



General expressions for the calculation of air flow and heat transfer rates in tall ventilation cavities

Guohui Gan*

Department of Architecture and Built Environment, University of Nottingham, University Park, Nottingham NG7 2RD, UK

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ABSTRACT

Solar heated tall ventilation cavities including solar chimneys are used to enhance natural ventilation of buildings. A validated CFD model was used to predict the buoyancy-driven air flow and heat transfer rates in vertical ventilation cavities with various combinations of heat distribution on two vertical walls ranging from symmetrical to fully asymmetrical heating. The natural ventilation rate and heat transfer rate have been found to vary with the total heat input, heat distribution on the cavity walls, cavity width and height and inlet opening position. General expressions for these variables have been obtained and presented in non-dimensional terms, Nusselt number, Reynolds number, Rayleigh number and aspect ratio (H/b), as $Nu = f(Ra, H/b)$ and $Nu = f(Ra, Re)$ or $Re = f(Ra, Nu)$, for natural ventilation design.

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1. Introduction

Design of a natural ventilation system requires determination of air flow and heat transfer rates. This can be achieved using analytical or numerical methods in addition to physical measurement. Analytical methods are generally based on an assumption of uniform air temperature in a space or zone. Such methods may be adequate for estimating buoyancy-driven ventilation of a building with simple vent openings but would not be of sufficient accuracy for design of tall ventilation structures such as solar chimneys, Trombe walls and double facades where the air temperature and velocity vary considerably.

Heat transfer through tall cavities consisting of two parallel plates/walls has been extensively studied. Most studies were concerned with symmetrical flow where both walls were heated at the same rate or fully asymmetrical flow where only one wall was heated while the other wall was insulated [1–4]. The flow in conventional solar chimneys [5–8] and Trombe walls [9] can be considered to be nearly fully asymmetrical as the exterior skin of these structures is made of glass to allow solar heat transmission with negligible absorption and storage of heat compared with the interior storage wall which acts as the main source of buoyancy.

However, when photovoltaic devices that transform most of the absorbed solar radiation into heat are used as a part or whole of the exterior skin of such a tall cavity structure [10], both the exterior and interior skins can behave as heated walls with different heat transfer rates. The flow patterns and heat and air flow rates through a cavity with two differentially heated walls differ from those with one heated wall or two walls heated at the same rate. Rodrigues et al. [11] numerically investigated natural convection in an asymmetrically heated channel with a fixed heat flux ratio of 1/5 between the cold wall and hot wall to model the flow in a solar collector and found that the flow rate increased with channel width and total heat flux. Nguyen et al. [12] measured the wall temperature along an asymmetrically heated 0.8 m high channel for a range of aspect ratios and percentages of heat distribution. They also used the heat balance model to calculate the flow rate which increased with channel size. Burek and Habeb [13] also measured the heat transfer and air flow in a 1 m high channel for different channel widths and heat fluxes. The mass flow rate through the channel was found to increase with channel width and heat input. The natural convection in such short channels could be laminar or involve mixed flow. Miyamoto et al. [14] experimentally studied turbulent natural convection heat transfer through 5 m tall parallel plates and the induced flow rate through the tall cavity with different widths and heat fluxes. The results were presented in dimensionless terms. Olsson [15] noticed from a review of literature on buoyancy-induced flow in symmetrically heated vertical

* Corresponding author. Tel.: +44 115 9514876.

E-mail address: guohui.gan@nottingham.ac.uk.