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From street canyon microclimate to indoor environmental quality in naturally ventilated urban buildings: Issues and possibilities for improvement

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ABSTRACT

Many buildings in urban areas are more or less naturally ventilated. A good understanding of the current status and issues of indoor environmental quality (IEQ) in naturally ventilated urban buildings and the association with urban microclimate is fundamental for improving their IEQ. This paper reviews past studies on (a) the microclimate in urban street canyons, (b) the potential influence of such microclimate on IEQ of nearby naturally ventilated buildings, and (c) the real-life IEQ status in these buildings. The review focuses mainly on studies conducted by on-site measurements. The microclimate in urban street canyons is characterized by low wind speed, high surface temperature difference, high pollutant concentration, and high noise level. Insufficient ventilation rates and excessive penetration of outdoor pollutants are two key risks involved in naturally ventilated urban buildings. Existing knowledge suggests that reasonable urban planning and careful building envelope design are the primary methods to ensure acceptable IEQ and maximize the utilization of natural ventilation. However, quantitative studies of both microclimate in street canyons and IEQ in buildings are still highly insufficient in many aspects, which make cross comparison and influencing factors analysis currently impossible. Based on the limitations of previous studies and the current issues of naturally ventilated urban buildings, suggestions are made for future studies to better understand and improve IEQ in naturally ventilated urban buildings.

Contents

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1. Introduction

Many buildings in a wide spectrum of geographical regions are more or less naturally ventilated, primarily because of the well-known advantages of natural ventilation in energy saving and health effect. Driven by wind and buoyancy forces [1–3], natural ventilation has a great potential to offset energy consumption by mechanical ventilation systems [4–8]. Compared to air conditioned buildings, naturally ventilated buildings are closely associated with reduced prevalence of sick building syndrome symptoms, cross-contamination risk of airborne infectious diseases, and short-term sick leave [9–15]. However, some buildings are naturally ventilated, essentially because their windows or doors have to be open to connect indoor with outdoor. Shops on the ground floors need open doors for business. Ordinary residential and school buildings must open windows or ventilation grilles, at least intermittently, to dilute indoor stale air, because ordinary domestic air conditioners provide no fresh air [16]. It was reported that continuous operation of such air-conditioners with closed windows and doors will rapidly elevate the indoor CO_2 concentration [17,18] and result in a deteriorated indoor air quality [8,19]. Regardless of intentions, the wide existence of natural ventilation in urban buildings highlights the need to pay special attention to their indoor environmental quality (IEQ).

IEQ in naturally ventilated buildings strongly relies on local outdoor microclimate, including particularly wind speed, air temperature, pollutant concentration and noise level [11,20–22]. Fig. 1 presents schematically the association between IEQ in naturally ventilated buildings and the microclimate in their nearby street canyon through the breath process at building envelopes. Wind speed in urban areas, especially in high-density cities, is seriously decreased [23]. Climatic data shows that wind speed at 20 m above the ground level in urban area of Hong Kong (specifically in Tseung Kwan O) has decreased from 2.5 m/s to 1.5 m/s over a 10-year period from 1994 to 2004 [24]. Low wind speeds in street canyons result in less pressure differences around buildings to drive indoor natural ventilation. It was reported that air temperature inside a street canyon is lower by 3–5 °C than the corresponding air temperature above the canyon [25] and is higher by nearly 2 °C than that in a suburban location [25,26]. In addition, traffic-related air pollution and noise are two serious environmental issues in urban street canyons. Owing to increased traffic emissions and adverse dispersion conditions including low wind speeds [27,28], pollutants can stagnate and accumulate to reach very high levels in street canyons [29–33]. Moreover, road-side noise levels measured in street canyons frequently exceed the legislated limit of 70 dBA [34–36]. Together with low wind speeds and high air temperature, such high pollutant concentrations and high noise levels could significantly deteriorate IEQ in naturally ventilated urban buildings and even hinder its use [21].

A good understanding of urban microclimate and the associated IEQ status in naturally ventilated urban buildings is fundamental for improving their IEQ. This paper provides an overview of past studies on the microclimate in urban street canyons and the associated IEQ in naturally ventilated urban buildings. To do so, it investigated relevant publications in related journals, including particularly *Building and Environment* and *Atmospheric Environment*. Major books regarding natural ventilation and urban environment were also investigated. Among these numerous publications, this paper further focused on studies conducted by on-site measurements, whereas studies by model experiments, numerical simulations, empirical and analytical models were paid little attention. On-site measurements were focused, essentially because they provide the first-hand data to reveal the real-life street canyon microclimate and IEQ in buildings, which are thus the best choice to answer the research questions defined in this paper (see next paragraph). Model experiments, such as atmospheric boundary layer wind tunnel experiments, use reduced-scale models to investigate the basic structure of flow and pollutant dispersion around building(s) and provide benchmark data for numerical validations, which, however, are constrained by similarity criteria [37]. Numerical simulations, such as computational fluid dynamics (CFD) simulations, are very powerful and widely used to investigate flow related processes in the built environment, which can provide whole-field data and do not have similarity problems [38,39]. However, both model experiments and numerical simulations use simplified physical models and cannot take the influence of all environmental parameters into account. Empirical models provide a rapid but crude estimation normally for engineering applications, while analytical models increase the understanding of physical mechanisms but are limited to very simple flow problems.

Reviews in this paper is intended to answer three questions: (a) what are the urban microclimate conditions around buildings and their possible influences on IEQ in naturally ventilated buildings; (b) what are the actual indoor environmental conditions in naturally ventilated buildings in urban areas; and (c) what are the limitations of current studies and the possible areas for future

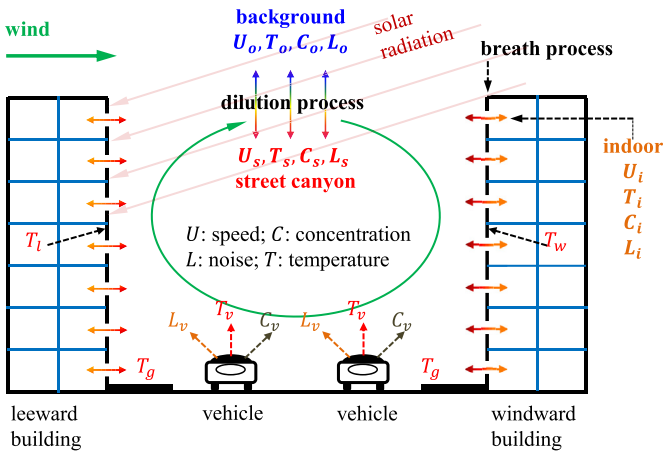

Fig. 1. Schematic view of the association between the IEQ in naturally ventilated buildings and the microclimate in their nearby street canyon; the subscripts *o*, *s*, *i*, *v*, *w*, *l*, and *g* of the *U*, *T*, *C*, *L* indicate outside the canyon (background), street canyon, indoor, vehicle, windward facade, leeward facade, and ground, respectively.