Building and Environment 46 (2011) 2598–2602

Contents lists available at ScienceDirect

Building and Environment

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

On the bidirectional flow across an atrium ceiling vent

W.K. Chow [a,*], J. Li [b]

[a] Area of Strength: Fire Safety Engineering, Research Centre for Fire Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[b] The College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100124, PR China

ARTICLE INFO

Article history:
Received 22 February 2011
Received in revised form
9 June 2011
Accepted 12 June 2011

Keywords:
Horizontal ceiling vent
Bidirectional flow
Pressure drop
Smoke exhaust

ABSTRACT

Sizing of horizontal ceiling vent in a tall atrium is usually based on vent flow models with unidirectional flow. This is only good for natural vents with large pressure differences between inside and outside. For low pressure differential across the horizontal ceiling vent as experienced in some atrium fires, bidirectional smoke flow rates were observed. The extraction rate through the vent would be reduced, giving poor performance of the smoke exhaust system.

Bidirectional flow across a ceiling vent will be discussed in this paper. Models available in the literature will be briefly reviewed first. A new model was developed on studying effects of bidirectional flow across a horizontal vent on the smoke layer interface height. A critical pressure difference between inside and outside across the vent can be estimated on inducing bidirectional flows. The approach is illustrated with an example sizing calculation for a cubic atrium commonly found in Hong Kong.

1. Introduction

There are many reasons why natural vents (known as static smoke exhaust systems in some places such as Hong Kong) are installed in atria in the Far East. Smoke generated from a fire in an atrium itself or in spaces adjacent to the atrium of open design can spread rapidly. Consequence can be very serious in exposing a number of occupants to risk. The time for escape will be reduced and the fire-fighting activities will be affected, though the smoke will be quite 'cool' due to the large atrium space. Horizontal ceiling vents are more commonly found than vertical natural vents. That is because most atria are found at the core of the building complexes. Only roof space is available for installing vents. Sizing of the vent area is based on some vent flow models. These traditional vent flow models were derived from the Bernoulli theorem e.g. [1–8] by taking buoyancy as the driving force as reviewed [9,10]. Only unidirectional flow of smoke moving out of the vent is assumed. However, the direction of the vent flow depends on the pressure difference across the vent. Large pressure differentials would not give any problem in removing smoke. But if the pressure differential across the vent is not large enough, cool air might also be pulled down in addition to hot smoke being extracted out. A dynamic equilibrium state of having bidirectional flow will be reached when the pressure difference across the vent is very low.

In fact, such two-directional flow was observed by Cooper [1–4], Epstein [11,12] and Lee et al. [13] under the conditions of 'near-zero' pressure drop across a horizontal vent. There is an exchange of cool air and hot gases in spaces above and below the vent. Unidirectional flow across a horizontal ceiling vent as in Fig. 1a as assumed in traditional flow models was not observed. Instead, bidirectional vent flow as in Fig. 1b occurred when the pressure drop across the vent ΔP_o was below some critical values ΔP_{cri}. The rate of exchange was found to be dependent on the critical characteristics of the problem e.g. [1,2]. All these were confirmed in more recent studies with different approaches [14–17].

When the smoke layer temperature is not hot enough as experienced in a big atrium with a small fire, the pressure drop across a horizontal vent is likely to be very small and approaching zero. In addition, poorly positioned inlet vents under wind conditions would also give 'near-zero' pressure across the vent even when the smoke layer is very hot [5,8]. Therefore, systems with vent size deduced from traditional vent flow models might not perform as expected under some fire scenarios.

2. Vent flow model by Cooper (1994, 1995)

Placing denser fluid above less dense fluid across a horizontal vent would not give a stable system. Bidirectional or exchange flow through the vent will be observed if the pressure difference across the vent is very small. It was explained by theoretical analysis and verified by experimental results by Cooper [4,6] and Epstein et al.

* Corresponding author. Department of Building Services Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong. Tel.: +86 852 2766 5843; fax: +86 852 2765 7198.
E-mail address: bewkchow@polyu.edu.hk (W.K. Chow).

0360-1323/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2011.06.018