Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 121 (2017) 222–229

Energy Procedia

www.elsevier.com/locate/procedia

International Conference on Improving Residential Energy Efficiency, IREE 2017

Numerical analysis of indoor thermal comfort in a cross-ventilated space with top-hung windows

Xiang Deng[a,*], Paul Cooper[a], Zhenjun Ma[a], Georgios Kokogiannakis[a]

[a] *Sustainable Buildings Research Centre, University of Wollongong, Wollongong 2522, Australia*

Abstract

Natural ventilation can be used in residential buildings in several Australian climatic zones and well-designed windows have the potential to facilitate indoor thermal comfort by allowing occupants to control volumetric outdoor airflow and indoor air velocities. Top-hung window is one of the most popular window types in Australia. This paper investigates the effect of the attributes of top-hung windows (i.e. window length, aspect ratio, height above the ground, window opening angle and the fly screen porosity) and outdoor air conditions (i.e. outdoor air temperature, wind speed and direction) on indoor thermal comfort during cross ventilation using CFD simulations. The Taguchi method was used to design the simulation scenarios and analysis of variance was used to determine the most significant factors influencing thermal comfort optimisation so as to reduce the number of CFD simulation cases. For the range of parameters considered and a particular case study building, results show that outdoor air temperature, window height and window opening angle are the most important factors influencing indoor thermal comfort in this room. The optimal window configurations for indoor thermal comfort of the case study building are also identified using a signal-to-noise ratio analysis.

Peer-review under responsibility of the scientific committee of the International Conference on Improving Residential Energy Efficiency.

Keywords: Cross-ventilated buildings; CFD simulation; Thermal comfort; Taguchi method

* Xiang Deng. Tel.: +610415484106.
E-mail address: xd902@uowmail.edu.au

1876-6102 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the International Conference on Improving Residential Energy Efficiency.
10.1016/j.egypro.2017.08.021

1. Introduction

Naturally ventilated buildings have the potential to provide significant energy savings as compared to mechanically ventilated buildings while maintaining good indoor air quality and thermal comfort. Over recent decades, many efforts have been made to examine the performance of different natural ventilation techniques [1]. The effectiveness of natural ventilation in a building is influenced by a combination of internal factors (e.g. floor layout, opening configuration) and external factors (e.g. urban form, building typology) and a number of studies have indicated that the configuration of the windows is one of the most influential factors among the indoor and outdoor factors [2-4]. Window configuration parameters include: window height, window size, presence of a fly screen and window type [5]. Favarolo and Manz [6], for example, simulated a single-sided naturally ventilated building with different window heights and widths, and concluded that the height of the window above the ground had the greatest impact on the effective opening discharge coefficient. Ravikumar and Prakash [7] used a 3-dimensional CFD model of an office room to determine the optimal window opening area and aspect ratio needed to maintain thermal comfort. It was found that the areas close to the walls without windows were more comfortable when compared to the other areas [7]. Maguel [8] compared windows with different types of fly screens to those without fly screen, and the pressure drops through different fly screen types were also determined through field measurements. Heiselberg et al. [9] studied two window types (i.e. side-hung and bottom-hung windows) and opening angles and concluded through laboratory measurements that, for single-sided ventilation, the bottom-hung window had less of a negative influence on indoor thermal comfort in winter. The impact of window parameters in the studies above were analysed individually and to date no thorough investigation appears to have been carried out to examine the overall contribution of all window parameters combined on indoor thermal comfort conditions.

One of the most commonly used methods to analyse indoor air movement and thermal performance is computational fluid dynamics (CFD) simulation [10]. The predicted mean vote (PMV) model is relevant to indoor thermal comfort analysis but it is not suitable for natural ventilation studies as the PMV model is usually used in an ambient environment with steady airflows [11]. As a consequence, an extended PMV model (PMVe) has been proposed for the evaluation of thermal comfort in naturally ventilated buildings [12]. This paper reports on an investigation of the performance of top-hung window configuration factors and how they affect the extended PMV metric (PMVe). The PMVe model was integrated into the CFD simulation tool, ANSYS Fluent [13], to simulate indoor thermal comfort conditions under different window configurations in a case study room.

2. Methodology

2.1. CFD modelling

A single top-hung window was placed in the upstream façade of a cross-ventilated room model of dimensions 5× 5 × 3 m (L×W×H) and implemented in ANSYS Fluent [13]. An plane opening was also placed in the downstream wall of the room with the same size and height above the ground as the window opening in the upstream façade, but without a window pane or fly-screen present. For a building model of height H, previous studies [14-16] suggest that the computational domain should be at least 5H in height, the lateral boundaries should be at least 5H from the region of interest and the domain downstream of the region of interest should be extended to at least 10H. These guidelines were followed in the present study. The standard k-ε turbulence model [17] was used for the CFD analysis. Convergence was assumed to be obtained when a minimum of 1‰ was reached for the scaled residuals of mass, momentum, turbulent kinetic energy (k) and turbulent dissipation (ε).

The simulation was a quasi-steady state simulation with the internal surfaces held of the room held at a nominal temperature of 24.0 °C. The effect on internal thermal comfort conditions of changes to outdoor air temperature, wind velocity and wind direction relative to normal to the upstream face of the room were investigated.