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Technical Note

Improvement of Positive Pressure Ventilation by optimizing stairwell door opening area

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ABSTRACT

This technical note presents a strategy to increase the effectiveness of Positive Pressure Ventilation (PPV) tactics in firefighting. It is shown that deployment of a Door Open Area Reducer (DOAR) in an appropriate position, which increases the resistance to the air escaping the stairwell, can significantly improve effectiveness of PPV performance. The simulation results demonstrate that an optimal placement of the fan combined with an optimized DOAR height can increase the pressure significantly yielding higher PPV effectiveness.

1. Introduction

Positive Pressure Ventilation (PPV) tactics have been shown to be successful in improving fighting fires in high-rise buildings [1,2]. Because of the increasing number of high-rise buildings, and significance of reducing related damages and fatalities, development of new fire fighting strategies has become a necessity for today's fire services [3,4].

When PPV fans are deployed at appropriate locations in the stairwell of a high-rise building, they create a high (positive) pressure zone in the stairwell by directing a significant amount of airflow into the stairwell. If the resultant static pressure is greater than that created by spread of fire, PPV fan deployment can drive away the flow of smoke, heat, and other combustion products from the stairwells and hallways, thereby keeping these tactically important locations clear and improving the safety of firefighters and building's occupants [1–3]. Number of studies have been carried out to develop tactics that can improve the performance of PPV operations. These studies are mostly focused on the use of multiple PPV fans, their placement locations, and their respective positions [5–9].

The present technical note is a continuation of a previous study where effectiveness and optimization of PPV tactics in high-rise fires have been experimentally and analytically studied [2]. During the on-site tests, it was observed that when PPV fan was deployed at the entrance of stairwell of the building, a significant fraction of air that was pushed inside the stairwell by the fan escaped through the upper areas of the open door frame at a relatively high velocity (see, for example, Fig. 1 of the previous study [2]).

This indicates that kinetic energy is being lost to the ambient instead of being converted to pressure energy in the stairwell. By introducing a Door Open Area Reducer (DOAR), a panel that covers the top part of the open door at the stairwell on the ground floor (see Fig. 1), resistance is introduced for the air that is escaping and a large stagnation zone is created in the stairwell. This enables the generation of higher pressure in the stairwell. Some studies have considered similar devices on the doors near the fire to block the flow of smoke in the upper layers [10].

An experimental demonstration of pressure buildup in a different building with almost similar layout where PPV performance had been tested was conducted. The results are tabulated in Table 1 showing the increase in the static pressures by deployment of the DOAR. These results support the proof of concept of the efficacy of DOAR implementation.

The effectiveness of application of DOAR on PPV performance is studied through numerical simulations using NIST's Fire Dynamics Simulator (FDS) and the results are subsequently utilized to select optimal deployment parameters.

2. Modeling

Fire Dynamics Simulator (FDS 5.0) is used to perform the simulations. FDS is second order accurate in space and time and can predict parameters to an accuracy of $5\%–20\%$ as compared to experimental results [11,12]. The better accuracy of the results is obtained with finer grids. As previously noted, an improvement to the already established PPV tactics is being investigated in this study. Therefore, all of the design and

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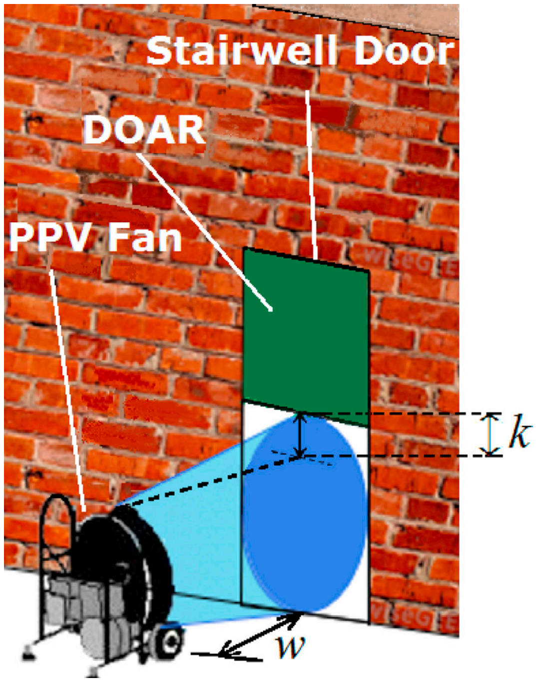

Fig. 1. Door Open Area Reducer (DOAR) deployment in conjunction with Positive Pressure Ventilation (PPV) fan at the stairwell door on the ground floor of a building with fire on a higher floor.

Table 1
Experimental results of the on-site pressure tests of PPV fan deployment and of PPV fan with DOAR to demonstrate the proof of concept (no fire), $w = 3$ ft and $k = 0.5$ ft.

Sensor Location (Floor Number)	Positive Pressure Differential[a]	
	Deployment of PPV[b]	Deployment of PPV and DOAR[b]
2	25 Pa	40 Pa
4	20 Pa	30 Pa
6	14 Pa	22 Pa
Roof Door	12 Pa	19 Pa

[a] Values are rounded to the nearest integer.
[b] Pressure sensor resolution = ±0.15 Pa.

operating conditions including the model, input conditions, timeline of the fire events, sensor locations, and modeling parameters are the same as the previous study [2], except explicitly noted otherwise. Also, grid convergence tests, meshing and boundary conditions have been established and validated previously [2]. Because of the limitation in the meshing and modeling by FDS which allows only rectilinear meshing of the objects, a number of minor construction details such as heating, ventilating, air conditioning (HVAC), water and draining systems can not be addressed and are not considered in the modeling.

Although the latest available version of the simulator is FDS 6.0, the accuracy of the results has been examined [2], which is consistent with the statement in the FDS 6.0 manual indicating that both versions produce similar but slightly different results for a variety of cases [13].

The entire domain is initially occupied by atmospheric air at 25 °C. To study the pressure variations inside the stairwell, a few locations for recording the pressure are selected in the simulation. The temperature variations inside the structure are also monitored and recorded by creating thermal sensors points inside the 3-dimensional model at various important locations inside the building. Considering the crawling motion of firefighters, these sensor points are located 1.3 m above the floor level. The seven-story building model consists of a stairwell, an apartment, and a T-shaped public hallway. The stairwell consists of eight landings with a door on each floor, the topmost door being the roof door. Each floor consists of a stairwell door leading to a public hallway where the apartment door opens into the living room and an adjoining kitchen. There are two windows in the living room, on adjacent walls. The apartment has a typical fuel load that consists of common furniture items such as a bed, TV, sofa, and wooden chairs. The physical building model has been discussed in details in the previous study and the accuracy of the aforementioned designed model for simulations has been validated [2]. Therefore, the same model is used in the present study.

3. Results and discussion

In order to establish the effectiveness of DOAR deployment in improving the performance of PPV tactics in high-rise fires, two basic FDS simulations, Fire with PPV (Simulation I), and Fire with PPV and DOAR deployment (Simulation II), without inclusion of wind as a significant factor, are run. It is assumed that the fire ignites in the kitchen of the studio apartment on the fifth floor and the apartment door was left open by the occupants. The fifth floor stairwell door and the roof door are initially closed. As the fire continues to grow, at the 70th second, a window failure occurs in the apartment, which provides necessary ventilation to the fire. At the 110th second, a firefighter opens the fifth floor stairwell door to perform search-rescue operation. For ease of comparison, this timeline is the same as that in the previous study [2].

3.1. Effect of DOAR deployment

Both simulations have the same fuel load and series of events. The difference is that in Simulation I, the firefighter activates a PPV fan at the first floor stairwell door to pressurize the stairwell and then opens fire floor stairwell door at 110th second. Simulation II, the firefighter activates one PPV fan at the first floor stairwell door and, also deploys the DOAR such that the vertical gap between the bottom of the DOAR and top of the fan is k (ft), and w (ft) is the distance of the PPV fan from the door (see Fig. 1). As noted, the timeline of fire events are described in the earlier study as are the details of the numerical implementation [2].

Consistent with the findings from the previous study, Fig. 2 shows that as a result of the PPV operation the temperature change at various strategically important locations on the fire floor are effectively lowered. However, the deployment of DOAR with PPV fan drops the temperatures

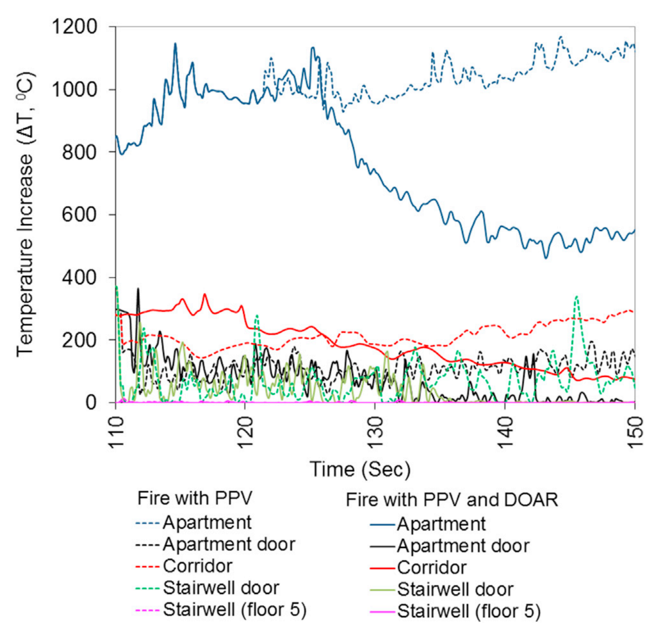

Fig. 2. Comparison between the temperature increase on the fire floor for fire with PPV (Simulation I) and fire with PPV and the deployment of DOAR (Simulation II) when $w = 3$ ft and $k = 0.5$ ft. Note that $\Delta T = 0$ for stairwell for both cases.