Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 198 (2017) 758 – 769

Procedia Engineering

www.elsevier.com/locate/procedia

Urban Transitions Conference, Shanghai, September 2016

The influence of building packing densities on flow adjustment and city breathability in urban-like geometries

Lan Chen[a], Jian Hang[a]*, Mats Sandberg[b], Leif Claesson[b], Silvana Di Sabatino[c]

[a]School of Amopheric Sciences,Sun Yat-sen University,Xingang Xi Road 135, HaiZhu, Guangzhou 510275, China
[b]Laboratory of Ventilation and Air Quality, University of Gävle, SE-80176 Gävle, Sweden
[c]Department of Physics and Astronomy - DIFA, ALMA MATER STUDIORUM - University of Bologna, Viale Berti Pichat 6/2, 40127 Bologna

Abstract

City breathability refers to the air exchange process between the flows above and within urban canopy layers (UCL) and that of in-canopy flow, measuring the potential of wind to remove and dilute pollutants, heat and other scalars in a city. Bulk flow parameters such as in-canopy velocity (Uc) and exchange velocity (U_E) have been applied to evaluate the city breathability. Both wind tunnel experiments and computational fluid dynamics (CFD) simulations were used to study the flow adjustment and the variation of city breathability through urban-like models with different building packing densities.

We experimentally studied some 25-row and 15-column aligned cubic building arrays (the building width B=72mm and building heights H=B) in a closed-circuit boundary layer wind tunnel. Effect of building packing densities (λ_p=λ_f=0.11, 0.25, 0.44) on flow adjustment and drag force of each buildings were measured. Wind tunnel data show that wind speed decreases quickly through building arrays due to strong building drag. The first upstream building induces the strongest flow resistance. The flow adjustment length varies slightly with building packing densities. Larger building packing density produces lower drag force by individual buildings and attains smaller velocity in urban canopy layers, which causes weaker city breathability capacity.

In CFD simulations, we performed seven test cases with various building packing densities of λ_p=λ_f=0.0625, 0.11, 0.25, 0.36, 0.44 and 0.56. In the cases of λ_p=λ_f=0.11, 0.25, 0.44, the simulated profiles of velocity and drag force agree with experiment data well. We computed U_c and U_E, which represent horizontal and vertical ventilation capacity respectively. The inlet velocity at 2.5 times building height in the upstream free flow is defined as the reference velocity U_{ref}. Results show that U_E/U_{ref} changes slightly (1.1% to 0.7%) but U_c/U_{ref} significantly decreases from 0.4 to 0.1 as building packing densities rise from 0.0625 to 0.56. Although U_E is induced by both mean flows and turbulent momentum flux across the top surface of urban canopy, vertical turbulent diffusion is found to contribute mostly to U_E.

Peer-review under responsibility of the organizing committee of the Urban Transitions Conference

Keywords: City breahability; Exchange velocity; In-canopy velocity; Flow adjustment; Building packing densiy

* Corresponding author. Tel.: +86 20 8411 0375; fax: +86 20 8411 0375.
E-mail address: hangj3@mail.sysu.edu.cn

Peer-review under responsibility of the organizing committee of the Urban Transitions Conference
doi:10.1016/j.proeng.2017.07.127

1. Introduction

In 2011, more than half of world population (about 3.5 billion) live in cities, and the percentage is predicted to reach 60% (about 5.0 billion) by 2030[1]. The rapid urbanization worldwide and the increasing vehicle emissions in cities have raised environmental concerns on urban air quality[2-4] and urban heat island with respect to the increasing urban energy consumption for summertime cooling [5,6]. Improving urban/city ventilation has been confirmed one of the effective technique in improving urban air quality and reduce urban heat island intensity[7-14].

Thus, recently more ventilation concepts have been applied to measure the capacity of UCL (urban canopy layer) ventilation. It is based on the assumption that the surrounding air is relatively cleaner or cooler, then the air exchange between the external flows and that of the in-canopy flow can bring clear air into cities (inhale effect) and remove pollutants or heat out (exhale effect) — hence the "city breathability". The capacity of city breathability is confirmed with respect to the urban airflow patterns resulting from the interaction between the approaching atmospheric flow and urban morphologies. Horizontal mean flows, vertical mean flows and vertical turbulent diffusions are verified to make significantly contributions. The city breathability (or part of it) can be evaluated by various bulk flow parameters and ventilation indices such as volumetric flow rate, air change rate per hour [24-25, 29-30, 32], purging flow rate, pollutant retention time [10, 34], age of air, ventilation efficiency [25-27, 29], net escape velocity [36], exchange velocity and in-canopy velocity [48-52] etc. Specially, as first originated by Bentham and Britter [48], the concept of exchange velocity (U_E) represents the average velocity of scalar transfer out of or into the UCL at a interface plane (i.e. roof level) between the in-canopy and above-canopy flows, measuring the overall vertical ventilation induced by mean flows and vertical turbulent diffusion. Besides for quantifying the horizontal dilution capacity, the in-canopy velocity (U_C) is defined as constant within the urban canopy layer rather than a velocity profile in street canyons. Then U_E and U_C were later introduced into CFD simulations to successfully estimate the overall capacity of vertical exchange and horizontal dilution in idealized or realistic urban areas [49-52].

According to Belcher et al. [53], the "adjustment region" is downwind of the windward UCL boundaries and below UCL rooftop where the horizontal flow substantially decelerates and a fraction of air is driven out upwardly across UCL roofs (i.e. U_E and U_C changes horizontally). Then it comes into the "canopy interior" region [53] or the "fully-developed region" [32], where a local balance is established between downward transport of momentum by turbulent stresses and removal of momentum by the drag of the canopy elements (i.e. U_E and U_C keep constants).

Defined by Grimmond and Oke [54], the building planar area index λ_p (i.e. the ratio between the planar area of buildings viewed from above and the total floor area) and the frontal area index λ_f (i.e. the ratio of the frontal area of buildings to the total floor area) are usually adopted to quantify urban compactness (Fig. 1). The ratio of street height to width has been proved to affect the street flow pattern. When the buildings space sparsely, there is good ventilation but low land utilization. Denser city layout means a higher land-use but may experience worse UCL ventilation [25-28]. In this context, we aim to attain the influence of building packing densities (λ_f varies from 0.0625 to 0.56) on the capacity of vertical ventilation (U_E) and horizontal dilution (U_C) within and through urban canopy layers. Such researches have been rarely reported.

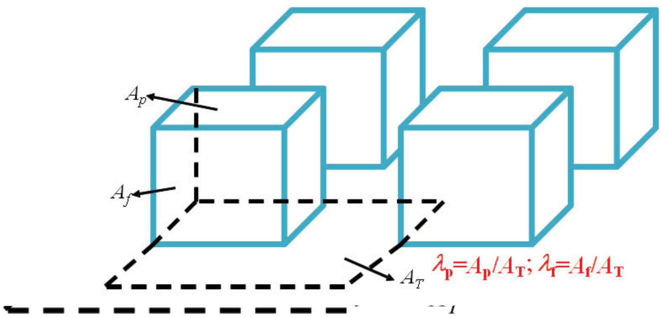

Fig.1 Definition of planar area index λ_p and frontal area index λ_f