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Flow of hot gases in vertical shafts with natural and forced ventilation

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ABSTRACT

This paper presents the results from an experimental investigation on the flow of hot gases induced by pressure and buoyancy in vertical shafts. This flow circumstance simulates the propagation of smoke and other combustion products in vertical elevator shafts due to fire in high-rise, multistoried, buildings. The effect of natural and forced ventilation, occurring through shaft openings or vents, on the spread of smoke and hot gases is of particular interest with respect to the development of hazardous conditions in the building. Different configurations are investigated, such as natural and forced ventilation at the top or the bottom of the vertical shaft. The inflow conditions for the hot gases, at a vertical opening near the base of the shaft, are varied and characterized in terms of the inlet Grashof and Reynolds numbers. Extensive temperature measurements are taken within the shaft. These data are used to investigate the steady state thermal field that arises for various scenarios. These results may then form the basis for developing appropriate approaches for smoke mitigation in high-rise building fires. Flow visualization, using smoke and a Schlieren system, is also used to study the flow characteristics in the shaft and near the hot gas inlet. The results obtained indicate that a wall plume arises in several cases and a relatively well-mixed flow in others. A strong wall flow arises at high Grashof numbers and low Reynolds numbers, while increasing Reynolds numbers leads to greater mixing in the shaft. The resulting flow and its effect on the spread of hot gases and temperature decay are investigated for different shaft configurations and inlet conditions. It is found that the best smoke or hot gas removal and lowest shaft temperatures occur with natural ventilation at the top and forced ventilation up from the shaft bottom. It is also shown that forced downward flow at the top can be used to arrest smoke spread, as well as to minimize the effects of the fire.

1. Introduction

Several studies in recent years have been directed at flows induced by fires in enclosures, such as rooms, warehouses and corridors. The focus has largely been on small aspect ratio (height/width) enclosures and both experimental work and numerical modeling have been carried out [1–5]. In these studies, interest was largely directed at the growth of the fire and the spread of smoke and combustion products. Various models have been developed to study fire dynamics and the resulting temperatures and concentrations under steady and transient conditions. The propagation of smoke and other combustion products in large aspect ratio enclosures, such as vertical shafts, which can have an important role in high-rise building fires, has not received adequate attention in the literature. Among the practical procedures for reducing smoke concentration are opening a vent on the roof before the combustion products approach individual floors and horizontal mechanical ventilation [6]. However, detailed basic studies on the flow can provide guidance for faster and automated response methods in order to expedite this operation and reduce human involvement.

Cannon and Zukoski [7] carried out an investigation on the flow and temperature field in vertical shafts and showed that buoyancy effects dominate in most cases. The mixing characteristics in the flow, density stratification and fluid propagation were determined. Obstacles, such as stairs, in the shaft were found to reduce the mixing rates. An increase in heat transfer rate from the shaft was found to reduce mixing, and could limit the vertical smoke movement by reducing the bulk temperature and thus the buoyancy. Marshall [8] utilized a scale model of a five-story vertical shaft to study turbulent entrainment into the flow from a lower vent and the effects on the development of a wall plume above the entrance of the hot gases. A recirculating region was found to arise adjacent to the plume. The height of the smoke layer was restricted due to entrainment of ambient air through the vent. Another scale model of a

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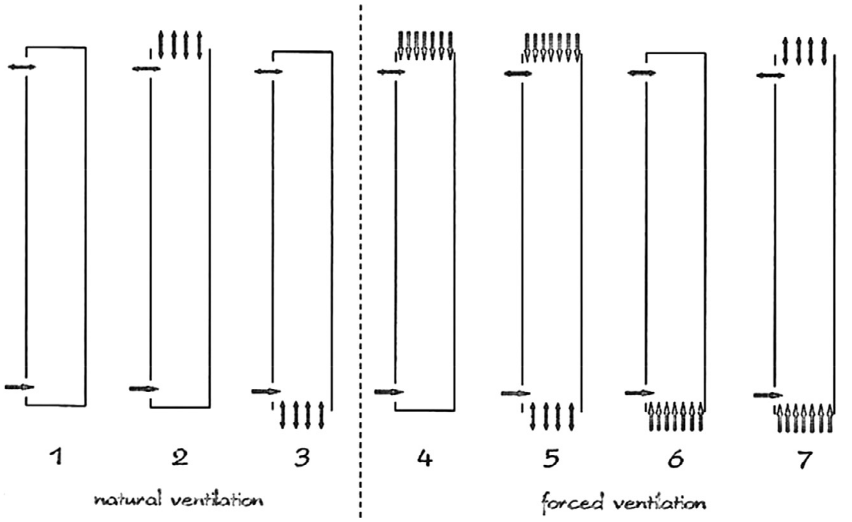
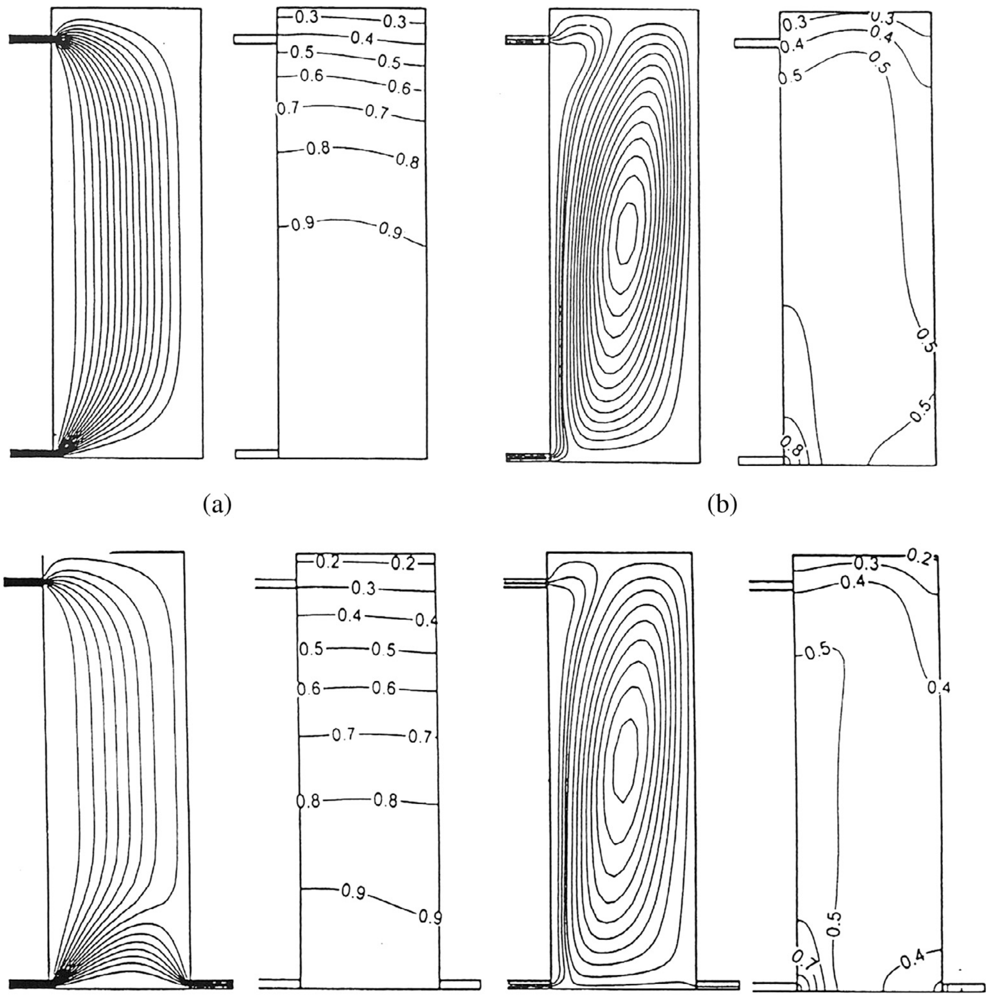


Fig. 1. The three configurations in natural ventilation and four in forced ventilation considered in this study.



(a) (b) (c) (d)

Fig. 2. Calculated streamlines and isotherms in the vertical shaft for $Re = 100$, A = 3 at (a) $Gr = 10^3$; (b) $Gr = 10^6$; (c) $Gr = 10^3$, side vent open; (d) $Gr = 10^6$, side vent open, where A is aspect ratio (height/width) and Re, Gr are based on shaft height [11].