Building and Environment 46 (2011) 315–323

Contents lists available at ScienceDirect

Building and Environment

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

Buoyancy and inertial force on oscillations of thermal-induced convective flow across a vent

W.K. Chow [a,*], Y. Gao [b]

[a] Department of Building Services Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong, China
[b] Department of Building Engineering, Harbin Engineering University, Harbin, Heilongjiang, China

ARTICLE INFO

Article history:
Received 10 March 2010
Received in revised form
21 July 2010
Accepted 22 July 2010

Keywords:
Vent
Buoyancy
Expansion pressure
Thermal-induced flow

ABSTRACT

Natural vents are commonly installed in buildings for smoke control. Air motion is induced by buoyancy of the thermal sources inside the building. Hot smoke is expected to be exhausted out of the vent. However, directions of air flowing across the vent might be oscillating under some conditions. The ratio B of buoyancy to inertial force defined by the Grashof number over the square of the Reynolds number is the key parameter in determining airflow oscillations.

In this paper, effects of buoyancy, pressure, and the combined effect of buoyancy and pressure denoted by B will be studied by simple flow equations. A room fire with a horizontal vent is taken as an example. The results indicate that pressure is the driving force for the airflow oscillations when $B < 0.1$. Buoyancy is the dominating factor when $B > 10$. However, the combined effect of pressure and buoyancy is important when B is close to 1. Results are useful for designing smoke exhaust systems with natural vents.

1. Introduction

Thermal-induced airflow through a vent of an enclosure had been studied extensively in the literature of fire, combustion, energy, nuclear industry and marine engineering. Experimental studies [1–4] on heating up water in a container indicated that thermal expansion and buoyancy would lead to mass movement. Periodic exchange of warm and cool air masses through a vent was observed in enclosure fires [5–7]. Those results are useful for modeling energy systems, room fires, onsetting of big fires in buildings with glass facades, indoor aerodynamics induced by heating, ventilation and air-conditioning systems, and smoke exhaust with natural vents [8,9]. Whether air would flow in or out of a vent in a compartment depends on the induced pressure difference. Any perturbations disturbing the equilibrium would lead to air movement, and might onset flow oscillations at the vent. The oscillations can be sustained or even amplified when heat is kept on supplying. Flow instability due to low frequency oscillation flow for combustion in rockets [10] is a good example.

For an enclosure with an opening, pressure difference across the vent induced by a heat source has four parts:

- Pressure difference ΔP_p due to thermal expansion (section 8.4.2 of Ref. [3]):

$$\Delta P_p = \frac{1}{2\rho_e}\left(\frac{\dot{Q}}{C_p T_e A_0 C_d}\right)^2 \tag{1}$$

where ρ_e and T_e are the density and temperature in the enclosure next to the opening, A_0 is the opening area, C_d is the flow coefficient, $\dot{Q}$ is the thermal power of the heat source and C_p is the specific heat capacity of air at constant pressure.

- Pressure difference ΔP_b due to buoyancy of the hot gas with density ρ_g:

$$\Delta P_b = (h - H_N)\left(\rho_a - \rho_g\right) g \tag{2}$$

where h is the height, H_N is the neutral plane height from a reference point, g is the acceleration due to gravity and ρ_a is density of the ambient air.

- Pressure difference ΔP_m resulted from mass exchanges around the surrounding wall [3]:

$$\Delta P_m = \frac{\dot{m}^2}{2\rho_e (C_d A_0)^2} \tag{3}$$

* Corresponding author. 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 © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2010.07.023