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Review

Doorway flow from a reduced scale isothermal air/helium approach

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ABSTRACT

This paper deals with an experimental study of buoyancy-induced gas flow at a doorway-like opening as part of a fire smoke propagation application. The experimental approach is based on a reduced scale air/helium protocol, which allows a wide range of density conditions to be studied. The flow at the opening has been studied for wide ranges of density (0.17–1.22) kg/m^3, flow rate (20–600) l/min and doorway width (0.4-14) cm usually associated with smoke propagation in life-size applications. The data set consists of measurements of flow thicknesses, spilling angles and laser tomography visualizations. The results show that flow behaviour is in harmony with the basic Bernoulli theory commonly applied to this type of flow. The value of the flow coefficient obtained with several density conditions corresponds to the behaviour found by Emmons for a given flow density. The magnitude of the spilling angle has been investigated and its dependency on the Froude number has been demonstrated. The opening width has a significant effect on flow behaviour and the associated spill plume. The reduction of the opening width enhances the mechanism of air entrainment and modifies the position of the transition height at which plume cross sections change from being rectangular to circular in shape.

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1. Introduction

Doorway flow is the gas flow that occurs through an opening like that of an open door due to the density gradient on the two sides of the orifice. Induced by buoyancy, gas expansion or forced convection, this flow is mainly horizontal and mono or bi-directional. It is found in the design of Heat Ventilation and Air Conditioning (HVAC) systems in buildings, fire smoke management systems and all other applications where a vertical opening connects two gas environments of different densities. Depending on the application, the flow may have a significant impact on the overall understanding of the process and require specific attention to assess the mass and energy of the smoke released and the oxygen flux for fire hazard applications as well as the efficiency of air conditioning for HVAC system applications.

There is an extensive bibliography, which mainly comes from the fire science community.

The first elements of a theoretical description were put forward in the 1970s by Prahl and Emmons [1] for fire applications and Lidwell [2] and Shaw [3] for HVAC applications. The theory is based on a one dimensional description from the Bernoulli relation. The flow is the result of a vertical hydrostatic pressure difference profile due to a difference in density on both sides of the opening. The Bernoulli relation gives the vertical velocity profile and the total flow rate is obtained from the vertical integration of the aforementioned velocity profile. According to the density conditions and static pressure on both sides of the opening and the shape of the opening [4], various bidirectional flow regimes can be expected with one or several neutral planes. The effect of the shape of the vertical density profile (constant over the height or dividing into two homogenous zones) can modify the flow [5].

Experimental investigations (mainly for fire applications) have been conducted in order to study the ability of the one dimensional Bernoulli theory to predict the flow unknowns (profiles of pressure and velocity, neutral plane position, in and out flow rates). An important parameter is the flow coefficient introduced in the theory. It traduces the flow contraction at the openings. Prahl and Emmons [1] show its dependency on the Reynolds number due to its low Reynolds value (below 10,000) and the flow direction (in or out flow). Above a critical Reynolds number, the flow coefficient is identical for the in and out flow. A value of 0.68 has been proposed and is commonly use nowadays. Recently, more advanced flow

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