J. Wind Eng. Ind. Aerodyn. 99 (2011) 1025–1035

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Wind tunnel tests on compartment fires with crossflow ventilation

H.X. Chen [a], N.A. Liu [a], W.K. Chow [b,*]

[a] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, Anhui, China

[b] Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong, China

ARTICLE INFO

Article history:
Received 24 February 2009
Received in revised form
27 June 2011
Accepted 1 July 2011
Available online 19 July 2011

Keywords:
Compartment fire
Wind
Cross ventilation

ABSTRACT

When a fire occurs in a room at ground level or a compartment located in the higher floors of a very tall building , the strong ambient wind will play an important role in fire spreading and smoke movement behavior. However, wind effect on compartment fire in cross ventilation condition has not been fully studied so far. In the present study, an effort has been made to study the wind effect on compartment fire in cross ventilation condition through experimental investigations. The experimental fire was generated by 250 ml n-heptane on the floor center of a cube enclosure with two opposite vents on the walls. The inside and outside gas temperature profiles at different vertical and horizontal locations were recorded by two thermocouple matrixes. The ambient wind velocity was set to 0, 1.5 and 3 m s^{-1}. It is observed that the ambient wind would enhance the fire severity by increasing the compartment fire temperature and reducing the time to flashover. The spilled-out flame/plume would extend horizontally farther with the increase of wind speed. Simple theoretical analysis shows that there is a critical wind velocity, or a dimensional number, to differentiate whether the gas flow across the vents is bidirectional or unidirectional, which is believed to influence enclosure fire behavior greatly.

1. Introduction

Many skyscrapers of very tall heights are constructed everywhere in the Far East. Fire safety provisions for these high-rise buildings have been a concern as the number of fires due to accidents, arson, etc., has been increasing in recent years. As for the fire scenarios in these buildings, the strong ambient wind plays an important role because wind velocity increases from zero at the ground to a higher value at some elevation. Strong wind may influence fire spreading and smoke movement behavior in the buildings greatly, for example, mechanical ventilation routines might not extract smoke efficiently under the action of wind (Yang et al., 2005). It is important to understand building fire behavior under wind effect before providing some actions to enhance the building fire safety. It is also important to wind engineering research for providing some clues to organize the airflow patterns or natural/mechanical ventilation equipments under wind for safer buildings. The research on compartment fire phenomena in high-rise buildings under wind effect is an essential step to provide guidelines for fire safety design of these buildings.

This paper presents the experimental investigation on wind effect on compartment fire with cross ventilation, which is the first step to understand this phenomenon and to arrange the ventilation measures for building fire safety under wind. In the experimental setup a fire compartment is burning under the forced airflow (steady airflow) generated by the wind tunnel, which is described in detail in the following section. The simulated fire scenario of these experiments is a compartment fire in the higher floor of a very tall building. In Hong Kong, there are many skyscrapers taller than 200 m. Some fire accidents had happened before in some skyscrapers. It is found that ambient wind played an important role in these accidents. In a high-rise building fire, usually, only one room or one floor is on fire. Because the height of the room/floor is small relative (mostly 3–4 m) to the building height, it is not necessary to consider the variation of ambient wind speed along one floor of the high-rise building. Therefore, the "steady airflow" assumption is adopted in the present experiments to study the wind effect on fire in the compartment located on one higher floor of the high-rise building. When one floor of the high-rise building is on fire, the remote ambient wind at the same level is blowing with an average speed. When wind approaches the building, its velocity changes because of the building blockage. In order to investigate such fire scenario, the wind tunnel test setup was arranged as described in the following section to generate steady wind flow to simulate the ambient wind. The prototype compartment was located at the wind tunnel exit to simulate the scenario that wind is blowing to the building to the largest extent. However, if the fire involves many floors, not a room or a floor, of the high-rise building, the

* Corresponding author. Tel.: +852 2766 5843; fax: +852 2765 7198.
E-mail address: bewkchow@polyu.edu.hk (W.K. Chow).

0167-6105/$ - see front matter
doi:10.1016/j.jweia.2011.07.006

ambient wind speed profile along the levels should be considered. In that case, the ''steady airflow'' wind tunnel setup would not be appropriate.

It would be more convincing if a model high-rise building could be used in the present study. However, it is not possible to simulate this in a wind tunnel in the conventional way. The scale factor would be very large and the model compartment too small. As we are focusing on a room or a floor fire in high-rise buildings, the present experimental setup and investigations could provide basic knowledge on wind effect on compartment fire, which can be helpful for fire safety design of high-rise buildings.

Besides representing a compartment located at higher floor of a high-rise building, the present experimental setup is also a representative of a single building at ground level. Though it is also important to investigate the wind effect on fire behavior of these buildings, there are very few studies on this topic, comparing to the considerable efforts on the investigation of the dynamics of compartment fire without ambient wind effect (Kumar and Naveen, 2007a; Lee et al., 2007, 2009).

With the present experimental setup, the wind effect on compartment fire can be investigated. Generally speaking, an uncontrolled compartment fire, with or without ambient wind action, usually follows the same typical sequence. After ignition, the fire generally goes through a growth phase followed by a transition known as flashover to a fully developed fire in the burning phase which may continue for some time, and lastly a decay phase as the fire burns itself out (Drysdale, 1999). Numerous studies on the experimental or theoretical modeling of compartment fires are available in the literature since the pioneering work of Kawagoe (1958). Most of these researches have been conducted for the compartment with single ventilation opening. In this configuration, outside air will be drawn into and hot gases/smoke will escape the compartment through the same opening, driven by buoyancy force. The air inflow rate of fully developed compartment fire has been shown to be weakly dependent on the room temperature but strongly dependent on the geometry of the opening, which is characterized by the ventilation factor, $A\sqrt{H}$, with A (m^2) being the opening area and H (m) being the opening height (Rockett, 1976). For compartment fires with two or more openings, some experimental studies are available for the enclosure with one wall vent and one roof vent (Jaluria et al., 1995; Li et al., 2002; Merci and Vandevelde, 2007), however, very few studies have been reported on the effect of two or more openings located on the walls. A compartment with openings on two opposite walls may have cross ventilation, especially if there is wind blowing, producing increased rates of burning (Feasey and Buchanan, 2002). Recently, an experimental study on the effect of two same-size openings located on opposite walls, i.e., in cross ventilation condition, on the development of fire in a compartment was reported by Kumar and Naveen (2007a). It was observed that the temperatures in cross ventilation condition are higher than those in single ventilation condition for larger fire size. Later, they proposed a simple mathematical zone model to predict the experimental temperature profiles (Kumar and Naveen, 2007b). Their work seems to be the first studying the compartment fire with two opposite vents; however, wind effect is not considered. Some discussions of wind effect on the motion of buoyant smoke motion and control in buildings can be found in the article of Porch and Trebukov (2000). The analyzed fire compartment in their work is an enclosure with dual openings on the opposite walls—the windward one at lower elevation near to floor and the leeward one at upper elevation near to ceiling. The opening heights are negligible so that the pressure difference distributions along the openings can be neglected and the flow is undoubtedly unidirectional. This configuration is suitable for theoretical analysis of the smoke movement under wind effect; however, it seems simple in real fire scenario because the buoyancy pressure difference usually varies along the door-like or window-like openings. It appears that the compartment fires with two opposite openings under wind action need more comprehensive investigation, experimentally and theoretically.

In this article, a series of experiments were conducted to study wind effect on fire behavior in the compartment with two opposite openings, i.e., in cross ventilation condition. The wind velocity was varied. The temperature profiles recorded at different locations inside and outside of the compartment, as well as heat release rate of the fuel were compared.

2. Experimental setup

The experimental layout is shown in Fig. 1, which indicates fuel in the compartment is burning under the forced airflow generated by the wind tunnel. The 20 m long wind tunnel can provide steady airflow with the velocity varying from zero to 15 m s^{-1} and the turbulence intensity of less than 2% in the 1.8 m (width) × 1.8 m (height) × 6 m (length) experimental section. In our experiments, an anemometer (Kanomax-KA12) with multi-sensors, placed in the experimental section of the wind tunnel, was used to measure the wind speeds at the locations numbered 3049–3051 (see Fig. 1). Another sensor numbered 3052 was used to measure the wind speed in front of the fire compartment which was placed near the exit of the wind tunnel on the same floor level.

The experimental compartment is a cube of inner dimensions of 0.6 × 0.6 × 0.6 m^3. The ceiling and the floor were constructed by a two-layer structure. The inner layer was fire-resistant board (8 mm thickness) to prevent heat loss and the outer layer was steel plate (2 mm thickness) to maintain the structure stabilization. Differently, there were three layers in the sidewalls. The inner layer was combustible fir board (25 mm thickness), middle layer fire-resistant board (32 mm thickness) and outer layer steel plate (2 mm thickness). Two square windows (20 × 20 cm^2) were opened in the center of the front and rear walls, respectively.

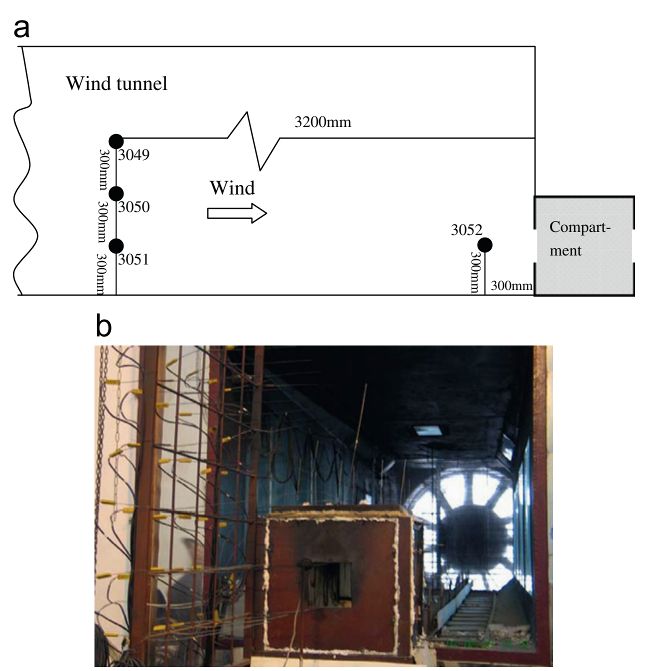

Fig. 1. Experimental layout: (a) experimental layout with the measurement positions of wind velocity and (b) photo of equipment arrangement.