Journal of Wind Engineering & Industrial Aerodynamics 179 (2018) 449–462

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

Two-dimensional numerical simulation of wind driven ventilation across a building enclosure with two free apertures on the rear side: Vortex shedding and “pumping flow mechanism”

Huai-Yu Zhong [a,b,c], Dong-Dong Zhang [a,b,c], Di Liu [d], Fu-Yun Zhao [a,b,c,*], Yuguo Li [e], Han-Qing Wang [f]

[a] Key Laboratory of Hydraulic Machinery Transients (Wuhan University), Ministry of Education, Wuhan, Hubei Province, China
[b] Hubei Key Laboratory of Waterjet Theory and New Technology (Wuhan University), Wuhan, Hubei Province, China
[c] School of Power and Mechanical Engineering, Wuhan University, Wuhan, Hubei Province, China
[d] College of Pipeline and Civil Engineering, China University of Petroleum, Qingdao, Shandong Province, China
[e] Department of Mechanical Engineering, The University of Hong Kong, Pokfulam Road, China
[f] School of Civil Engineering, University of South China, Hengyang, Hunan Province, China

ARTICLE INFO

Keywords:
Wind-driven natural ventilation
Single-sided fluid flow
Vortex shedding
Numerical simulations

ABSTRACT

This paper investigates the single-sided wind driven natural ventilation with two apertures on the rear wall, regarding different horizontal aperture separations, magnitudes of incoming wind speed and various side ratios (*L/D*, length/width). In the present work, CFD simulations are performed with Reynolds-Averaged Navier-Stokes (RANS) approach, and pressure correction linked equation is adopted to provide closure. The simulation results indicate that wind flow behind the rear wall is essentially driven by the pumping mechanism due to vortex shedding, in which wind flow direction alternates at a mean rate. The frequency of the “pumping” flow increases dramatically with the wind flow velocity at a wide range of Reynolds numbers. The decrease of free aperture separation reduces the enclosure flow rate whilst the frequency of the wind flow almost maintains at a constant value. The increase of sidewall length has similar impacts on the ventilation frequency and the dimensionless ventilation flow rate. Numerical investigations further demonstrate that non-dimensional ventilation rate can be promoted by increasing incoming wind velocities when the wind speed is less than 5 m/s. This promotion will be restrained when the wind speed is further increased. The simulation results of built enclosure flow rate, frequency of enclosure flow can be applied to improve the ventilation performance of buildings merely with rear wall openings.

1. Introduction

Energy demand and consumption have been increasing worldwide, which has resulted in huge negative impacts on our dwelling environment. In the contemporary world, buildings are one of the largest contributors to energy consumption due to lighting, ventilation, air conditioning, domestic and commercial appliances. Natural ventilation could be an efficient way to save the energy consumption of buildings and to provide better thermal comfort and good indoor air quality for people (Chenari et al., 2016).

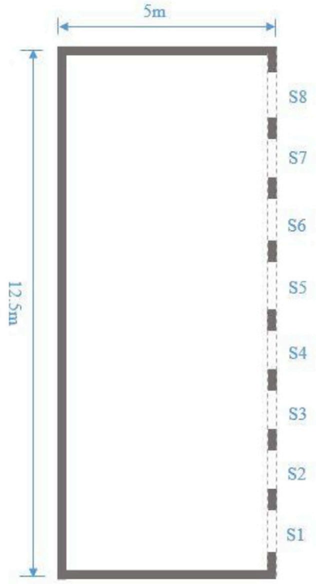
The two main predominant mechanisms for natural ventilation are wind pressure and temperature differences. Wind-driven flow is dominant in building ventilation unless the wind is negligible and/or the temperature differences are large enough. In this paper, since the wind pressure effect is dominant, only wind-driven natural ventilation is considered and buoyancy driven ventilation or the interaction between buoyancy and wind is not discussed.

Regarding wind driven natural ventilation, cross ventilation and single-sided ventilation are two representative ventilation configurations. Many former published investigations focused on cross ventilation due to its effective ventilation configurations, which ensure relatively large flow rates (Ayad, 1999; Ohba et al., 2001; Chu et al., 2009; Visagavel and Srinivasan, 2009; Cheung and Liu, 2011; Bangalee et al., 2012; Ramponi and Blocken, 2012). However, in modern city, large and thick building shapes, security requirement and privacy concerns often impede the design of cross ventilation. Thus, in some situations when the rooms

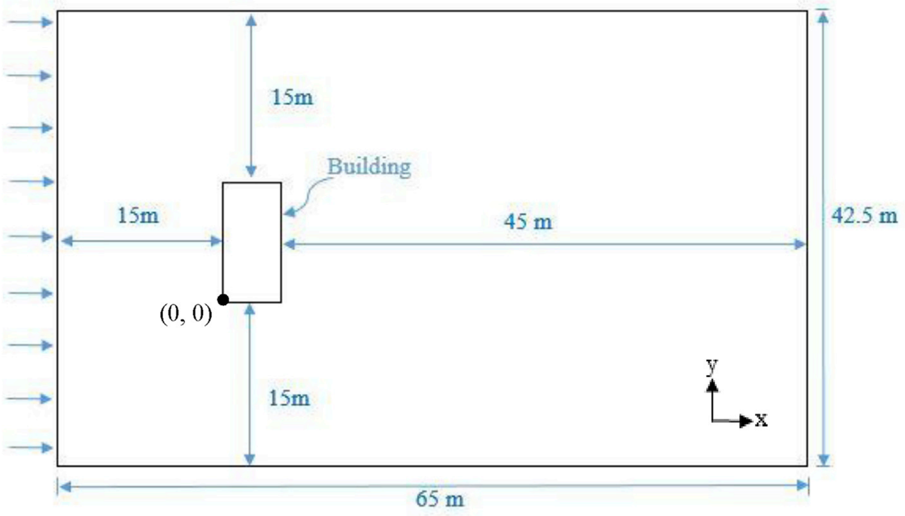
---

* Corresponding author. School of Power and Mechanical Engineering, Wuhan University, Dong-Hu Southern Road, 430072, Wuhan, Hubei Province, PR China.
E-mail addresses: liudi66@163.com (D. Liu), fyzhao@whu.edu.cn (F.-Y. Zhao).

https://doi.org/10.1016/j.jweia.2018.07.002
Received 13 January 2018; Received in revised form 1 July 2018; Accepted 1 July 2018



(a) 2-D profile of building sketch



(b) Computational domain of natural ventilation

Fig. 1. General presentation of the investigated building arrangement and its numerical wind tunnel domain, (a) 2-D profile of the building sketch and (b) the computational domain of natural ventilation.

do not have opposing windows, single-sided ventilation becomes an acceptable mode in spite of its lower efficiency (Allocca et al., 2003).

In terms of the physical configurations, single-sided ventilation can be divided into single-aperture ventilation (SS1) and multiple-aperture ventilation (SSn). For SS1, the unique opening serves as inlet and outlet simultaneously; whereas, for the situation of SSn, inlet and outlet can be clearly divided, and this configuration will probably give a more efficient supply of fresh air.

There exist some researches on the SS1 (Cockroft and Robertson, 1976; Dascalaki et al., 1995, 1996; Yamanaka et al., 2006). Cockroft and Robertson proposed a theoretical model to predict the airflow rate of an enclosure through a single opening (Cockroft and Robertson, 1976). Dascalaki et al. (1995) experimentally investigated 52 single sided ventilation configurations and compared their airflow rates with the predictions of natural ventilation models. They also carried out four single sided natural ventilation experiments to derive the average airflow rate through the opening by the technique of tracer gas decay (Dascalaki et al., 1996). Yamanaka et al. (2006) validated the pulsation theory and mixing layer theory by a wind tunnel test and they correlated an equation from their experimental results to predict air flow rate through an opening. The airflow rate of the single sided ventilation has been predicted by a numerical model, theoretical definition, or on-site experiment. In addition to analytical and experimental methods, CFD approach has also been widely applied to predict SS1 flow due to its acceptable accuracy and convenience. Caciolo et al. (2012) used both LES and RANS methods to predict the complex flow generated by the interaction of buoyancy and wind in single side-sided ventilation with only one opening. Their simulation results were compared with experimental data and there was little discrepancy for LES method. Ai et al. utilized RANS method with RNG k - ε model to provide a sensitivity analysis of some important computational parameters that may affect the prediction accuracy of SS1 flow (Ai and Mak, 2014a).