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Effects of Wind and Adjacent High Rise on Natural Smoke Extraction in an Atrium with Pitched Roof

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Abstract

The effects of wind and adjacent high rise on natural smoke extraction in a pitched roof atrium were investigated numerically by Large Eddy Simulation. The soot volume fraction combined with the velocity field were analyzed. Results show that adjacent high rise without wind has little effect on natural smoke extraction. The vents facing the wind directly lose their exhaust capacity. The weakening degree of extraction effectiveness under back wind with high rise is nearly the same as under front wind without high rise. A strong recirculation is formed between the leeside of the roof and its adjacent high rise and finally almost no smoke is exhausted in this condition.

Keywords: PITCHED ROOF ATRIUM, NATURAL SMOKE EXTRACTION, EXTERNAL WIND, ADJACENT HIGH RISE, LARGE EDDY SIMULATION

1. Introduction

Atrium is a popular design feature of modern buildings because it gives a large interior open space with good directionality. Besides, atrium has been considered to have a great potential for enhancing natural ventilation and reducing energy use. However, due to the overall connectivity of atriums, the most fatal hazards like soot particle and carbon monoxide [1] generated by fires will spread to upper storeys quickly. So smoke extraction system becomes one of the most pressing issues in fire protection engineering of huge buildings with atriums.

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Natural and mechanical systems are the two main methods for exhausting fire-induced smoke in constructions [2]. The mechanical smoke extraction is not wind sensitive and with fixed extract volume guaranteed. But it requires costly installation and maintenance fees, even so, system failure is unavoidable due to machine or power problems. The natural smoke extraction method should be given the first priority when implementing concepts of green economy and sustainable development. The skylights and high side windows at the top of the atriums can be served as air ventilation at ordinary times and smoke extraction in fires. Nevertheless, natural extraction system ought to be designed according to ambient environments as flow field is sensitive to wind pressure [3, 4] and adjacent buildings [5].

Several researchers have conducted preliminary studies on airflow and smoke movement through experiments or simulations. Li et al. [6] studied airflow pattern inside a five-story wind-driven naturally ventilated atrium building under different wind directions and opening ratios. Chen et al. [7] investigated the wind effect on smoke motion direction and temperature in a two-vent compartment and found that ambient wind has a complex influence on the steady temperature of the smoke layer. Previous efforts [6-8] on natural extraction in atrium buildings mainly focused on studying the influence of stack effect, opening shape, and wind speed on ventilation performance.

Even until now few studies [9] have been carried out on smoke extraction effectiveness under the joint action of wind and adjacent building. The most relevant study was done by Chow et al. [9] in a flat roof cargo hall, in which wind has a positive effect in taking smoke away without adjacent wall but induces a downward push on smoke with an adjacent wall. After a general survey [9-10], it is found that investigation on external conditions should be done with deeper discussion. In the present paper, a numerical study was conducted to investigate the effect of wind and adjacent high rise on natural smoke extraction in an atrium with pitched roof.

2. Numerical modeling

Computational Fluid Dynamics (CFD) technique has been widely and successfully used in the prediction of airflows inside and around buildings [11, 12]. Fire Dynamics Simulator (FDS) [13], a CFD software package developed by National Institute of Standards and Technology (NIST) of USA, is a efficient numerical tool to simulate fire scenarios. The high-efficiency model Large Eddy Simulation (LES) in simulating fire-induced smoke flow behavior was selected in this study.

2.1. Architectural layout

The architectural layout and computational domain of the atrium model are shown in Fig. 1. Since the present study focused on revealing the effects of external conditions, the CFD model did not take into account its internal structure. The atrium in the present study was specified as 40 m long, 20 m wide and 26 m high with 45 degree pitched roof of 10 m high. Cartesian coordinate system (x, y, z) was used with its geometry of grid system shown in Fig. 1 (c). The computational domain is (20m, 80m), (20m, 80m), and (0, 50m) with grid numbers of 150 by 150 by 125 along the x, y, and z axes. The hollow atrium located in the geometric center of the computational domain. To note that, there was one more computational gird in the right side of the atrium as a consequence of mesh-adjustment by FDS. This asymmetrical arrangement represents a real fire scenario. There were five natural vents on each side of the pitched roof with projected dimension of 2 m on both x and z axes. An default material "CONCRETE" in FDS was assigned to the walls and the roof.

The effect of wind was simulated by imposing incident air flow with a speed of 3 m/s at one computational boundary. And a wall of 50 m high, 40 m wide and 2 m thick just sticking on the atrium served as an adjacent high rise. An NFPA fast T^2 fire [14] with steady value of 4000 kW was designed, representing the typical