

Smoke exhaust experiments in an atrium model^{*}

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Abstract: A series of experiments under various smoke control conditions during an atrium fire were conducted in a reduced-scale compartment that was constructed to be a 1/8-scale modeling of the PolyU/USTC Atrium. The steady-state fire experiments were conducted and the distributions of temperature and smoke visibility were measured. The result indicates that the smoke exhaust rate, exhaust inlet location, fire source power and the lower region pressurization can impact the effectiveness of the exhaust systems. As expected, the descent of the smoke layer can be reduced with the increase of smoke exhaust rate. It also can be found that the exhaust system, which the exhaust inlets were located equably under the smoke layer, is effective in extracting gases from hot layer. The lower region pressurization experiments demonstrated that this method is an effective smoke control method. This will be contributed to the fact that the exhaust system needs the air supply from the lower of the space to replace the air flowing out of the vents. More comprehensive studies on exhaust inlet location, exhaust rate, makeup air inlet location and air supply rate are needed.

Keywords: Atrium building, fire, smoke control

1. Introduction

In recent years, the atrium building has become commonplace in China. This concept is widely adopted by architects in designing modern buildings, such as luxurious hotels, multi-level shopping centers and prestigious office buildings. By interconnecting floor spaces, an atrium violates the concept of floor-to-floor compartment, which is intended to limit the spread of fire and smoke from the floor of fire origin to other stories inside a building. With a fire on the floor of an atrium or in any space open to it, smoke can fill the atrium and connected floor spaces. The fire risks of atrium building are different from those of traditional buildings, and the associated problems related to smoke should be dealt with carefully. Therefore smoke movement and smoke management in an atrium is one of the most important life safety considerations in atrium development and studying this becomes a research focus in the fire engineering fields.

There are two fundamental design guides available to provide the procedures and criteria on smoke control system in atrium buildings. One is the "NFPA 92B, Guide for Smoke Management Systems in Malls, Atria, and Large Areas" published by the National Fire Protection Association (NFPA) [1]. The other is "the design approaches for smoke control in atrium building" by the Fire Research Station of the building

Research Establishment (BRE), United Kingdom [2]. However, there is no full set of codes and regulations in Mainland China to govern the atrium design. Code for Fire Protection Design of Tall Buildings (GB50045-95) provides some regulations of fire safety in atrium building [3]. The air change rate method is taken for designing a smoke extraction system. Obviously these regulations are not good enough for designing a workable extraction system. It is not reasonable to use the volume of atrium space as a design criterion for designing smoke extraction system. The geometrical configuration should be included. Fire size and the risks posed by the position of a smoke layer interface may also be considered in the requirements [4]. Therefore further research on atrium fire is urgently required. To study atrium fire smoke management system, a research project sponsored by the National Science and Technology Commission of China was developed. The object of this project is to provide a basis research results for design of the smoke management systems. This project includes both physical and numerical modeling of an atrium smoke movement.

This paper presents the mechanical exhaust test results in the same physical model. In this study, a series of smoke mechanical exhaust tests with diesel pan fires of different diameters were performed.

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2. Description of physical model

Froude modeling was used as the scaling law of smoke movement in atrium in this study. The reduced-scale atrium was designed to be a 1/8 scale model of the Large Space Fire Experimental Hall co-constructed between Hong Kong Polytechnic University and University of Science and Technology of China [5] (PolyU/USTC atrium). The experimental facility used for this study is shown in Fig. 1.

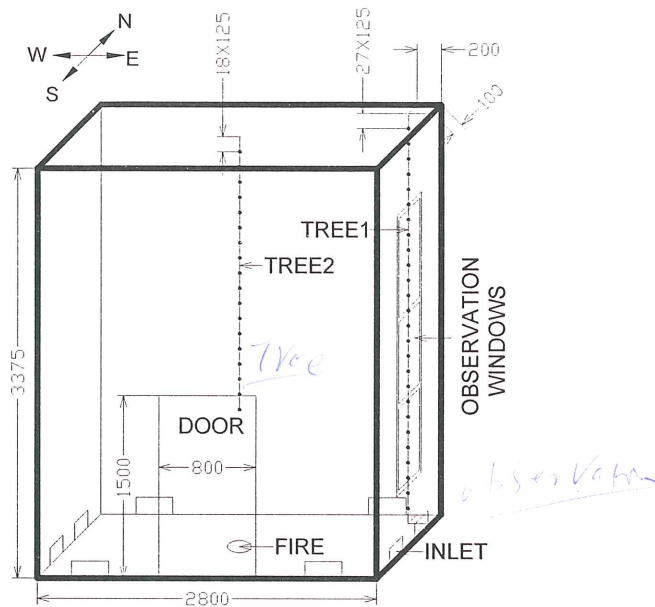


Fig. 1 Model dimensions and instrumentation

The facility is a compartment with interior dimensions of 2.8m length by 1.49m width by 3.38m height with a door on the center of the south wall. The two inlets were designed on the bottom of every wall. These inlets had a width of 300-mm and height of 200-mm. To allow for visual observation within the compartment, a glass strip observation window in the center of the East wall was outfitted.

Two exhaust smoke systems were used. One is the system that extracts smoke through the vent on the sidewall. The other system is that extracts the smoke through the vents on the ceiling. An exhaust inlet with a diameter of 150-mm was located in the West wall and ten electric lamps were installed on the interior West. An exhaust fan was used between the exhaust duct and the vent in the West wall. The smoke was led through the duct and finally exhausted to the outdoor. Eight exhaust inlets with a diameter of 30-mm were located in the ceiling of the compartment. These smoke inlets were also used to extract the hot smoke from the compartment during the tests. All exhaust inlets were connected to a central plenum. Two exhaust fans were

used between the plenum and exhaust duct. The smoke was led to the outdoor by the main exhaust duct. By using multiple exhaust inlets in the ceiling, the effectiveness of smoke exhaust system made by the exhaust inlet location could be investigated.

Inside the test compartment there were two vertical thermocouple trees. A set of 26 thermocouples with 125-mm intervals was vertically placed at the northeast corner of the compartment. A second set of 18 thermocouples with 125-mm intervals was also vertically placed at the center of the compartment over the fuel fire source, as shown in Figure 1.

The diesel was burned as the fire source in the fuel pan. A weighing system was established to record the mass of fuel during the experiments. The mass release rate was deduced from derivative of record against time during burning.

The volume flow rate was measured using the throttle aperture mounted in the each main exhaust duct. The rate of the smoke exhaustion was deduced from smoke temperature and the static pressure difference through the throttle aperture measured by a differential gauge during tests.

Visual evidence of the development of the smoke layers was obtained by post-test managements of videotapes, which recorded the obscuration of vertical arrays of incandescent lights. Smoke density or visibility along the vertical was approximately estimated using the photographs of the light obscuration captured by a digital camera. Facular region areas of lights during tests were calculated based on an image soft developed by author. At the beginning of starting burning, the facular area is the largest; the smoke density in all the space is taken as zero. When the smoke layer drops the location of the light, the facular areas of this light is zero, the smoke density in this position is taken as 1.0.

The smoke layer height was deduced from the temperature profile collected by thermocouple and the smoke density profile calculated by the image soft. In this study the smoke interface height was determined by using the N-percentage rule to process experimentally measured temperature and smoke density data [6].

The rate of natural air supply induced through the opening at the lower part of the space was produced based on the flow velocity measurements made using hot wire anemometer.

One computer was used to monitor and record collected by thermocouples and weighting sensor. Data were recorded every one seconds during the test times on a multi-channel data acquisition system. The conditions in the test space were observed by a video camera.

3. Experimental results

3.1 Exhaust Rate

Fig. 2 shows a comparison of the development of smoke layer height with different exhaust rate. The exhaust rate of the mechanical exhaust system is major factor impacting its effectiveness. As expected, the increase of the capacity of exhaust system can delay the descent of the smoke interface when the heat release rate is almost equivalent.

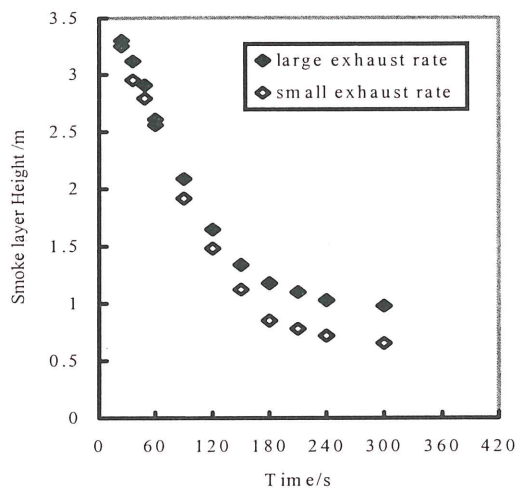
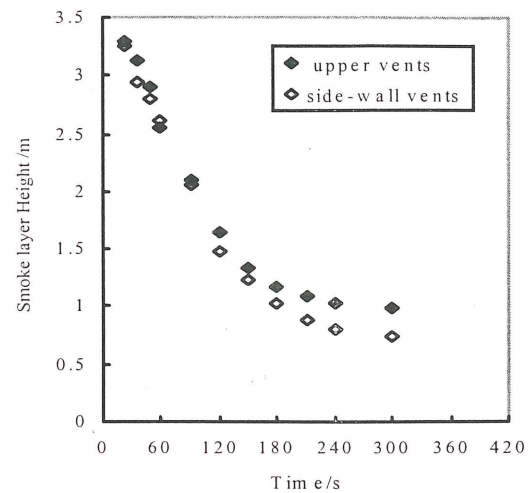


Fig. 2 Development of smoke layer height with different exhaust rate

3.4 Exhaust Mode

Fig. 3 shows a comparison of the development of smoke layer height with different exhaust mode. It is obvious that the exhaust system with the vents located in the ceiling is more effective when the heat release rate is almost equivalent. It is probably reason that plugholing of fresh air into the exhaust occurs in the exhaust system with a vent on the West sidewall. When the exhaust at an inlet beyond the maximum flow rate that can be efficiently extracted, plugholing may occur. This phenomenon reduces the effectiveness of the smoke exhaust system [7]. As a result, the clear height in the space is reduced. For ceiling vent exhaust system in which the exhaust system is under good operating conditions there was a well-developed smoke layer below the exhaust inlets. To prevent plugholing, the

exhaust inlet location, its flow rate and the smoke layer depths should be considered in the design of smoke control system.



3.3 Heat Release Rate

Fig. 4 shows a comparison of the development of smoke layer height from different fire source. It is obvious that heat release rate also impacts the effectiveness of the exhaust system under the same exhaust rate condition. But the effect of the fire source on the smoke layer height is unapparent.

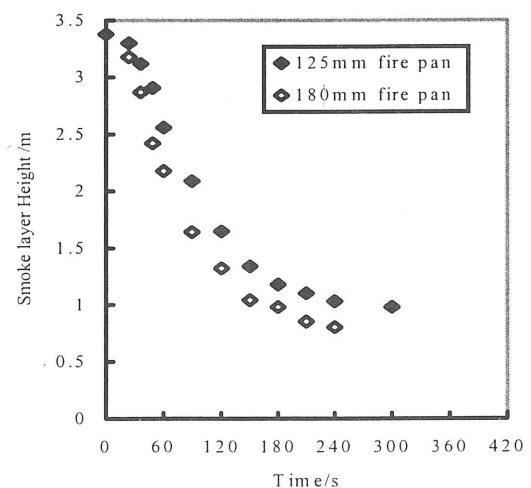


Fig. 4 Development of Smoke Layer Height with Different Fire Source

3.5 Air Supply

Fig. 5 shows the development of smoke layer height in the case of the lower part pressurization. This method increases the efficiency of exhaust system. Makeup air should flow into open vents located away from the fire. And the velocity of makeup air should

not deflect the plume significantly, which would increase entrainment [8].

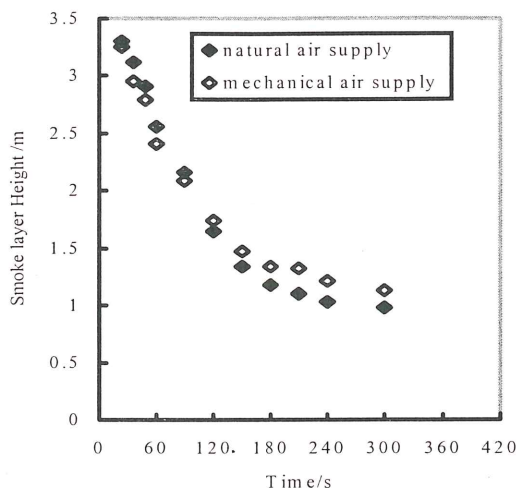


Fig. 5 Development of Smoke Layer Height with air supply from the lower

The lower part pressurization through the vents might be worth being considered in the design of smoke control system.

4. Conclusion

From the result of this study it may be concluded that:

The smoke exhaust rate, exhaust inlet location and fire source power can impact the effectiveness of the exhaust systems. The effect of the exhaust rate is apparent; the descent of the smoke layer height can be reduced with the increase of smoke exhaust rate. It also can be found that the exhaust system, in which there was a well-developed smoke layer below the exhaust inlets, is more effective in extracting gases from hot layer. The lower region pressurization experiments demonstrated that this method is an effective smoke control method. This will be

contributed to the fact that the exhaust system needs the air supply from the lower of the space to replace the air flowing out of the vents.

The results from small-scale model are consistent with these from the full-scale atrium. The degree of the effect of the different exhaust conditions was not so conspicuous. This may be attributable to the relatively small and narrow range of parameter in these experiments. More comprehensive studies on exhaust inlet location, exhaust rate, makeup air inlet location and air supply rate are needed.

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