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Wind-driven natural ventilation in a low-rise building: A Boundary Layer Wind Tunnel study

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ABSTRACT

Indoor Air Quality (IAQ), energy efficiency through passive building design strategies and sustainable construction practices have been highly prioritized in recent years. This paper presents a Boundary Layer Wind Tunnel study on wind-driven natural ventilation for a low-rise building at a model-testing scale of 1:20. The experiment consists of testing various size openings in a single wall, opposite side walls and adjacent side walls with and without portioning walls, with and without opening cover screens, with and without internal volume correction for 36 different wind angles of attacks (unless symmetrical). For the size of the building and openings considered, the experimental analyses indicated that internal volume correction using velocity scaling was important, although this criterion could be relaxed for cross-ventilation with openings in opposite walls. The internal pressure due to cross-ventilation was 1.5–2.5 times higher for $A_{inlet}/A_{outlet} > 1$ compared with ratios $A_{inlet}/A_{outlet} < 1$. In general, the lower the opening ratio (or inlet to outlet ratio), the higher the pressure drop inside the building. For an equivalent opening ratio, openings on opposite-walls generated a higher pressure drop compared to openings on adjacent-walls. Room-partitioning significantly affected the distribution of internal pressures, and hence the pressure drop that favored the ventilation in each room for the considered partitioning case. In addition, the total discharge coefficient C_{d_total} and the ventilation rate $Q/(V_rA)$ increased with an increase of the opening ratio. The inlet discharge coefficients obtained in this experiment ranged from 0.65 to 1.08, similar to the results of various early studies.

1. Introduction

Most households today use domestic equipment and appliances that operate with electric energy generated by non-renewable sources. Active (mechanical) ventilation systems are one of the most common residential-sector equipment used today for *indoor air quality (IAQ)* and human comfort, which have a high energy consumption cost. Many historical buildings have passive and natural ventilation systems that utilize thermal buoyancy and wind flow. With growing awareness of greenhouse-gas emissions and the rising cost of energy, wind-driven cross-ventilation can be considered as one of the potential alternatives to reduce the cost of energy consumption, and create acceptable *indoor environmental quality* (*IEQ*) in mild climates. Wind-driven air circulation inside a building depends on pressure differences and the design process of buildings. A thorough understanding and assessment of airflow mechanisms is required to effectively and optimally utilize wind-driven natural ventilation.

Wind and temperature differences between building environments are the major natural driving force natural ventilation systems rely on (*BSI*: 1991). For wind speeds beyond 1.8 m/s, thermal buoyancy can be neglected [21]. Full-scale measurement and numerical simulations show that buildings with wind-driven cross-ventilation have their indoor environment more comfortable than those without cross-ventilation [21]. *Computational fluid dynamics* (*CFD*) and field studies performed on a 3 and 4-room houses have also shown the opening performance in comparison with closed cases [21,30]. The effective ventilation of buildings and airflow in the built environment is highly correlated to the arrangement and configuration of buildings, room

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partitioning, location and size of dominant openings (i.e., doors and windows), topography, and wind direction [1,13,14]. This reveals that the potential of cross-ventilation for maximum *IAQ* and human comfort requires careful consideration regarding the size and location of inlet and outlet openings and vents, as well as room sizes [8,9,18].

The wind-building interaction often creates variation of pressures inside buildings, as well on buildings' envelopes. Numerous full-scale, *Boundary Layer Wind Tunnel (BLWT)* studies have been carried out to examine the external aerodynamics, and effects on *IAQ* and natural ventilation. However, detailed internal-aerodynamic information has been limited. Several parameters have been involved in the study of internal pressure, both for effective natural-ventilation and design-wind load [16]. These have included, but have not been limited to the shape of buildings, location and size of dominant openings, fluctuation of external pressure at the openings, relative upstream wind direction with respect to the dominant openings, internal volume and compartmentalization, natural ventilation openings, and background leakages due to construction cracks and outlet ducts [7,10,13,15,17,20,23,25,27,28]. Effects of compartmentalization due to room partitioning on internal pressures were studied by [17]; and ceiling partitioning effects by [3,15] also showed that the effect of opening size was of little significance if the leakage area was less than 10% of the windward-dominant opening area. A full-scale boundary layer and separately-performed numerical studies showed the sensitivity of internal pressure characteristics to the size of the dominant openings, as well as the size of the internal volume [6,11,24]. While the study by [10] and [15] incorporated internal volume scale correction to maintain dynamic similarity of wind tunnel model with its respective full scale model, the studies by [14] relaxed the volume corrections. Most of the previous studies were limited to a single internal volume case.

The main objective of this paper was to study the internal pressure dynamics for a low-rise building with a focus on cross ventilation for various door and window openings, soffit openings, a uniformly-distributed background leakage, and a realistic room partitioning arrangement. Internal volume correction was also systematically investigated to examine its relevance for low-rise cross ventilation application studies. The effects of door and window screens were also investigated.

2. Methodology

2.1. Test-building model and opening dimensions

A low-rise test-building model with a 5:12 hip roof slope constructed at a model scale of 1:20 was studied in *RWDI USA Inc. BLWT* in Miramar, Florida. *RWDI USA, LLC's* Wind Tunnel had a cross-sectional area of 2.13 m × 2.44 m (7 ft. × 8 ft.), and the test-building model was placed on a turntable at a 13.3 m (43.5 ft.) distance from the tunnel's entrance. The model was constructed from a Plexiglas sheets. The test-building model had an equivalent full-scale plan dimension of $L = 15.44$ m (50.67 ft.) by $W = 7.92$ m (26.00 ft.) with a roof eave height of $h_1 = 2.49$ m (8.17 ft.). The total effective height of the building level was 4.57 m (15 ft.) (i.e., the building had an attic room with height $h_2 = 2.08$ m (6.83 ft.) (Refer to Fig. 1)).

The building had a number of dominant openings (doors and windows), soffit vents, and uniformly-distributed background leakages. All the dominant openings and vents were a replica of a typical low-cost, full-scale low-rise building in South Florida, USA. In addition, the external envelope of the building had uniformly distributed circular holes (1.6 mm in diameter) to represent a background leakage due to cracks and joints. The background leakage was set at 0.1% of the respective envelope surface area for

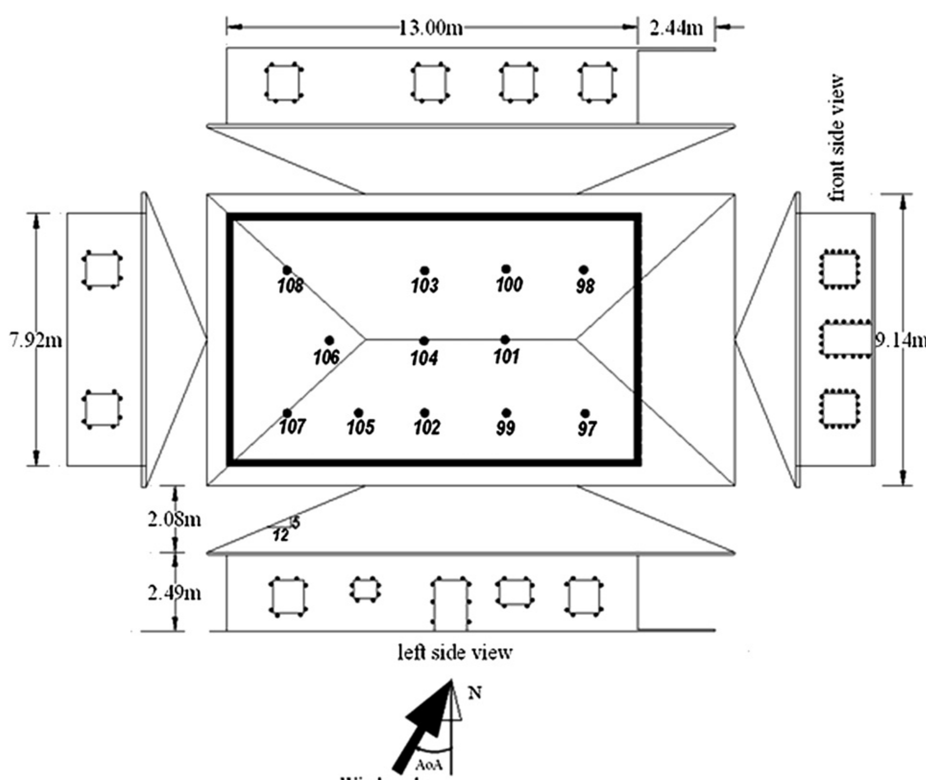

Fig. 1. Exploded view of building model with external and internal pressure taps layout and location of dominant openings. (Dimensions given at full scale).