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The Physics in Natural Ventilation of Cities and Buildings

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EXTENDED SUMMARY

Asian cities are mostly taller, denser, deeper and larger than those in the West, and the magnitudes of building drag or urban heat island circulation and their effects on city ventilation are also stronger. The physics of urban climate in these large cities is complex, as a combined result of local circulation and synoptic winds modified by the mountainous topography and land/sea breeze, if any. Natural ventilation of a city refers to the penetration and distribution of rural air into an urban canopy layer. The weakened city ventilation has become one major reason for worsening urban warming and air pollution in cities. Two distinct situations need to be considered, i.e. when the synoptic wind is strong; and when the synoptic wind is weak respectively. For the former, designers are interested to manage city ventilation for removal of the urban heat, moisture and pollutant, or retain of urban heat and moisture. The latter become mostly the conditions for the worst urban extreme heat or haze scenarios to occur. Natural ventilation of a building refers to the introduction of outdoor air into a building by natural forces such as wind and buoyancy. High-rise buildings present an interesting challenge as the top of the building may be in the urban roughness layer or even beyond the atmosphere boundary layer.

Many excellent review papers exist on relevant urban airflows (e.g. Roth, 2000, Britter and Hanna 2003, Arnfield, 2003, Belcher 2005), but not specifically on city ventilation. City ventilation is mainly driven by winds and buoyancy forces such as slope flows, sea-land breezes, etc. The importance of city ventilation may be seen by long recognition that the restricted air flows were the causes of the all major pollution disasters (Brimblecombe and Sturges, 2009). Rigby et al (2006) presented a rose analysis showing the influence of boundary layer ventilation. The wind speed in London is often found to be lower than in a rural area, whilst occasionally accelerated due to urban heat island effects (Lee, 1979).

The purpose here is to review the status of our understanding of the physics in city ventilation under both strong and weak wind conditions. It is known that understanding the urban air flows in calm wind conditions is crucial, as most urban heat wave and severe air pollution episodes occur when wind calmness and inversion coexist, leading to formation of a heat dome or urban heat island circulation. Heat dome comprises a convergent inflow at the lower atmospheric level, divergent outflow at the upper, and a dome-shaped flow field resulting from entrainment and overshoot at the top. Numerous field studies worldwide have confirmed the existence of UHIC during the day and night in many cities. It is interesting that though a strong wind would destroy the heat dome and breakup the inversion, a weak wind may only elongate the dome to become a plume or dome shadow, transport the pollutant downstream to other cities. How such a weak wind impact on the dome formation has not been well studied.

Examples given here including wind weakening phenomenon in a dense high-rise city (Peng et al. 2018), the roles of heat dome formation on urban extreme high temperature events,

spread of SARS CoV virus when there is inversion, and the urban heat domes (Fan et al 2017) and their merging (Fan et al 2018). Different methods are available for investigation, i.e. simple theoretical estimates (Fan et al 2017), water tank models (Fan et al 2016), city scale CFD (Wang and Li, 2016), and meso-scale WRF (Wang et al 2017).

It is concluded that there is a need to establish the need and an approach for designing city climate and environment as for buildings, for example, designing building density and height in a city for better urban climate, and between-city distance needed to avoid regional haze formation.

KEYWORDS

Natural ventilation, city ventilation, fluid mechanics, heatwave, heat dome, urban climate

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