Ventilation of street canyons with various complexity of geometry

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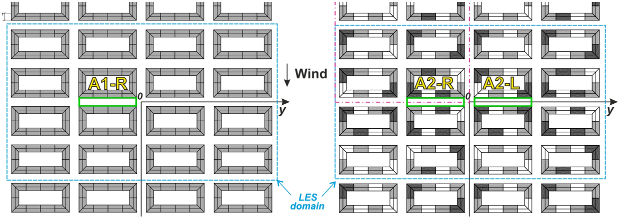
Outline

Motivation

- Prediction of pollution levels within street canyons challenging.
- Simplified models often employ parametrizations of scalar fluxes from the streets and between streets.
- Parametrizations often derived from LES or DNS of idealized street networks.
- Often only simple boxes for the blocks of buildings and streets are considered.
- Here we investigate what is the influence of the level of complexity of the street network on the pollution fluxes and on the concentration levels within the canyons.

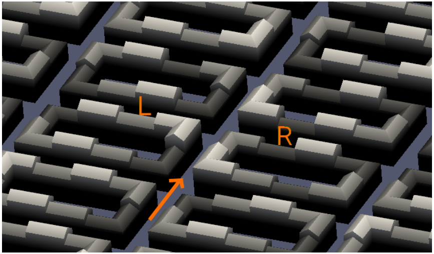
Selected problem geometry

- Street network, periodically repeating.
- The average height of buildings in all street canyons is equal.
- All canopies the same λ_{p} and λ_{f}.
- Pitched roofs and flat roofs
- Uniform height buildings and buildings of three different heights.



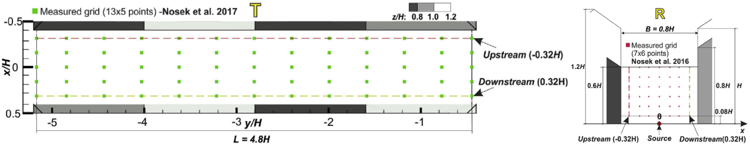
Building types

- Reference height $H = 25\,\mathrm{m}$ real scale, 62.5 mm model scale
- Smaller buildings $0.8H$ and taller ones $1.2H$
- Building width 0.6 H
- Canyon width 0.8 H
- street length $L = 4.8H = 120\,\mathrm{m}$ real scale



Wind tunnel experiment

- So far only pitched roofs.
- Measurements of turbulent scalar fluxes
  - simultaneous measurement of two velocity components by LAD
  - and concentrations by fast FID



Grid for the measurements.

Measurements published in Nosek, Kukačka, Jurčáková, Kellnerová, Jaňour, *Impact of roof height non-uniformity on pollutant transport between a street canyon and intersections*, Env. Pollution 227 (2017) and Kluková, Nosek, Jaňour, Kukačka, *Lateral transport of traffic pollutants in complex urban area*, EPJ Web of Conferences 180, 02125 (2018).

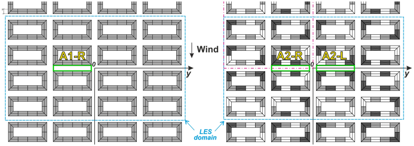
LES model ELMM

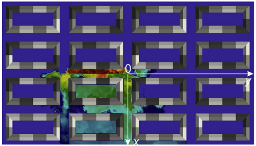
- Extended Large-eddy Microscale Model
- in-house code, open source https://bitbucket.org/LadaF/elmm/
- parallel: MPI, OpenMP
- FFT-based fast Poisson solver PoisFFT
  https://github.com/LadaF/PoisFFT

Numerical methods

- Projection (fractional step) method
- 3rd order Runge-Kutta
- 2nd order central differences
- Direct forcing immersed boundary method for complex geometries
- Mixed Time Scale subgrid model

Simulation set-up

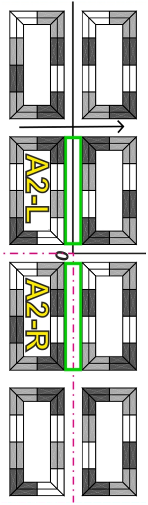




- Horizontal area covers 4x4 building blocks, periodic BCs
- Vertical domain extent $8H$
- Periodic boundary conditions for flow variables
- Resolution $\Delta z = H/20$, $\Delta x = \Delta y = H/18.75$, in total $240 \times 480 \times 160$ cells
- Tests with grid nesting with higher resolution in the source canyon did not show large differences
- Expensive simulations with $2\times$ resolution (but short averaging time) underway, differences not large so-far

Scalar sources

- Line source at the bottom of the canyon.
  - one grid cell width in LES
  - a row of many needles injecting tracer gas in WT
- Two street canyons, containing the line source, were chosen for the analysis.
  - L canyon step-down or equal at the corners
  - R canyon step-up at the corners
- Four scalar sources considered.
  - S1 long source as an approximation of an infinite oneleft canyon source
  - S2 the R canyon source
  - S3 the L canyon source
  - S4 intersection source
- Only S1 used in the wind tunnel experiments.

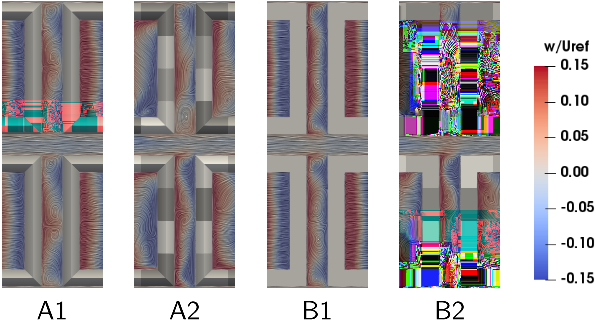


Validation

metrics for C^*	A1	A2
FAC2	0.91	0.87
FB	0.1	0.0
MG	1.11	1.0
VG	1.21	1.18

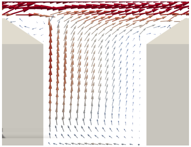
- Mean concentrations in measured points on the top and lateral canyon openings and at $z = 0.6H$.
- Only the long scalar source S1.
- Many points located in shear layers with large gradients.
- More in Nosek, Fuka, Kukačka, Kluková, Jaňour, *Street-canyon pollution with respect to urban-array complexity: The role of lateral and mean pollution fluxes*, Building and Env. 138 (2018) – pitched roofs only.

The street canyon flow field at $z = 0.4H$

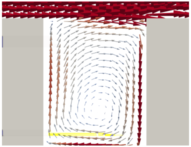


- Larger mean vertical velocities for flat roofs.
- The flow pattern strongly deformed for variable heights.
- Cross flow in the intersection for variable heights.

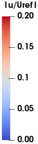
The street canyon flow field - street centre



A1



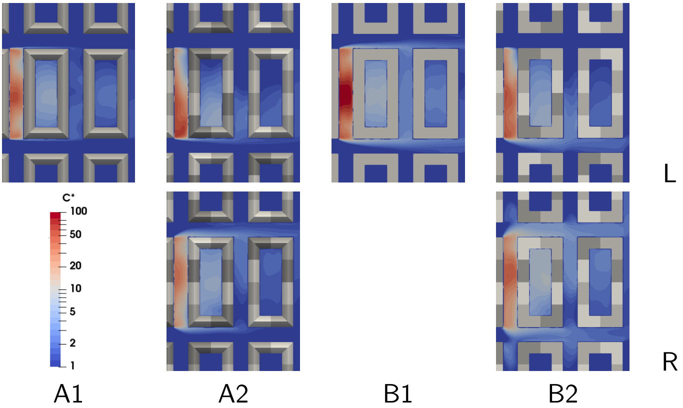
A2



B1

- Only uniform heights shown.
- For flat roofs a horizontal vortex across the whole street length.
- For pitched roofs the vortex is interrupted in the centre of the canyon.
- The vertical flow in the centre means horizontal convergence at the bottom.

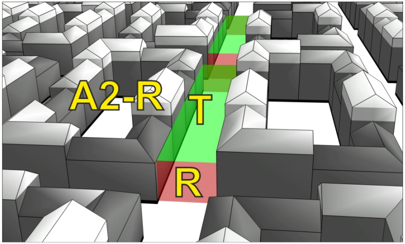
The mean concentrations at $z = 0.4H$



- The source only within the street of interest.
- Maxima concentrated in the centre of the canyon, stronger for uniform heights.
- for A2 and B2 the right canon's scalar getting into neighbouring canyons.

Mean concentrations averaged over the canyon

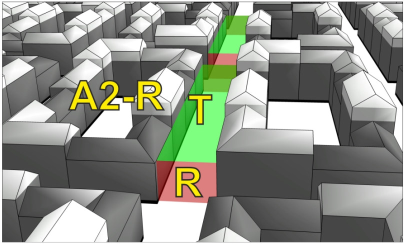
canyon	$\langle C^* \rangle$
A1	33.9
A2-L	36.0
A2-R	22.3
B1	**48.1**
B2-L	30.1
B2-R	28.0



- Averaging volume not the same, eaves of the lowest building (pitched) and the top of the lowest building (flat).
- Large differences between cases.
- A2-R significantly lower than A1, but A2-L slightly higher.

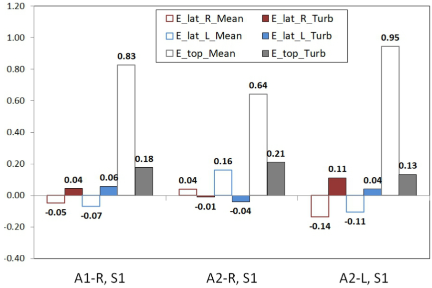
Fluxes integrated across the top opening

canyon	$\frac{\int c' w' \mathrm{d}x\mathrm{d}y}{Q}$
A1	96%
A2-L	97%
A2-R	84%
B1	63%
B2-L	88%
B2-R	68%

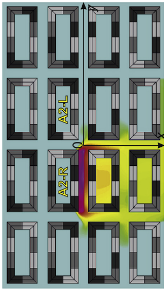


- Normalized by the source strength Q.
- The remaining part escapes the canyon through the lateral openings.
- Lower values correlated with higher concentrations.
- Air exchange rate for pitched roofs: Kluková, Nosek, Fuka, *Capability of air exchange rate to predict ventilation of three-dimensional street canyons*, EFM 2018, to appear in EPJ Web of Conferences

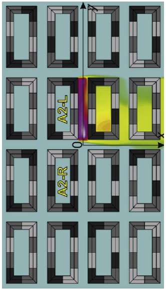
Fluxes integrated through all openings



(long) source S1



source S2 and S3



$z = 0.05H$

- The long scalar source S1, normalized source within one street.
- The turbulent and the advective (mean) part separately.
- Now only for pitched roofs. Even more lateral transport for B2-R.
- With variable heights the L canyon receives $\sim 0.10Q$ through the lateral openings while the R canyon exhausts $\sim 0.15Q$.
- For lateral openings the turbulent and the advective fluxes have the opposite sign and comparable magnitude.

Conclusions

- The building shape and height configuration has a strong influence on pollution dispersion.
- All canopies had the same λ_{p} and λ_{f}.
- Pitched roofs and geometry complexity increase the role of advective fluxes.
- Horizontal transport important and strongly depending on local geometry.
- Box models and similar dispersion model parametrizations might need to take the possible unresolved geometry complexity into account.
- Simulations in a 2x finer resolution are being run.