The Influence of Street Canyon Design on Hospital Air Quality

Marco-Felipe. King[1,*] and Catherine J. Noakes[1]

[1] PaCE Institute, School of Civil Engineering, University of Leeds, Leeds, UK.

[*]Corresponding email: m.f.king@leeds.ac.uk

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Abstract

This study considers air exchange between outdoor and indoor environments in the context of a hospital room with single-sided natural ventilation. Computational fluid dynamics (CFD) simulations are used to examine the trade-off between outdoor pollutant ingress and indoor contaminant dilution, and the influence of the street canyon design.

Two street-canyon aspect ratios were investigated (Height/Width=0.5 and 1) with roof angles of zero and 26.6º. An open window was located on the on the leeward side connecting to an interior room. ANSYS Fluent 15 was used to model airflow in the indoor and outdoor spaces and employed a k-omega turbulence model. A tracer was released in the outdoor location between the buildings and concentrations determined inside the open window. A second tracer released inside the building was used to establish concentrations at the pedestrian level outside.

Increasing canyon width reduced the residence time of the outdoor pollutant and reduces ingress. Flat roofs for both ratios drew the tracer to the leeward side of the building due to negative pressures. However, pitched roofs created more complex systems that reduced contaminant in the canyon due to unsteady vortices. Contaminants released inside the room result in proportionally higher concentrations outside for narrow canyons.

INTRODUCTION

The importance of urban airflow on hospital ventilation is an area of crucial but challenging research (Tang et al., 2006). Although USA guidance recommends mechanical ventilation, in the UK and many other countries natural ventilation is advocated as an energy efficient approach to ventilating some areas of hospital buildings, particularly patient rooms (Department of Health Estates and Facilities Division, 2008). While natural ventilation has been shown to provide effective ventilation with good levels of dilution (Escombe et al., 2007; Gilkeson et al., 2013), there are concerns that poor air quality in urban environments may counter the benefits of diluting indoor contaminants. Investigating the trade-off between pollutant ingress into hospitals, through single-sided natural ventilation, and pathogen egress is fundamental in understanding the indoor/outdoor environment nexus.

METHODOLOGY

The CFD package ANSYS Fluent 15 was used to investigate contaminant dispersion in and around 3D street-canyons (Figure 1.). Four cases similar to (Barlow and Leitl, 2007) were studied in a domain of 120mx24mx30m: Aspect ratios (Height/Width=0.5 and 1) and two roof angles (flat and 26.6º) were chosen. Building height was 5m from ground to eves in all cases.

An open window (1m x 0.5m) was positioned on the leeward façade of the second row of buildings leading to a hospital room inside (4.6 m x 4.6m x 4.6m).

The atmospheric boundary layer profile was modelled with a reference velocity of 6m/s at eve height. Pressure-Outlet conditions were 0Pa. NO_2 was released continuously from a volume source at ground level in the second street canyon (source A) and relative concentration was measured inside the building. To represent an indoor contaminant, a CO_2 source was located inside the hospital room (source B) and relative concentrations measured at pedestrian level in the adjacent street canyon. Source strength in both cases was given a value of 1 as relative differences were investigated.

Mesh cell count was ~3.5 million after mesh sensitivity analysis. The k-omega SST turbulence closure with standard wall-functions was solved via the SIMPLE algorithm with second order accuracy for all variables under steady state. Three vortex generators (1m high) were introduced upwind of the canyons to create building induced turbulence. Results were considered converged when continuity residuals reached 1E-6 for 100 iterations.

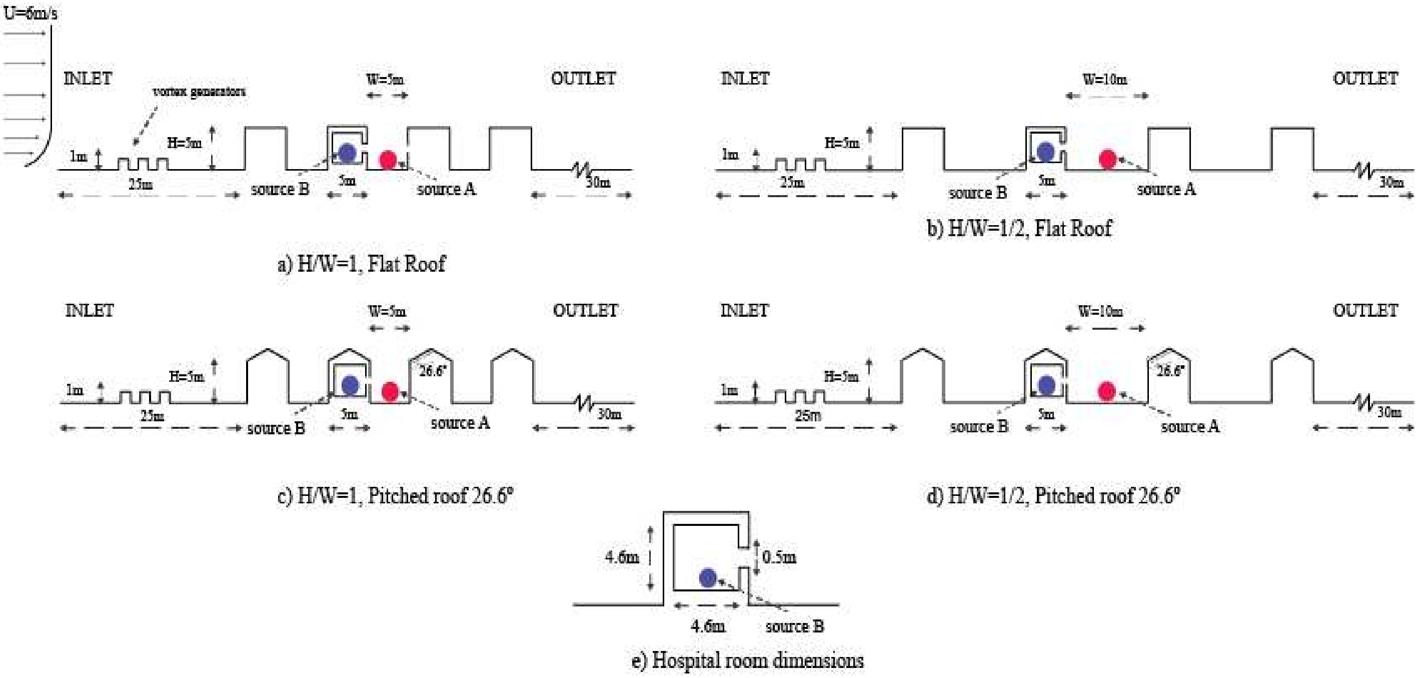


Figure 1. 2D representation of case set-up

RESULTS AND DISCUSSION

Figure 2. shows velocity vectors around the four canyon shapes. Complex turbulent structures are apparent within the narrower canyons, in particular in those containing buildings with pitched roofs.

Figure 3. shows contour plots of mass fraction of NO_2 on the central vertical plane released from source A in the four cases. NO_2 is drawn to the leeward side of the building where the window is located due to negative pressures on the façade. This facilitates ingress into the hospital room in all cases. However, pitched roofs created more complex systems that reduced contaminant in the canyon (Figure 3d) due to unsteady vortices but increase indoor concentration in the case with a narrow canyon (Figure 3b).

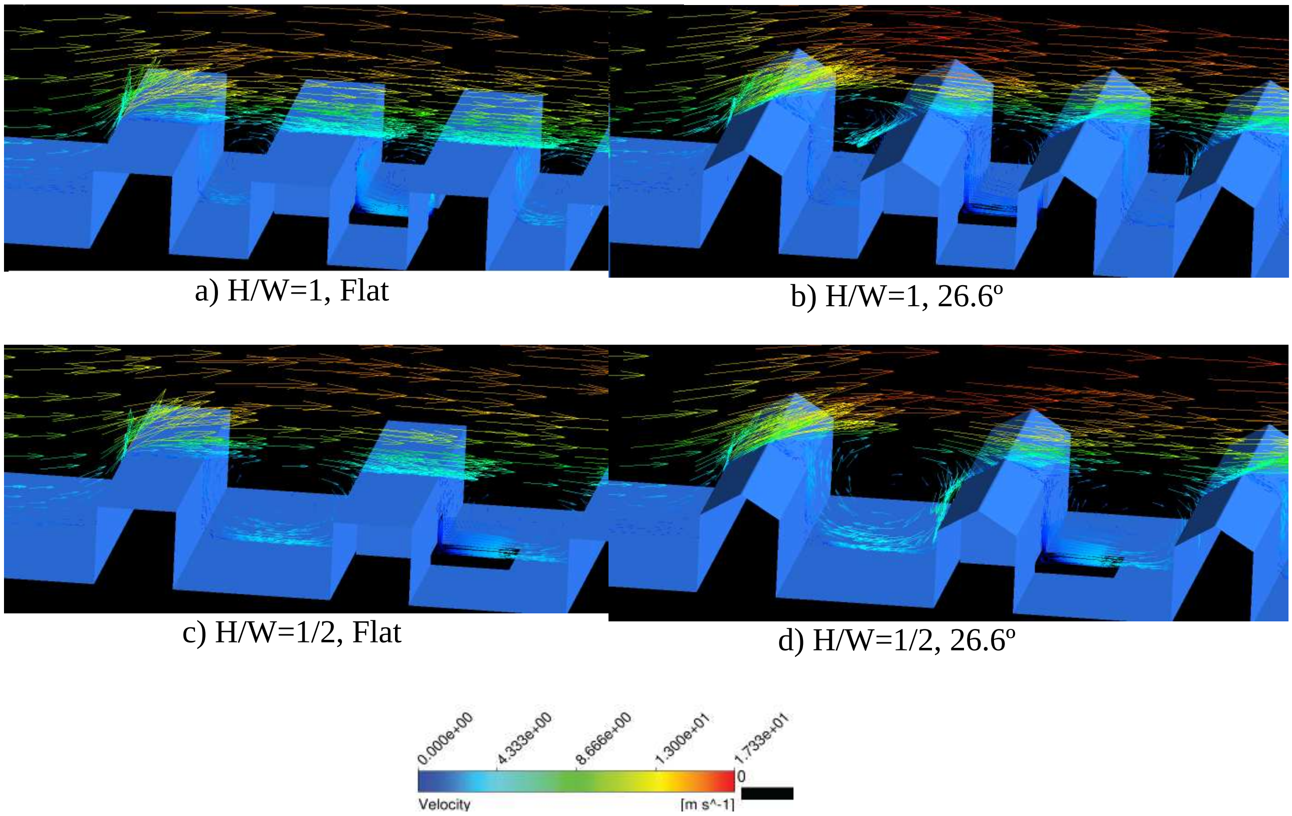


Figure 2. Velocity vectors in the four canyon shapes

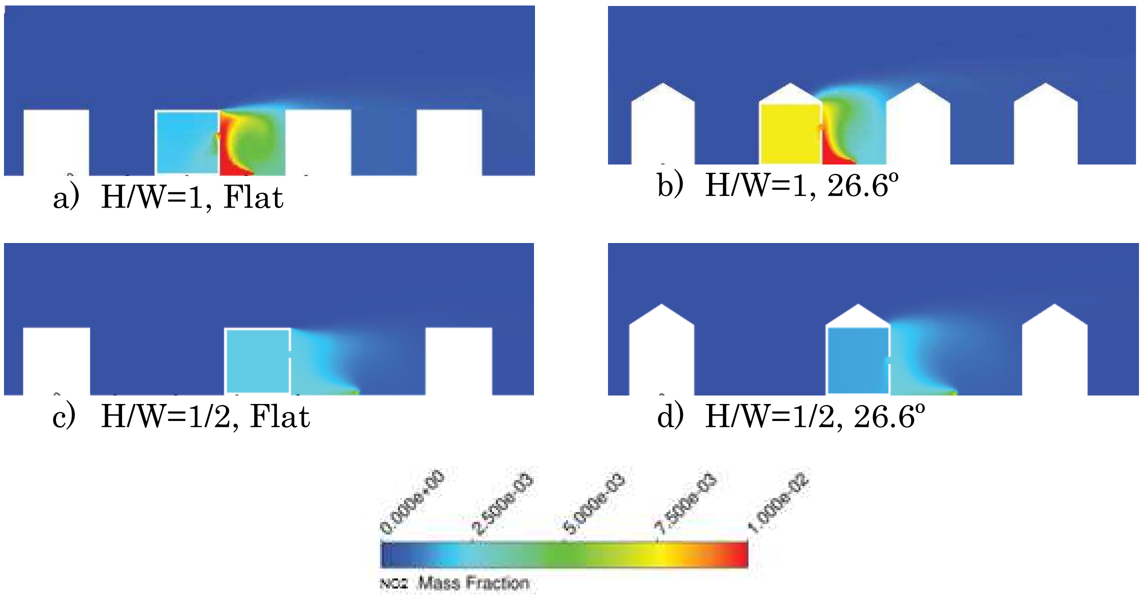
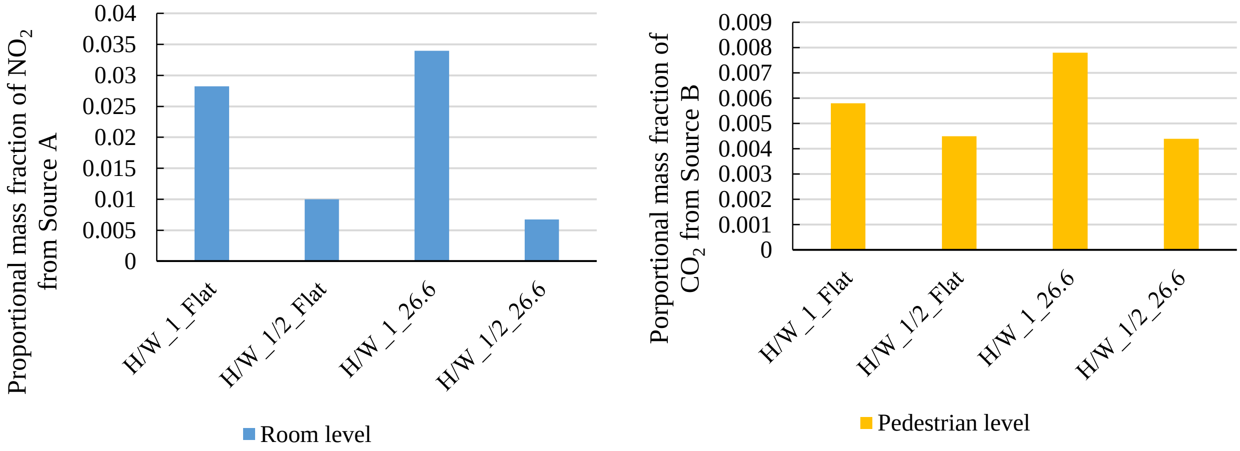


Figure 3. CFD contour plots of mass fraction of NO_2 released from Source A

Figure 4. a) and b) show graphs of mass fractions of contaminants comparing relative ingress and egress quantities. Doubling canyon width decreases ingress by more than a factor of three from street to inside (Figure 4a). On the other hand proportional egress of contaminants is reduced by a factor of less than 1.8 at best (Figure 4b). The impact of building design could be related to quanta concentration of a particular disease such as TB giving a quantitative metric through the application of the Wells-Riley infection transmission mathematical model (Noakes and Sleigh, 2008).



a) NO_2 inside the room from outside b) CO_2 at pedestrian level from the room

Figure 4. Graphs showing proportional mass fraction of NO_2 and CO_2 against source strength inside the room and at pedestrian level respectively.

CONCLUSION

Contaminants are found to be entrained by the turbulent eddies close to the leeward side of the buildings in all cases but predominantly within narrower canyons. Pitched roofs with wider canyons improve pollutant dispersal due to turbulent detachment at the apex. This has a result of increasing the height of the recirculation zones and decreasing ingress into the building envelope. Potential risk to pedestrians could be exacerbated when hospital windows are opened in narrow canyons, therefore investigating building shape and window design could be mitigating factors.

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