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Airflow assessment in cross-ventilated buildings with operable façade elements

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This paper presents an experimental study of basic cross-ventilation flow characteristics that are essential inputs for accurate natural ventilation modelling and design. The study focuses on a generic single-zone building model tested in a wind tunnel under isothermal flow conditions (wind-driven ventilation). An advanced experimental method based on particle image velocimetry (PIV) was developed to investigate the air velocity field in buildings with cross-ventilation. It was found that airflow patterns in rooms with cross-ventilation are complex and cannot be predicted by simplified macroscopic models such as the orifice equation. Inlet-to-outlet ratio and relative location of openings on a building façade are important parameters to be considered, in addition to the wall porosity. This study provides new insights that enable improved design and control of operable façade elements to enhance space cooling using natural ventilation.

1. Introduction

Hybrid ventilation systems with operable façade elements designed and controlled to utilize the potential for cross-ventilation represent an area of significant interest in modern building design as they can substantially reduce energy consumption for cooling [1–3]. Hybrid ventilation systems can be described as two-mode systems using both passive and active features at different times of the day or season [4]. In these systems the cooling potential is variable (and often small), as it is driven by wind or thermal buoyancy forces. An additional element in mixed-mode ventilated buildings is night cooling, which makes use of the building's thermal mass and is applicable in many climates [5]. With cool outdoor air driven into the building at night, the thermal mass can be cooled to reduce the cooling load for the next day. These hybrid building systems require an integrated design approach, including façade optimization for solar heat gains and daylighting control, exposed thermal mass made possible by the structural design and interior space planning, together with improved understanding of the physics of ventilation to enable high performance. Even for a simple building geometry, naturally induced flows can be complex. Placement of operable elements on a façade requires careful consideration of (i) the exterior wind environment and its interaction with building components and (ii) basic characteristics of room airflow patterns, as these determine the magnitude of local heat transfer from building interior surfaces with significant thermal capacity (such as floor or ceiling concrete slabs) to the room air.

This paper focuses on wind-driven cross-ventilation, and addresses two issues, which are important to the use of natural ventilation as a feasible way of space cooling of buildings. The first involves the prediction of ventilation airflow rate and pattern and the second relates to the design of openings and particularly their size and location on a building façade. A schematic representation of wind-driven cross-ventilation in a single-zone building with two openings is shown in Fig. 1.

With respect to airflow rate prediction, a simple mathematical model, the orifice equation is commonly used for cross-ventilation analysis, although its accuracy is questionable [6–22]. Choiniere et al. [11] reported large discrepancies between measured and predicted airflow rates attributed to the use of pressures from measurements on sealed building surfaces. Seifert et al. [20] pointed out that the macroscopic orifice model under-predicts ventilation flow rates when a "stream tube" connecting the inlet and outlet is formed. Although the study provided an interesting theoretical insight into the physics of cross-ventilation, the CFD model used for the analysis was developed for uniform approaching flow conditions and was not validated against measured data for the ventilation airflow rate. Various alternative models have been proposed for configurations with large openings, namely the "*Power Balance Model*" by Murakami et al. [11], Kato et al. [14] and

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