Building and Environment 46 (2011) 1589–1599

Contents lists available at ScienceDirect

Building and Environment

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

Transient buoyancy-driven ventilation: Part 2. Modelling heat transfer

Steven D. Sandbach*, Gregory F. Lane-Serff

School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Pariser Building, Sackville Street, Manchester M13 9PL, UK

A R T I C L E I N F O

Article history:
Received 4 October 2010
Received in revised form
13 January 2011
Accepted 18 January 2011

Keywords:
Buoyancy
Ventilation
Doorway
Displacement
Heat transfer
Modelling

A B S T R A C T

A new mathematical model for buoyancy-driven ventilation [Sandbach SD, Lane-Serff GF. Transient buoyancy-driven ventilation: Part 1. Modelling advection. Building and Environment, 2011] is modified to include heat transfer at the boundaries. Heat transfers at the ceiling and floor are included, using Newton's law of cooling to model convective heat transfer between the air and the solid boundaries, Fourier's law to model conductive heat transfer through the floor and ceiling, and a linear version of the Stefan–Boltzmann law to model radiative heat transfer from the ceiling to the floor. The effectiveness of the model was assessed using experimental results obtained in a full-scale test room. In these experiments, the vertical temperature stratification was measured using an array of T-type thermocouples. Speed measurements were obtained to estimate the ventilation flow rate (for displacement ventilation) and the velocity profile across the doorway (for doorway ventilation). Buoyancy was introduced using a twin-hob ($\sim$2.35 kW) heat source, and in most cases a diffuse two-layer temperature stratification developed. The results from these experiments are compared with the model and existing adiabatic models. Our results indicate that the effect of heat transfer at the boundaries on the final stratification is significant and should not be ignored. Furthermore, direct comparisons between the measured and modelled results are in general very good.

1. Introduction

In an accompanying paper [1], a new mathematical model for buoyancy-driven ventilation was proposed. The filling with buoyant fluid of a ventilated space due to a localised source of buoyancy was considered. Both doorway and displacement ventilation were considered where the temporal stratification that develops is calculated using a modified version of Germeles' [2] filling-box model. The model was developed and validated using results obtained from a series of reduced-scale salt bath experiments. In these experiments, salinity differences are used to drive the flow. Consequently, there is no buoyancy transfer modelling heat transfers at the boundaries.

For thermally driven flows, this heat transfer leads to conductive heat losses and secondary heat transfers (convective and radiative) that redistribute the energy in the room. These heat transfers play a role in determining the final temperature distribution and in most of the full-scale experiments of displacement ventilation [3–7], a largely linear temperature profile was observed. There is, however, a full-scale experimental investigation of forced displacement ventilation, where a two-layer temperature and concentration stratification was measured [8]. For this particular case, significant effort was invested in ensuring a diffuse inlet to prevent the ventilation flux from significantly modifying the flow in the room.

In this paper, the advection model described in part 1 [1] is developed further to incorporate heat transfers at the boundaries. The effectiveness of the model is assessed using experimental results obtained in a full-scale test room. These experiments are described in the following section, with the heat-transfer calculation detailed in Section 3. Results obtained using the new mathematical model are then compared with both experimental results and existing adiabatic mathematical models [9,10] in Section 4 and finally some conclusions are drawn in Section 5.

2. Experiments

The experiments were conducted in a test room measuring 2.78 m high by 7.46 m wide by 5.59 m deep (see Fig. 1). The test room was constructed primarily from plasterboard and was located in a laboratory approximately 7.5 times larger in volume. The walls were constructed from two sections of plasterboard 15 mm thick, separated by an air gap of 54 mm. The chamber floor was located above the laboratory floor by 200 mm and constructed from wood

* Corresponding author. College of Life and Environmental Sciences, University of Exeter, Amory Building, Rennes Drive, Exeter EX4 4RJ, UK.
E-mail address: s.sandbach@exeter.ac.uk (S.D. Sandbach).

0360-1323/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2011.01.019