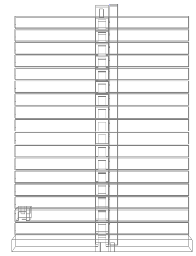


Figure1: High-Rise Building In Section

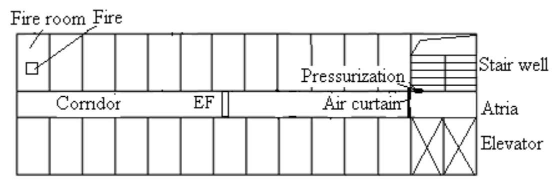


Figure 2: Schematic Diagram Of The Floor In The Fire

Figure3: Wind Tunnel Of Long Corridor

Figure 4: The Installation Of Thermocouples In The Corridor

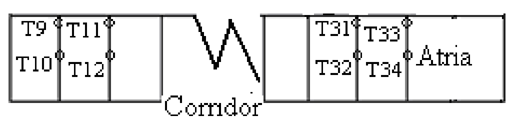


Figure 5: Schematic Map Of The Thermocouples In The Corridor

2.2 Test Design

According to the "Code for Fire Protection Design of Tall Civil Buildings" (GB50045-95), there are two basic formulas to calculate the volume of pressurization air in atria: one is the differential pressure method, the other is the velocity method. In this paper, the velocity method was used and the volume was 7689m^3/h. According the reference 10, the velocity of air curtain was 12m/s, which the sum of this part was 2567m^3/h. In test 3 the volume of pressurization air in atria was

Journal of Theoretical and Applied Information Technology
31st December 2012. Vol. 46 No.2

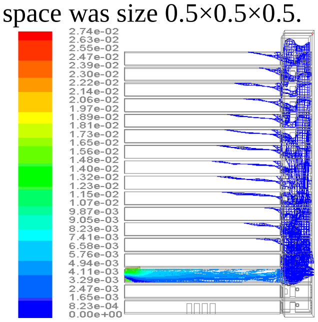
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2563m^3/h, one third of the conventional positive pressure. The exhaust area was the sum of the ground area of the corridor (45m^2) and the area of the fire room (8.64m^2), so the smoke extraction volume was 3240m^3/h. Smoke exhaustion volume in evacuation area was 1/3 (854m^3/h) and 1/2(1281m^3/h) of pressurization respectively. And the exhaustion fan was set in the top wall of the middle of the tunnel.

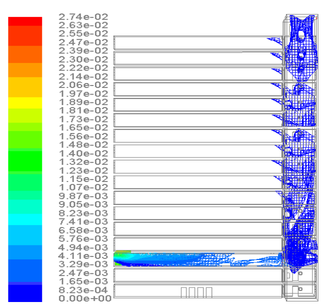
4. RESULTS ANALYSIS

There are mainly three aspects of smoke: high temperature, shading and toxicity, respectively, the smoke concentration and temperature of the characteristics height of human eye from the simulation were analyzed. The characteristics height of human eye is usually 1.2m-1.8m, and 1.6m was took in the simulation.

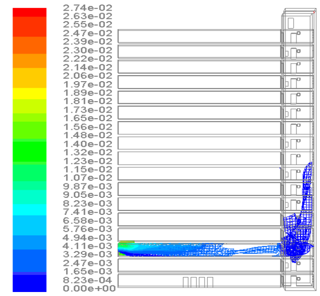
After the fire, people can only evacuate from atria to the staircases, and the fire alarm devices worked after 60s. The speed of people walking was 1.0m/s in the room and 0.5m/s in the corridor, the confirmed reaction time was 120s [10]. So it was known that the necessary preparation time for the safe evacuation was 242s (consider the farthest room from the atria). Finally, 300s was took as the decision basis [11].The calculation space was divided into three main parts: the fire floor, the shaft area and other regions. The basic unit of calculation of fire floor size was 0.1×0.1×0.1, the basic unit of calculation in the shaft size was 0.2×0.2×0.2, the basic unit of calculation of the remaining space was size 0.5×0.5×0.5.



(A) Model 1



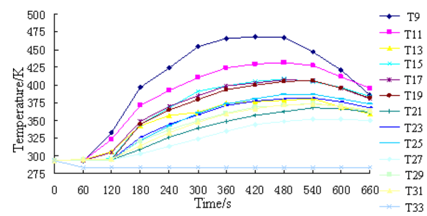
(B) Model 2



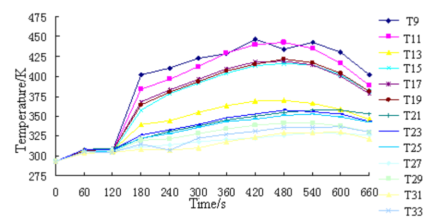
(C) Model 3

Figure 6: Smoke Diffusion At 300s

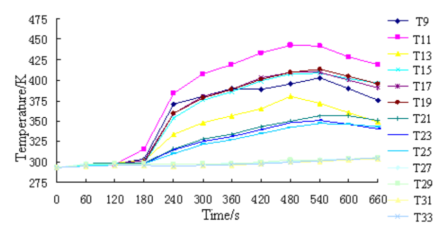
The Simulation Results Of Smoke Diffusion At 300s Was Shown In Figure 6. In Model 1, The Smoke Was Full Of Shaft And Began To Spread To Rooms Above The Neutral Layer. In Model 2, The Shaft Was Filled With Smoke, But There Was A Few Smoke Spread To Rooms Above The Neutral Layer. In Model 3, Only A Few Amount Of Smoke Spread Into The Shaft. Comparing The Three Models, It Was Obviously That The Smoke Was Control Efficiently With The Vertical Composition Smoke Control Model.



(A) Model 1



(B) Model 2

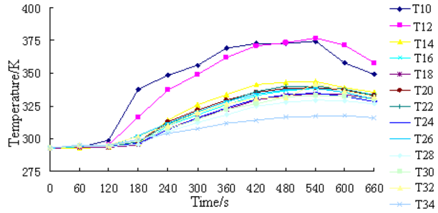


(C) Model 3

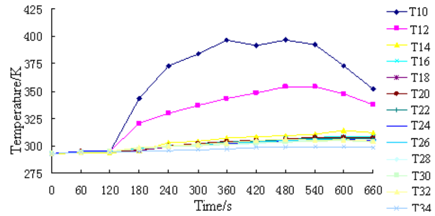
Figure 7: Temperature Distribution In The Gallery At The Top Of Wall

Journal of Theoretical and Applied Information Technology
31st December 2012. Vol. 46 No.2

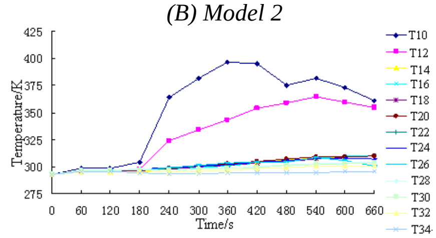
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195



(A)Model 1



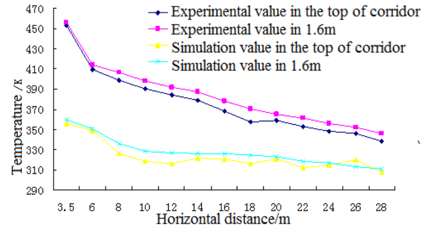
(B) Model 2



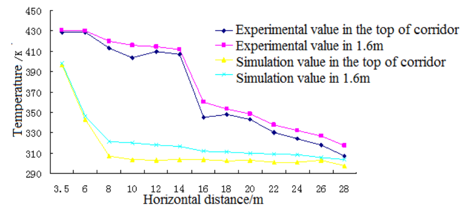
(C) Model 3

Figure 8: Temperature Distribution In The Gallery At The Height Of 1.6m

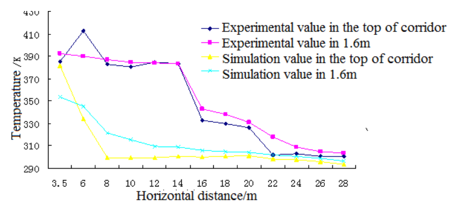
The smoke temperature distribution of experimental results in the corridor were shown in Fig.7 and Fig.8. In model 1, the smoke was full of the corridor at 300s, visibility was basically 0. Only setting the air curtain could not effectively block the smoke for a long time, some smoke control measures should be taken. At 300s, the temperature of the corridor at 1.6m, except near the air curtain, had reached 320K, which could easily cause burns injure to persons. In model 2, after setting the exhaust fan, a large number of smoke was exhausted from the corridor, the smoke concentration greatly reduced, which made the visibility increase. At 300s, the temperature of the corridor after the exhaust fan at 1.6m was 305K, and it was relatively favorable. In model 3, with the vertical composition smoke-control model, most of the smoke in the corridor was blocked, only a small amount of smoke broke into the atria through the bottom of the air curtain, the visibility of the corridor was best comparing the former models. At 300s, the temperature of the corridor after the exhaust fan at 1.6m was 295K, which was also best relatively.



Model 1



(B) Model 2



(C) Model 3

Figure 9: Temperature comparing of model 1-3 at 300s

The temperature distribution of simulation and experiments at at the top and 1.6m high were shown in Fig 9. Comparing the values between the simulation and experiments, the trend of the temperature was basically the same. Comparing the model 1(setting the air curtain) and model 2(setting the air curtain and exhaust fan), the temperature distribution at the top of the corridor could be divided into two zone: exhaust fan affected zone, air curtain affected zone. Comparing model 2(setting the air curtain and exhaust fan) and model 3(setting the air curtain, exhaust fan and pressurization), the temperature was descended for once by air curtain in model 2, and it was descended for twice in model 2. It was well shown that the temperature changing with different devices. Form the Fig.9, in model 3, a "secondary pressure zone" by the effects of the air curtain and the pressurization was formed in the corridor (the atria was called a "first pressure zone"), which could block the smoke further away from the atria.

5. CONCLUSION

In this paper three models are introduced to prove the vertical composition smoke control model. Form the simulation and experiment results,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

it is known that the model 3 is more reasonable. And some conclusions are listed:

(1)Comparing the model 1 and model 2, in model 1, the air curtain can effectively block the smoke flowing into the atria in a relatively short time, while after adding the exhaust fan, the time for blocking the smoke increases 60s, and this models work well as using pressurization from "Code for Fire Protection Design of Tall Civil Buildings", but the amount of fresh air is reduced by 1/3.

(2)Comparing the model 2 and model 3, the temperature is descended for twice in model 3, a "secondary pressure zone" by the effects of the air curtain and the pressurization is formed in the corridor, which could block the smoke spreading further away from the atria.

(3)The smoke diffusion from the simulation is higher than the experiment, but it can reflect the smoke field flowing in the whole building well, especially in the corridor and in the shaft. And this work has an important role in the arrangement of smoke control in high-rise building.

ACKNOWLEDGEMENTS

This work was supported by the China Postdoctoral Science Foundation funded project (2012M511742) and Natural Science Fundamental Research Project of Jiangsu Colleges and Universities (11KJB620002).

REFERENCES:

[1] H. JiaPeng, L. Jing-Xian, Z. Ru, "Simulation of evacuating buffer in high-rise building fires", Journal of Civil, *Architectural and Environmental Engineering*, Vol. 33, No. 1, 2011, pp. 98-104.

[2] C. Yanyan, Z. Hui, Y. Rui, "Building fire smoke control strategies simulation using fire and evacuation information", *Journal of Tsinghua University*, Vol. 50, No. 8, 2010, pp. 1158-1162.

[3] B. W.Z, "Floor pressurization as a means of controlling smoke during a high-rise fire", *Engineered Systems*, Vol. 26, No. 1, 2009, pp. 76-80.

[4] B. W.Z, "Smoke movement in elevator shafts during a high-rise structural fire", *Fire Safety Journal*, Vol. 44, No. 2, 2009, pp. 168-182.

[5] C. Haixiang, L. Naian, C. Wanki, "Wind effects on smoke motion and temperature of ventilation-controlled fire in a two-vent compartment", *Building and Environment*, Vol. 44, No. 12, 2009, pp. 2521-2526.

[6] B. W.Z, "COSMO Software for designing smoke control systems in high-rise buildings", *Fire Safety Journal*, Vol. 45, No. 6-8, 2010, pp. 337-348.

[7] Z. Ru, H. Jiapeng; J. Juncheng, "Experiment of smoke-preventing air curtains in high-rise building fires", *Transactions of Nanjing University of Aeronautics and Astronautics*, Vol. 25, No. 3, 2008, pp. 224-229.

[8] C. Charles, "A fire safety study of refuge floor building wall layout design", *Fire Safety Journal*, Vol. 44, No. 4, 2009, pp. 545-558.

[9] C. Gutiérrez-Montes, E. Sanmiguel-Rojas, R. Guillermo, "Experimental data and numerical modelling of 1.3 and 2.3 MW fires in a 20 m cubic atrium", *Building and Environment*, Vol. 44, No. 9, 2009, pp. 1827-1839.

[10] H. George, Q. Jia, "Comparison of FDS prediction of smoke movement in a 10 storey building with experimental data", *Fire Technology*, Vol. 45, No. 2, 2009, pp. 163-177.

[11] C. Charles, L. Kam, "Effects of building wall arrangements on wind-induced ventilation through the refuge floor of a tall building", *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 96, No. 5, 2008, pp. 656-664.