# Effects on Courtyard Ventilation caused by Openings

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## Why we did it

- Within the urban environment, courtyards act as areas of recreation for citizens
- In the surrounding of courtyards, large amounts of air pollutants are emitted threatening people's health
- Deep understanding of local ventilation effects are crucial for urban planning and design to keep pollutants out of courtyards
- Former studies of courtyard ventilation focused only on isolated structures (Hall, 1999)

→ **How do openings influence the ventilation of courtyards in a turbulent wind field?**

## How we did it

- LES simulation of an idealized building array, using the model PALM
- Neutral condition with a mean flow along x direction
- Cyclic boundary conditions to ensure turbulent inflow conditions
- 3 cases using a different aspect ratio (AR): 1.0, 3.0, 0.3
  Definition: AR = height of courtyard / width of courtyard
- Passive scalar emitted along the streets
- Spatial resolution: 0.4m, building height: 20m, opening size: 4m x 4m

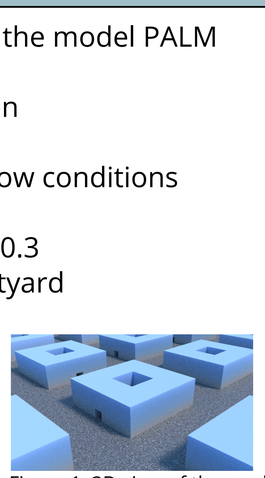


Figure 2: Model domain for (a) AR=1 and AR=3, and for (b) AR=0.3



Figure 1: 3D view of the model domain

## Validation

- Validation was done simulating a single closed courtyard and comparing the mean wind speed with results from literature
- According to Hall et al. (1999) and Ryu and Baik (2009), PALM gives very similar results for u using 1m grid resolution

Definitions:

H : building height
$u_{ref}$ : u at height H
Δ : gird width in x, y, z direction
$s_B$ : background concentration

- Comparing simulations of different Δ shows that Δ=0.4m sufficiently resolves the flow within the courtyard as well as the flow through th opening

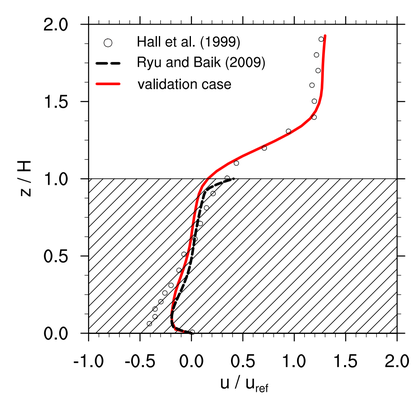


Figure 3: Vertical profile of normalized wind velocity at the center of a closed courtyard.

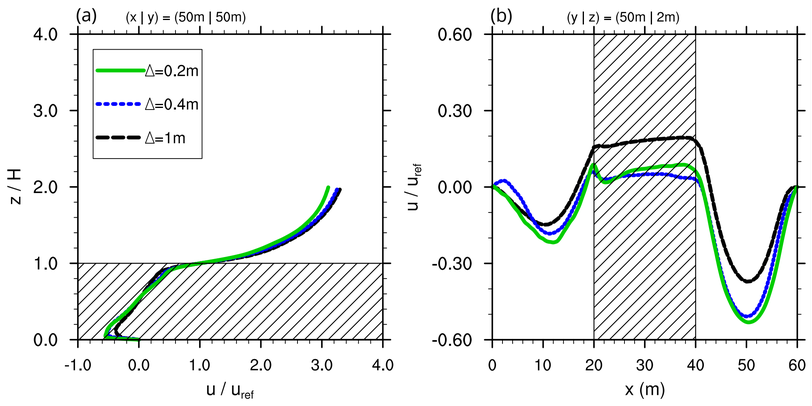


Figure 4: (a) Vertical profile of normalized wind velocity at the courtyard center; (b) wind velocity along the opening.

## Flow field within the courtyards

- Scalar concentration differs significantly between different couryard openings
- Depending on orientation of opening, it ventilates or pollutes the courtyard
- Also the flow condition around the building structure can change the influence of the opening on the ventialtion
- Changes between different cases are also significant (less influence for AR=0.3, stronger influence for AR=3.0)

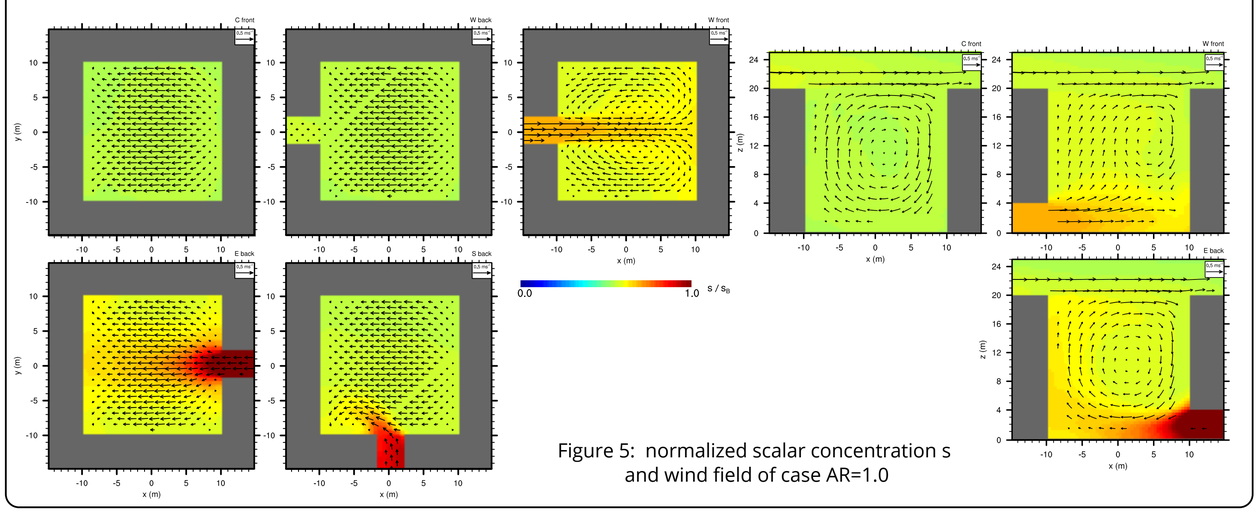


Figure 5: normalized scalar concentration s and wind field of case AR=1.0

## Pollution / ventilation through opening

- In case AR=3 (fig. 6a), openings at the eastern and western side pollute the courtyard while northern and southern openings have close to no effect
- In case AR=1 (fig. 6b), all eastern openings pollute while western openings either pollute or ventilate, depending on the row (front or center/back)
- In case AR=0.3 (fig. 6c), the influence of openings is significantly smaller than in the other two cases

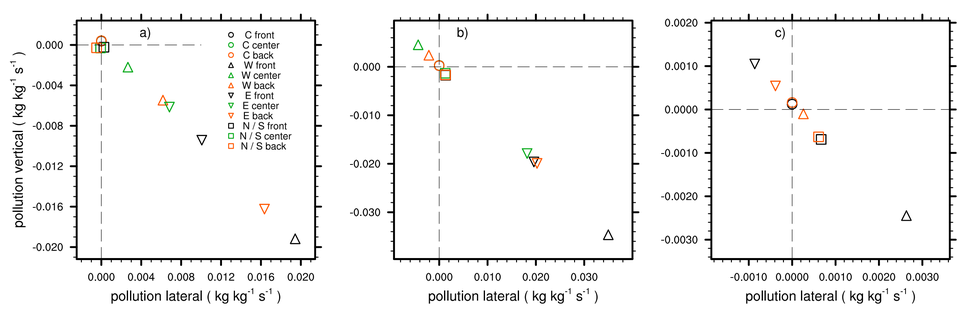


Figure 6: Conatmination rate of courtyard volume through lateral and vertical opening; (a) AR=3, (b) AR=1, (c) AR=0.3

## Residence time of pollutant

- Residence-time scale τ gives the time which a pollutant resides within the courtyard volume
- In case AR=3 (fig. 7a), τ shows largest values; N/S and E courtyards show bi-modal distribution, which indicates intermittend turbulence
- In case AR=1 (fig. 7b), W front courtyard shows higher τ more often, therefore pollutants tend to reside longer in these kind of courtyards
- Case AR=0.3 (fig. 7c) does not show any significant changes for different openings

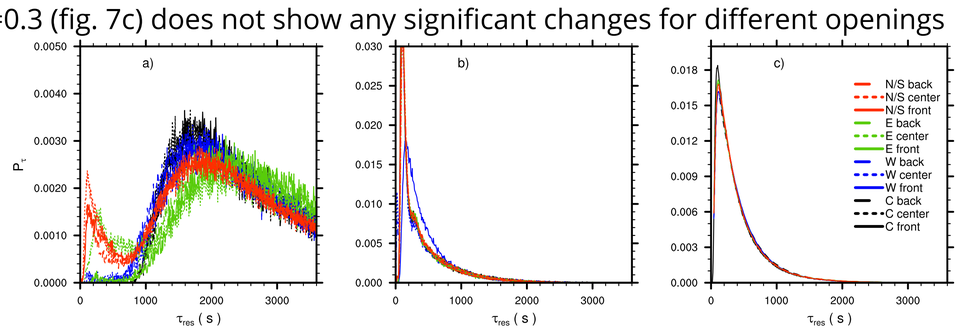


Figure 7: Probability density function of Lagrangian residence-time scale within a courtyard volume; (a) AR=3, (b) AR=1, (c) AR=0.3

## Let's summarize

- Wind field within a courtyard can be significantly altered by openings
- The influence of the opening on courtyard ventilation depends on the aspect ratio (AR), the orientation of the opening, and the flow field surrounding the building
- Openings can either pollute or ventilate the courtyard
- Residence time of pollutants can be extended by openings

→ **Openings must be considered when courtyard ventilation is analyzed**

## What's next

- Following this study, further research is required to properly assess the influence of openings on realistic courtyard scenarios
- In many cases, courtyards accommodate trees and shrubs, which were excluded in this research. This should be considered in a future study
- The used building setup was highly idealized. A more realistic building setup with varying building height and orientation might give a more sophisticated view on the influence of openings

## References & Acknowledgments

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