FDS Research on Smoke Control in the Stair Enclosure of a High-rise Building Fire Event

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***Abstract*—The paper briefly reviewed the methods of smoke control in a high-rise building fire accident and the research status of this topic. It shows that the stair enclosure, which is almost the only path for the building occupants to safely egress the building during a fire event in a high-rise building, plays a very important role in the performance based design of a high-rise building. Four fire scenarios of a stair enclosure, namely no measure, natural ventilation, pressurization and dilution, are simulated by FDS. The simulation results are compared and analysis to obtain the optimal solution. The further studies also address.**

Keywords-fire event; performance-based design; smoke control; FDS

I. INTRODUCTION

During a fire event in a high-rise building, the stairs are the only way to evacuate. The environment inside the staircase is a vital factor for the occupants to safely evacuate the building. Given many high-rise building fire events that have shifted the mindset toward total building evacuation, delays due to occupants queuing in the staircase can result in occupants being exposed to the environment of the staircase for long periods of time. It is therefore imperative for the exit stairs to be free of smoke to the greatest extent possible and to incorporate design features that improve the speed of occupant egress via the stairs [1].

For the safety of the high-rise building, a stairs pressurization system, have been used to prevent the smoke from entering the stairs [2]. Some countries in Europe and America, where usually have the temperature difference more than 30℃ between the indoor and outdoor, the stack effect will highly possible occur [3]. In those buildings specifically exceeding 25–30 stories in height, the stair pressurization systems are difficult to design due to the impact of stack effect on maintaining uniform pressures over the building's height [4].

In addition, the effectiveness of a stair pressurization system is dependent on maintaining the doors predominately closed to maintain the required pressure differential to keep smoke from entering the stair enclosure [5].

Openings in the stair created by doors held open during occupants egress, a particular problem during a full building evacuation, or due to structural damage to the stair would severely compromise the performance of the system.

This paper examines the design issues associated with stair pressurization systems and evaluates a potentially viable alternate approach involving supplying and exhausting the stair at a high rate of airflow to provide clean air into the stair and remove/dilute any smoke that may be present [6].This system can control the pressure differential in the high floor, and reduce the smoke in the stairs, so it is practical for the stairs in high-rise building.

II. PERFORMANCE-BASED DESIGN CODES

Performance-based design is a methodology using engineering methods to achieve stated fire protection and life safety goals. It is not a new approach in engineering applications. The concept was first implemented in 1963. The approach was then converted into a five stage framework called NKB level for use in five countries in Northern Europe. In 1980 and 1984, these criteria were enacted by The International Organization for standardization (ISO) in the building codes (ISO 6420-1980/BS 6019:1980 and ISO 6421-1984). This implementation was followed by other nations such as the UK in The Building Regulations (1991), the New Zealand Building code (1992), the US in seismic resistance performance of buildings (1995), Australia's Building Codes Board (1996) and Japan's Standard Building Law (1998).

III. PERFORMANCE-BASED DESIGN CODES

Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires. Smokeview (SMV) is a visualization program that is used to display the output of FDS simulations.

The Fire Dynamics Simulator and Smokeview applications are developed by the National Institute of Standards and Technology (NIST) of the United States Department of Commerce, in cooperation with VTT Technical Research Centre of Finland. And both FDS and Smokeview are free software.

FDS_5.1.0 and SMV_5.0.7 are used to simulate the fire and smoke in this paper.

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IV. NUMERICAL SIMULATION

A. Physical Model

This paper focused on the staircase of a 30-floor high-rise building in Beijing. The outdoor design temperature is assumed to be -8℃. According to Chinese code GB50045-95 [7], the minimum net width of egress stair should be no less than values in the below table.

TABLE I. MINIMUM WIDTH OF STAIR FOR EVACUATION

Building Type	Minimum Net Width of Egress (m)
Hospital	1.3
Apartment	1.1
Others	1.2

An egress staircase with the net width 1.2 meters as below is designed in the paper. The stairs for a floor is of 6 meters long, 2.4 meters wide and 3.5 meters high. Fig.1 shows a partial of the stair system.

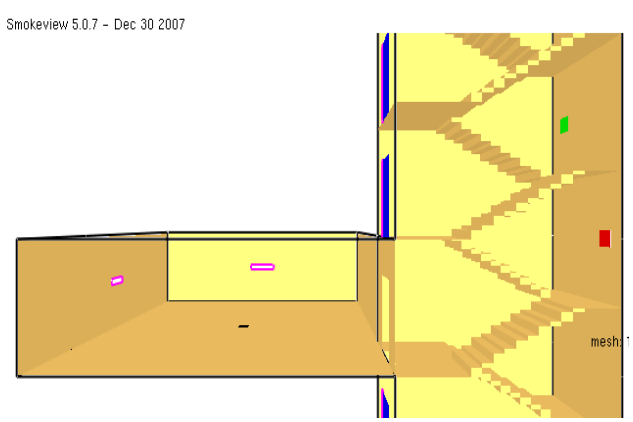

Figure 1. FDS partial model for stairwell

B. FDS Simulation Scenario

The fire occurred at the 5th floor, the size of fire is 5MW. In consideration of the most dangerous circumstances, stairwell door of the 5th floor is open. By opening or closing the doors and windows of stairs of each floor, FDS is used to simulate a series of fire scenarios. Beijing's indoor and outdoor winter design temperatures, namely 18℃ and -8 ℃, were used. Four basic ventilations of stairs are as follows:

- No measure: it is not feasible in this paper, and it is mainly used to analyze the stack effect.
- Natural ventilation: according to the Chinese code GB50045-95, the total area of opened windows of the stairwell in every five-story should not be less than 2 m^2 [7]. The building has a window (1m*0.6m) in each floor, which is directly open to the air.
- Pressurization: staircase's pressurization system supplies the wind through nine fans and provides 32400m^3/h ventilation. It means each fan provides 1m^3/s ventilation. The total pressure of fan is 500Pa.
- Dilution: 32400 m^3 of air flows into the stairwell, while the same amount of air is discharged form the stairwell per hour. Assumed that the area of opened stairwell door is 2.4 m^2, and the half-opened door is 0.4 m^2. When doors are closed, the total leakage area of each door is about 0.02 m^2. The simulation results vary to the opening and closing of stairwell doors, and also vary to the opening extent of other stairwell doors.

Decreasing rate of light is very important factor. Visibility is used to describe the situation of smoke spread in the simulation. The relationship is as follow [8]:

$I/I0 = \exp(-KL)$

where: I — the intensity of the light at the moment of leaving the space;

I0 — the intensity of the light at the moment of entering the space;

I/I0 — the balopticon rate of the space, in %;

K — decreasing rate of light, 1/m;

L — the length of the space, m.

Decreasing rate of light is dependent variable of smoke mass per unit volume. And other relationship as follow:

$K = Km*Ms$

Where: Km −− the decreasing rate of light of concentration per unit smoke mass, m^2/kg, in this situation it is 8700 ;

Ms — the mass of the smoke per unit volume, kg/m^3.

The computation of visibility as follow:

$S = C/K$

Where: S — visibility, m;

C — proportional modulus, C is 8 for the illuminants, and 3 for the reflectors. In this situation C is 3.

Figure 2 and figure 3 shows the visibility after the fire had lasted for 8 minutes with all the doors closed and semi-closed. As expected, smoke occupied most of the staircase due to the heat pressure and stack effects in the natural ventilation system; smoke was prevented from entering the staircase in the pressurization system; a little smoke entered the staircase in dilution system. Compared with the natural ventilation system, the dilution system improves the evacuating environment, however, with permission of a little smoke entering the staircase under the stack effect produced by minus pressure. If some of the doors open, on one hand it quickens the flow under the stack effect and makes the smoke climb fast, while on the other hand, some amount of smoke leave the staircase to enter upper floor. Both effects are approximately equal and counteracted, so we can't see big changes of visibility in the figure.

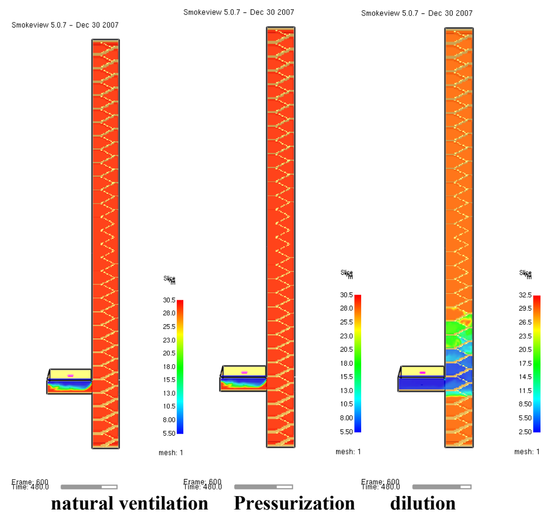

Figure 2. Visibility with all doors assumed closed

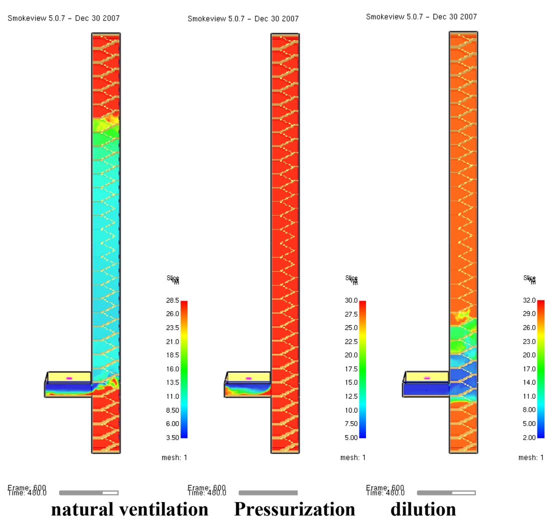

Figure 3. Visibility with all doors assumed semi-closed

The minimum visibilities are 13m and 5m for the people not familiar and familiar with the building respectively [8]. Figure 4 shows that in the natural ventilation condition, the visibility is smallest at the 5th floor and from 6th to 23rd floor, the visibilities are around 10m, a little lower than what the code require. In the dilution ventilation condition, the smallest visibility occurred at 6th floor and other floor's visibility is more than 13m except the 5th to the 7th floor. The pressurization system prevents the smoke entering the stairwell, so the visibilities are all more than 30m.

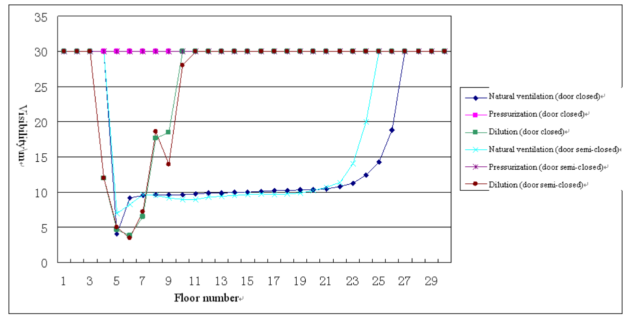

Figure 4. Visibility in three kinds of ventilation conditions

Figure 5 and figure 6 shows the pressure differential after the fire (opening area is 0.02 m^2 and 0.4 m^2) kept burning for 2 minutes with all doors to the stairwell closed, for the three ventilation conditions. Stack Effect, caused by the temperature differential between the indoor the outdoor, occurred obviously in the stairwell. Negative pressure which caused by the stack effect occurred at the 4 floors downstairs. It means that if the fire appeared at the 4 floors downstairs, the smoke will spread to the stairwell rapidly. Pressurization may make the pressure too high at the top of the stairwell to open the door to escape from the side building. As the pressure is -12Pa at low, yet it is over 70Pa at the top. To the opposite, natural ventilation makes the pressure distribute equably as the largest pressure is lower than 10Pa.This perfect result is due to the convection of air. When Pressurization makes the pressure at the bottom is 0 Pa, it reaches 120Pa on the top. And if the pressure at the bottom if raised, it will become much higher at the top. Pressure too high will stop the door from opening, then impacts the people's escape. In the dilution condition, though negative pressures occur, but it distribute equably as the height change, with the highest pressure is less than 30Pa, so the result is best. The pressure get a little smaller at each staircase in the three conditions after some doors are opened, yet, the result for the pressurization is still unsatisfactory as it is not easy to open the door.

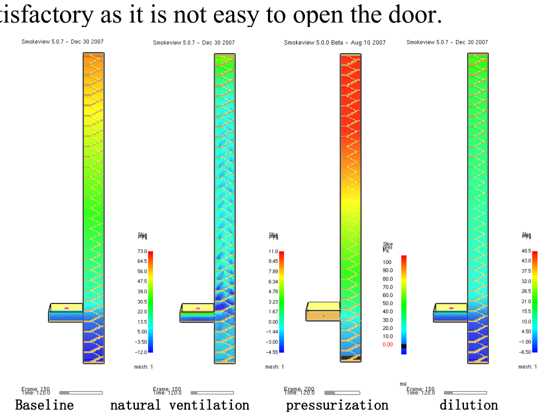

Figure 5. Pressure differential with all door closed

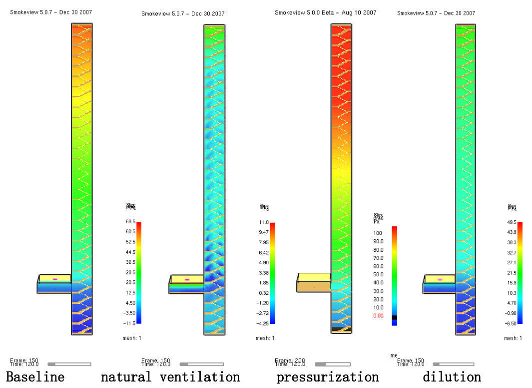

Figure 6. Pressure differential when all doors semi-closed

C. *Result analysis*

Now we give the summaries of simulations in the below table:

TABLE II. EVALUATION FOR THE RESULT OF SIMULATION

Basic ventilations	*Visibility*	*Pressure differential*
Natural ventilation	Unacceptable	Very good
Pressurization	Very good	Unacceptable
Dilution	Acceptable	Very good

From Table II includes the closed and semi-closed condition. Dilution system is a possible compromise. The premise is to change the visibility of ventilation cycle system to make it meet the requirements. Therefore, we can increase the amount of the ventilation until it meets the requirements and worthy. In a High-rise buildings with the temperature difference between the indoor and outdoor is large, if we take the pressurization system, it is suggested that we build a refuge to cut the stairwell at the middle, so that we can weaken the pressure difference caused by stack effect.

V. CONCLUSIONS

In this paper, FDS is utilized to take the numerical simulations for four situations: no measure, natural ventilation, pressurization and dilution. The results show that, dilution obviously has a better effect than other methods at the pressure difference and visibility in the stairwell, and it is worth to apply in performance based design. Still, the optimal amount of air for exchange in dilution needed a further research.

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