*The 2012 World Congress on*
***Advances in Civil, Environmental, and Materials Research (ACEM' 12)***
*Seoul, Korea, August 26-30, 2012*

# Wind Effect on Smoke Exhaust by Natural Vent

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## ABSTRACT

Natural vent is commonly installed to remove smoke during fires in tall and big halls. In static exhaust systems, buoyancy of the smoke layer is the driving force for removing smoke. However, air pressure perturbations due to unstable air speed or thermal environment in the surroundings would affect the system performance. This is particularly obvious for systems with horizontal ceiling vents installed at height under strong wind. Smoke might even be pulled down by wind action if the building is located near to an adjacent vertical wall. In the paper, the importance of studying this issue carefully while designing static smoke exhaust system will be pointed out. The scenarios at an atrium floor with and without an adjacent vertical wall will be studied, and effects on the smoke exhaust rate across the vent will be compared.

## 1. INTRODUCTION

In the Far East, natural vents can be used for removing smoke during a fire in large halls with height (Chow and Li 2004, Chow and Chow 2009, Chow and Li 2010). Such design was only acceptable to the authority in tall cargo terminals with low occupant loading. Buoyancy of the hot smoke layer is strong (Klote and Milke 1992, National Fire Protection Association 2000) for a big fire. Therefore, natural vent design was based on the assumption of buoyancy asthe driving force in smoke removal.

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However, when sufficiently strong wind blows towards the hall, positive or negative pressure might be induced at the windward and leeward sides. The ceiling vent might become an air intake point rather than an extract point (Marchant 1984, Kandola 1990, Than 1992, Ingason and Persson 1995, Poreh and Trebukov 2000). Therefore, there are deep concern in the installation of natural vents in crowded halls, particulary in underground subway stations. The instanteous vent pressure relative to the indoor air pressure distribution must be estimated carefully.

## 2. NUMERICAL EXPERIMENTS

An atrium, with its geometry shown in Figure 1, is taken as an example. For wind blowing from one side, the effect of the vertical wall at the leeward side on the vent flow will be discussed. Two scenarios labeled as S1, S2 with or without vertical wall at the leeward side are set up.

- Scenario S1:
  No vertical wall is put at the other side of the building. The effect of the external wind speed and fire size on the vent flow will be simulated. The conditions with and without wind, and fire size of 5 MW will be looked into. The wind speed is 5 $ms^{-1}$.
- Scenario S2:
  The settings are almost the same as above, but a vertical wall is placed 20 m away from the leeward side of the building.

As discussed before (chow and Chow 2009), free boundaries have to be handled properly. Therefore, the computing domain is extended outside the atrium to be 51.3 m long, 41.3 m wide and 25.0 m high, as shown in Figure 1. For each scenario, a grid system of 2,620,800 cells (divided into 200 by 144 by 91 parts along the three directions) was simulated for each scenario.

The CFD software Fire Dynamics Simulator (FDS) version 5.0 (McGrattan et al. 2008a, 2008b), which is developed by the Building and Fire Research Laboratory at the US National Institute of Standards and Technology, is used for the numerical studies.

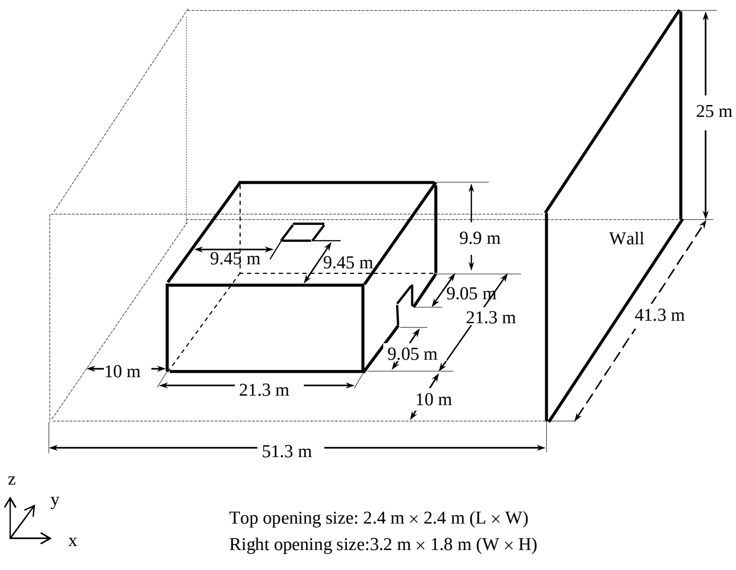



Fig. 1. Geometry of the atrium and computation domain.

## 3. NUMERICAL RESULTS

The wind-induced flow fields around a building with and without a wall under the wind speed of 5 $ms^{-1}$ are shown in Figures 2 and 3.

Prompted by the wind effect, positive pressures with respect to atmospheric pressure are induced at the windward side of the building. In the two scenarios without fire, it was observed negative pressures were distributed at the top of the leeward side of the building. Higher negative pressures with respect to atmospheric pressure were observed in S2 rather than in S1, due to the vertical wall at the leeward side.

The mass vent flow of the scenario S2 is found to be lower than that in most cases for scenario S1. The vertical wall at the leeward side of the building would lower the smoke exhaust rate in an atrium. It should be noted that the vertical wall would change the wind pressure distribution along the leeward surface of the building. The pressure at the top of the building which is induced by external wind in scenario S2 is higher than that in scenario S1, although air pressures at the top of the vent in both cases are negative. The pressures at the leeward side of the building in scenario S1 are negative with respect to another. However, air pressure at the same spot for S2 is positive. The differences in pressure between the inlet opening and the top vent opening in S1 are larger than those in S2. As shown in figures 2 and 3, this gives higher air speed up across the vent, hence higher flow rate across the vent in a 5 MW fire under wind speed of 5 $ms^{-1}$.

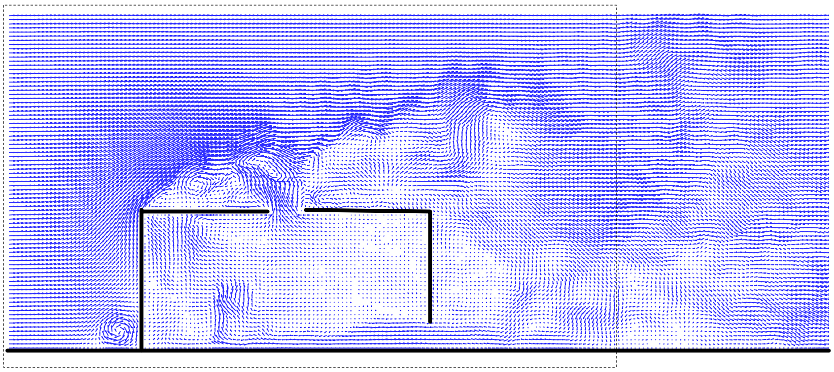
The transient air pressure differences $\Delta P_v$ between the predicted pressures $P_U$, $P_L$ at one grid above, below the vent and at the centre are estimated by:

$$\Delta P_v = P_U - P_L \tag{1}$$

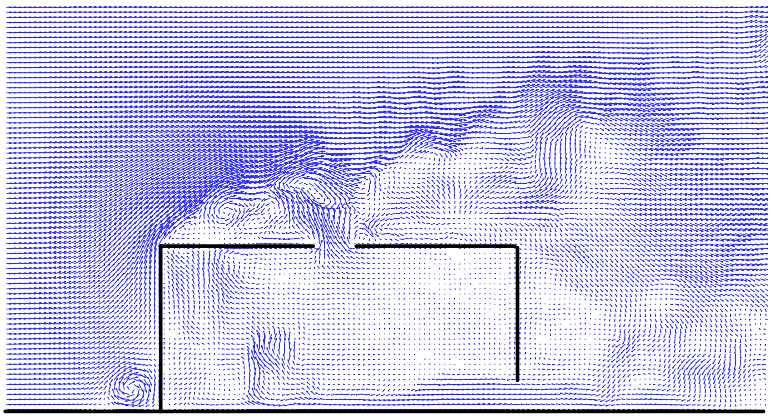
Results are also shown in Figure 4a. Values of the pressure difference $\Delta P_v$ across the ceiling vent in S1 are higher than that in S2. This will give a higher vent flow rate in S1 than that in S2.

Figure 4b shows the wind effect on mass vent flow across the ceiling vent, in two cases in a 5 MW fire, it is found the wind effect can increase the mass flow in these two cases.

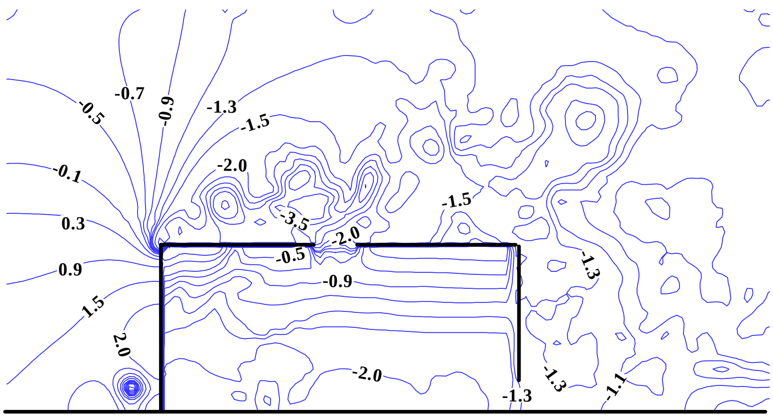
**Part A**




(a) Velocity distribution in the whole computing domain

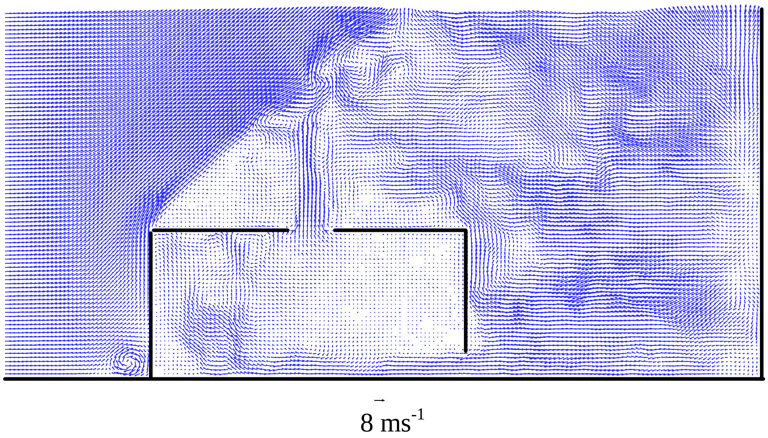



(b) Velocity distribution in Part A

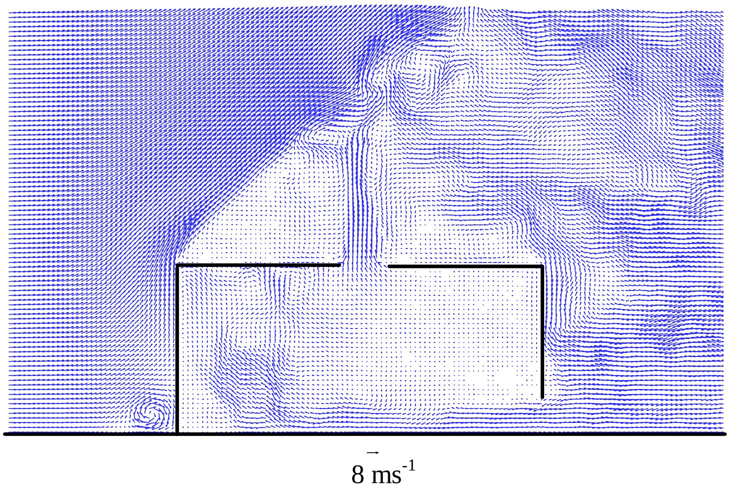



(c) Pressure coefficient distribution in Part A

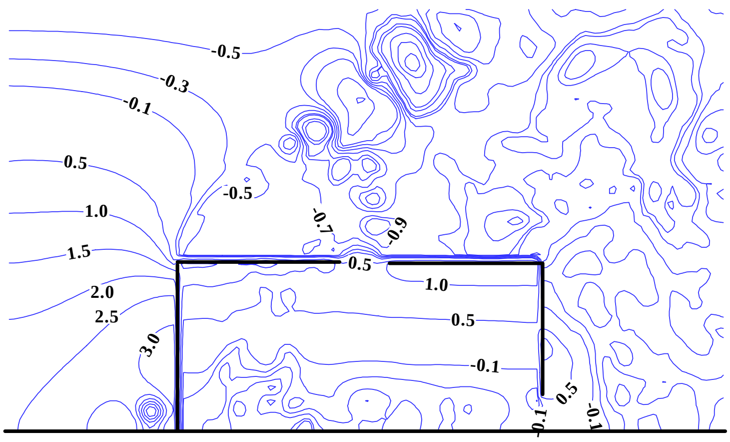
Fig. 2. Numerical results of scenario S1 under a 5 MW fire with wind speed of 5 $ms^{-1}$.




(a) Velocity distribution in the whole computing domain

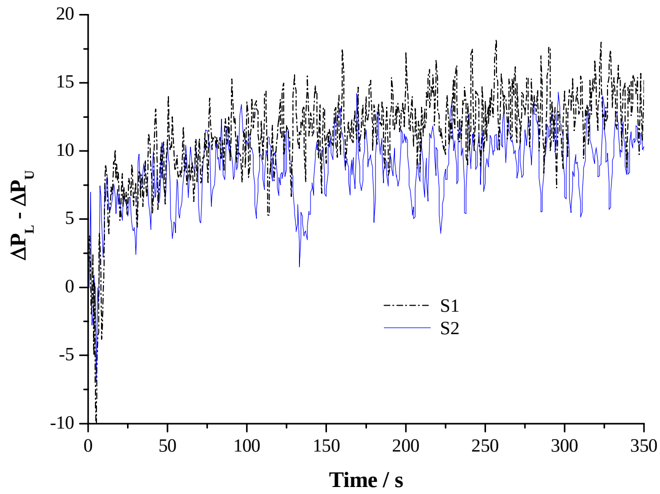



(b) Velocity distribution in the Part A

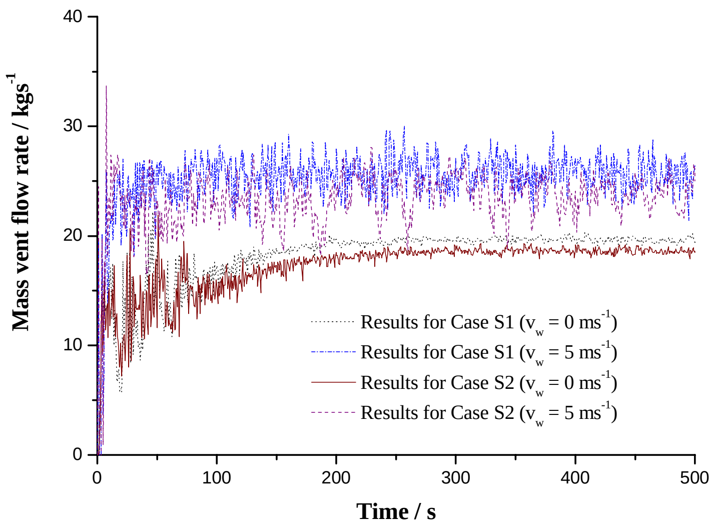



(c) Pressure coefficient distribution in the Part A

Fig. 3. Numerical results of scenario S2 under a 5 MW fire with wind speed of 5 $ms^{-1}$.




(a) Numerical pressure difference across the ceiling




(b) Mass vent flow rates across the ceiling vent

Fig. 4. Predicted results under a 5 MW fire and wind speed of 5 $ms^{-1}$.

## 4. CONCLUSION

Buoyancy is the driving force for extracting smoke out of a horizontal natural ceiling vent. However, wind effects cannot be ignored in some places next to vertical walls. In this paper, wind effect on a horizontal ceiling vent was studied by computational fluid dynamics. It is found that negative wind pressure coefficients for the intake vent at the leeward side would facilitate smoke exhaust. Effects of wind action should be included in the design of natural vents for smoke exhaust. Terrains around the building would affect the preformance of the static smoke exhuast system. This part should be evaluated carefully while designing static smoke exhaust system for large, crowded halls.

It should be noted that air movement would also be triggered while the sprinkler system is in operation. While static smoke systems are in use in crowded subway stations, fire hazard assessment should be reviewed thoroughly. This is very different from cargo terminals [8] with low occupancy.

## ACKNOWLEDGEMENT

The work described in this paper was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China for the project "Appropriate Safety for Lift shafts and Adjacent Lobbies of Evacuation Elevator Systems for Supertall Buildings under Big Fires" (PolyU 5148/08E) with account number B-Q11T.

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