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Passive air exchanges between building and urban canyon via openings in a single façade

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Abstract

The results of an experimental study examining the steady exchange of air and heat between a building and an urban canyon are presented. The focus is on the effect of the canyon aspect ratio on the airflow through openings made exclusively in one side of the building. The interaction of the external wind flow and the internal thermally-driven flow was shown to depend upon the ratio of the building height H_b to the canyon width W (distance between buildings forming the canyons). The trends observed as this aspect ratio (H_b/W) was varied allow for identification of canyon geometries that yield reduced or enhanced building ventilation airflow rates.

Keywords: Single-sided passive ventilation; Urban canyon; Laboratory modelling

1. Introduction

An urban canyon refers to the space formed by two typically parallel rows of buildings separated by a street and it forms the basic unit of modern cities. Passive, or natural, ventilation refers to the exchange of air between the interior of a building and the external environment that is driven by naturally-occurring pressure differences, i.e. without mechanical intervention. Convection induced by heat gains inside and incident on a building, and the action of wind provide the motive forces of natural ventilation, Etheridge and Sandberg (1996).

Airflows in urban canyons have been studied extensively as they provide a mechanism for pollutant dispersion, see, for example, the review by Vardoulakis et al. (2003). Besides the quality of outdoor air, indoor air quality (IAQ) has also received considerable attention in response to the increasing amount of time spent indoors by recent generations and to a heightened awareness of links between health, productivity and IAQ. The movement of air and heat, or other pollutants, within a ventilated space plays a key role in determining the IAQ. Predicting this movement in naturally-ventilated buildings using laboratory and theoretical modelling techniques has formed the focus of a number of studies, see the review by Linden (1999), Hunt and Kaye (2006).

Urban settlements are exposed to urban flows. The surface pressure imposed by the external flow on building walls and roofs yields an additional driving force to supplement the thermally-driven natural ventilation. The driving wind-induced pressure difference depends on the opening locations, and on the surrounding urban geometry, Hussain and Lee (1980). The difference in surface pressure typically present between windward and leeward or side façades (Baturin, 1972; Orme et al., 1994) generally results in a robust pressure drop that tends to drive a cross-ventilation flow (Aynsley et al., 1977) within the enclosure when openings are made in more than one façade.

Designs of naturally-ventilated buildings often incorporate low-level and high-level openings in order to harness the stack effect (Etheridge and Sandberg, 1996) associated

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with temperature differences between the interior and exterior environments. The typically warmer internal air rises to be exhausted through high-level openings. This outflow is balanced by an inflow of cooler ambient air through low-level openings. A so-called displacement flow is thereby established, Etheridge and Sandberg (1996).

Cross-ventilation of enclosures via a combination of high-level and low-level openings located in opposite (windward/leeward) façades in an urban canyon context has been studied experimentally by Syrios and Hunt (2007). We found that the presence of adjacent canyons can reverse the effect of the wind on the thermally-driven internal flow of an otherwise isolated building.

Occupied spaces situated in the urban environment often have access to the external environment via a single façade. The ventilation is then referred to as *single-sided* as air is expelled from the building and replacement air is drawn in to the building through a single side. Even for enclosures with openings on more than one façade, it may be preferential to limit connections to a single façade (e.g. linking to a courtyard), if, for example, the others link to polluted streets.

To date the internal (building) and external (canyon) flows have been studied mostly in isolation. The need to improve our understanding of their interaction and, in particular, of the exchanges between interior and exterior environments they induce provides the motivation for the current study. The effect of canyon flows on passive ventilation via high-level and low-level openings in a single side of a heated building is examined experimentally. Forced, rather than natural, single-sided ventilation has been studied experimentally and numerically by Moureh and Flick (2005). They found that, depending on the position of the horizontal inflow jet, a poorly ventilated region near the opposite wall may emerge.

The bulk of previous work on the natural ventilation of buildings has considered simplified building geometries and primarily isolated buildings as a means of enhancing understanding and predictive capability. As a starting point, flows within the simplified geometry of a single-spaced rectangular enclosure flanked by two symmetric urban canyons are studied herein. The ventilated building was empty. Detailed internal geometries (including furniture, appliances, etc.) have been considered in the comparative study of numerical models simulating thermally-driven ventilation alone by Jouvray et al. (2007).

Each canyon aspect ratio H_b/W (building height to street width) examined resulted in the building being subject to a mean wind-induced pressure difference but with that mean pressure difference varying with canyon aspect ratio. Despite pressure fluctuations induced by the impingement and separation of the external flow on the canyon's sharp edges (see Syrios, 2005) a quasi-steady state was established for all H_b/W considered. This was verified by consecutive measurements. For a building subject to a mean wind-induced pressure difference the effects of varying the heat source strength, the wind speed and the opening area (or building porosity) have been studied previously by Hunt and Linden (2001, 2005), Li and Delsante (2001), Gladstone and Woods (2001). The novelty of the current study lies in addressing the effect of changes in the external canyon geometry H_b/W on the ventilation flow and the known effects of heat source strength, wind speed and opening area are not reproduced herein.

In Section 2 the experimental technique applied to study the exchange of air and heat between building and canyon is outlined. Our experimental results that establish the effect of canyon airflows on single-sided building ventilation are given in Section 3 and the conclusions are drawn in Section 4. Arrows in figures indicate mean flow direction.

2. Methodology

The effect of neighbouring urban canyons on the single-sided ventilation of a building was studied using the 'salt-bath' technique: water was the working fluid and brine was used to achieve density differences. This technique has been used to successfully simulate thermally-driven building ventilation flows at small scale (Linden et al., 1990; Baker and Linden, 1991) and was extended by Hunt and Linden (1997, 2001) to include ventilation flows driven by combined thermal and wind forces.

By using brine, high Rayleigh number turbulent convection can be achieved at small scale. The reduced diffusivity of salt in water compared to the diffusivity of heat in air also ensures sufficiently high Peclet numbers despite the reduced model scale. Furthermore, the relatively large density differences that can be achieved by dissolving salt in water allow for high velocities through openings in the model and, hence, high Reynolds numbers. Approximate dynamical similarity can, thus, be achieved (Hunt and Linden, 1997) and measurements made in the laboratory provide useful insights to the flow at full scale and may be scaled to make predictions of, for example, airflow rates and thermal stratification.

A highly-insulated ventilated enclosure was represented by a clear Perspex box of length 598 mm and of 170 mm × 170 mm vertical cross section (internal height $H = 150$ mm). Two plastic boxes of the aforementioned external dimensions were positioned with their long sides parallel to, and on either side of, the long side of the Perspex box. The three boxes were suspended in the test section of an 8.6 m long, 0.6 m wide and 0.6 m deep recirculating water-filled flume with their long sides spanning the flume width. In this way, two symmetric and inverted urban canyons were formed, see Fig. 1. The plastic boxes could be translated and locked at ten predetermined positions along horizontal plastic boards which formed the streets between the buildings so that the canyon aspect ratio H_b/W ('building' height to 'street' width) could be varied between 1/5 and 2. The ventilation of an isolated enclosure was studied simply by removing the two plastic boxes, in which case $H_b/W = 0$.