Sustainable Smoke Extraction System

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Smoke extraction systems, either static with natural ventilation, or dynamic with mechanical ventilation are required to keep smoke layer at high levels in many tall atria. It is observed that a design fire with high heat release rate (HRR) is commonly used for designing natural vents, but a low HRR is used for mechanical ventilation system. This will not produce a sustainable environment. A sustainable smoke extraction system is proposed by combining natural and mechanical ventilation.

Keywords: numerical simulation ; smoke extraction system ; atrium ; natural vent ; mechanical ventilation

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1. Introduction

There are many construction projects with big atria while developing sustainable urban areas in the Asia-Oceania regions since 1980s [1][2]. The Greater Bay Area, which includes nine cities in Guangdong, Hong Kong and Macao, is a very good example [3]. Many buildings with large atria have been constructed or planned. It is required that fire safety provisions have to be installed for crowded atria. The smoke layer in a fire has to be kept high to allow people to see through so that smoke will not give adverse effects to people staying inside, occupants trapped inside can locate the exits, firemen can identify the fire sources, and high thermal radiation will not act on the firemen fighting against the fire [4][5]. A high smoke layer will also provide an environment free of toxic smoke for the occupants and reduce thermal radiative heat flux from the hot smoke. There are no internationally agreed design guides [3] with applicable correlation expressions.

There are two types of smoke extraction systems in large halls: natural venting or static smoke extraction systems, and mechanical ventilation systems or dynamic smoke extraction [3][4][5]. HRR is important in designing a smoke extraction system [6]. It is observed that large design fires up to 20 MW are commonly used for designing natural vents, while a small design fire (e.g., five MW) is commonly used for mechanical ventilation [6][7]. It is obvious that fire size should not be a function of the venting method that depends on how the combustibles are burnt. Fire size should be selected based on hazard assessment.

The performance of the two smoke extraction systems under fires of different HRR were explored in an earlier paper [8][9] using Computational Fluid Dynamics (CFD) simulation. A new proposed sustainable hybrid design combining static and dynamic extraction system was explored and compared with the traditional ones, which could result in a lower smoke temperature and higher smoke layer interface height, indicating a better extraction design.

2. Example Atrium

Numerical experiments were carried out [9] in an example atrium with 150 m length, 40 m width and 30 m height to study the performance of the two traditional extraction systems under big, medium and small fires as well as the proposed hybrid extraction system under the same conditions. The CFD predictions on smoke extraction were validated using full-scale burning tests data in two example buildings [10][11].

The calculations for static and dynamic smoke extraction systems were presented by following local guides [12]. A thick enough smoke layer was formed below the ceiling to have adequate buoyancy before opening the vents.

A 4 m by 4 m fire was put at the center of the example atrium floor. Four groups of simulations, each with three cases of fire sizes commonly accepted in different applications (5 MW, 20 MW and 50 MW), for a specified scenario were considered in the example atrium.

The performance of the two types of smoke exhaust systems is evaluated by simulating the smoke environment inside the example hall. The performance of a ventilation system is determined by the stable smoke layer interface height.

It was observed from the above results that a static smoke extraction system with natural vent is not able to extract smoke from small fires. Similarly, a dynamic smoke extraction system with mechanical ventilation is not good for big fires.

3. New Hybrid Design for Sustainable Smoke Extraction

A hybrid design that combines the two is proposed to produce a sustainable and safe atrium. Half of the volume of smoke is extracted by natural vents, and the other half is extracted by mechanical vents. The calculations for the proposed hybrid system were presented [9].

The performance of the hybrid system can also keep the smoke layer at high level for both small and big fires.

4. Discussions

Buoyancy was demonstrated to be important in removing smoke by static smoke extraction systems. The static extraction system is thus more appropriate for a fire with a large HRR. A large fire can produce enough buoyancy to form a thick enough hot smoke layer.

For a small fire with low HRR at the initial stage, a dynamic smoke extraction system performs better. The fan exhaust rate is a key part in designing a dynamic smoke extraction system. To save electrical power, the fan sizing used to be small and cannot handle big fires.

The proposed hybrid design will produce a sustainable smoke extraction system that uses less electrical power in operating the fan and is capable of keeping the smoke layer high under both small and big fires.

5. Conclusions

The performance of static and dynamic smoke extraction systems in an example atrium were studied using CFD. The objective was to compare the efficacy of mechanical ventilation and natural ventilation for small, medium and large fires. The CFD simulations on natural smoke filling, static and dynamic smoke extractions with three design fires of 5 MW, 20 MW and 50 MW confirmed that static smoke extraction is good for big fires but not good for extracting smoke under the initial stage of small fires. A dynamic smoke extraction system performs well for small fires, but not for big fires. The new hybrid design combining static and dynamic systems is proposed to produce a sustainable and safe atrium and is expected to perform well in both big and small fires.

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