Sensitivity of LES simulations to resolution, subgrid models and boundary conditions

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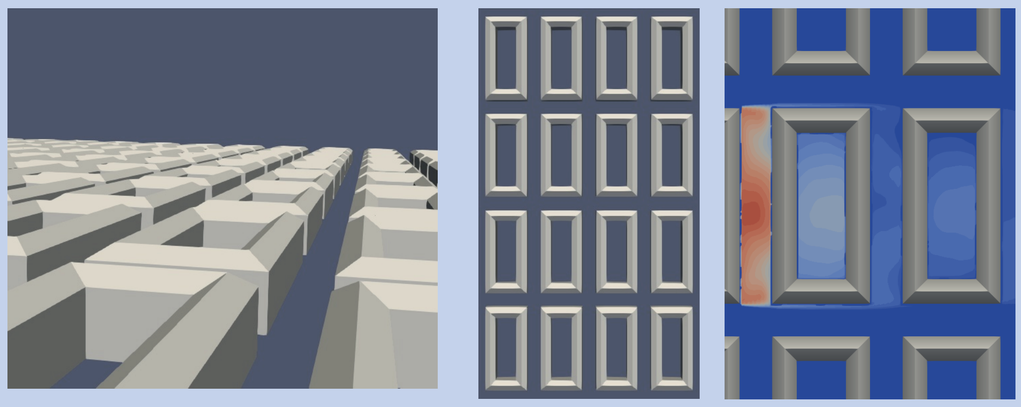
Idealized urban geometry

- Based on Nosek et al., 2018 (Building and Environment 138)
- Selected layout A1 = pitched roof, equal height
- Wind tunnel scale H = 62.5 mm, street width 50 mm
- Detailed PIV and LDA wind-tunnel measurements available, including the turbulent scalar fluxes.

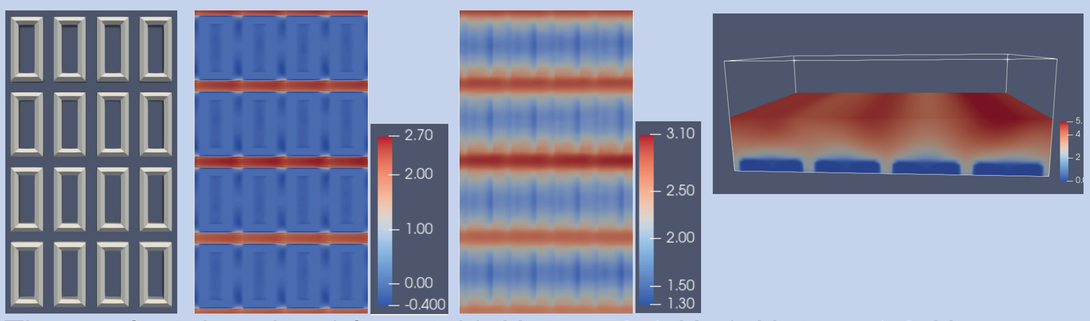


The default LES setup

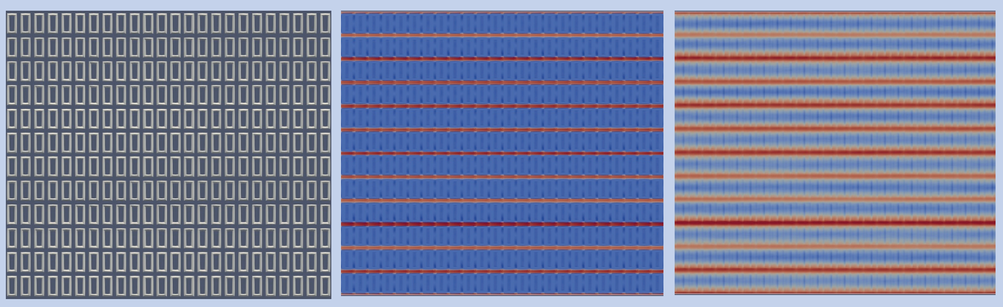
- In-house open source model ELMM
- Immersed boundary method and uniform orthogonal grid
- 2nd order central discretization in space
- 3rd order Runge-Kutta in time
- mixed-time-scale (MTS) subgrid model (Inagaki et al, 2005)

Periodic BC vs. turbulent inlet

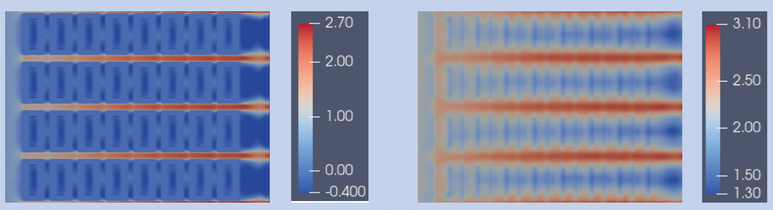
- Periodic boundary conditions with increasing domain size.
- Synthetic turbulence inflow, integral lengthscale varied.
- Equal time averaging period 320 H/u*.



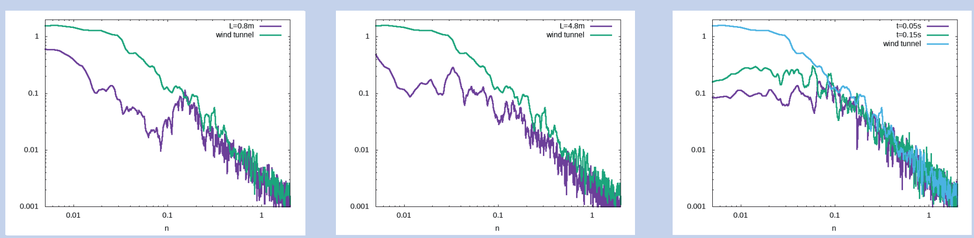
The smalest domain: a) layout, b) U at z = 0.4 H, c) U at z = 1.2 H



The largest domain: a) layout, b) U at z = 0.4 H, c) U at z = 1.2 H



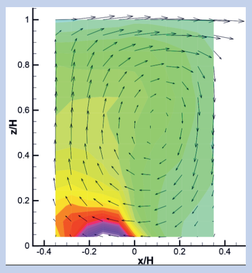
Synthetic turbulent inflow BC: a) U at z = 0.4 H, b) U at z = 1.2 H



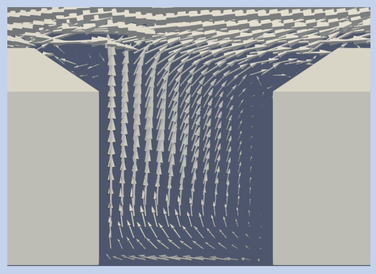
Simulated streamwise velocity (u) C spectra at z = 2 H compared with PIV at z = 1.6 H. a) small domain, b) large domain, c) turbulent inflow.

Detailed flow-field in the stret canyon

- ELMM had problems inside the street canyon particularly for pitched roofs with equal height. In older simulations at $\Delta z=H/20$ the vortex disappeared at the central plane. Despite of that scalar fluxes were simulated well.



PIV



ELMM $\Delta z=H/20$

- We used this test case for a sensitivity analysis.
- Small periodic domain with only one building block and one canyon.
- Only points inside the canyon on the central plane compared with PIV.

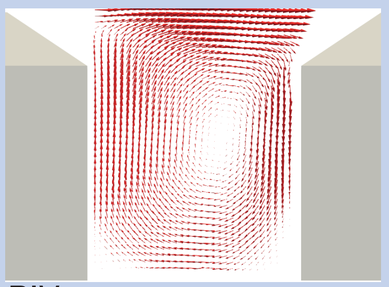
Tests:

- grid resolution
- 2nd order vs. 4th order discretization
- subgrid models
- LES vs. DNS with lower Reynolds number (Re = $H\,U_{1H}/\nu$ ≐1000)

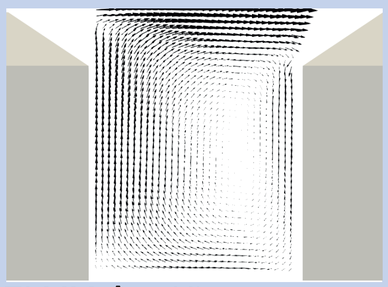
Setup	Discretization order	RMSE U, W [m/s]	HR U, W %
$\Delta z=H/25$, MTS subgrid model	2nd order	0.10 / 0.13	67 / 66
$\Delta z=H/50$, MTS subgrid model	2nd order	0.25 / 0.19	37 / 49
$\Delta z=H/100$, MTS subgrid model	2nd order	0.17 / 0.14	50 / 58
$\Delta z=H/50$, MTS subgrid model	4th order	0.25 / 0.20	37 / 44
$\Delta z=H/100$, MTS subgrid model	4th order	0.18 / 0.14	50 / 55
$\Delta z=H/50$, Vreman subgrid model	2nd order	0.25 / 0.19	38 / 46
$\Delta z=H/50$, sigma subgrid model	2nd order	0.26 / 0.20	36 / 49
$\Delta z=H/100$, DNS, lower Re	4th order	0.12 / 0.16	66 / 48
$\Delta z=H/40$, OpenFOAM, pimpleFoam, WALE sgs model	2nd order	0.10 / 0.15	67 / 64

(hit rate: relative error < 10% or absolute error < 0.05 m/s)

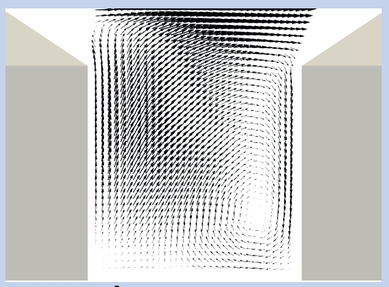
Velocity vectors interpolated to the PIV measurement points



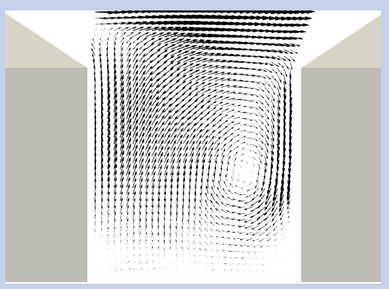
PIV



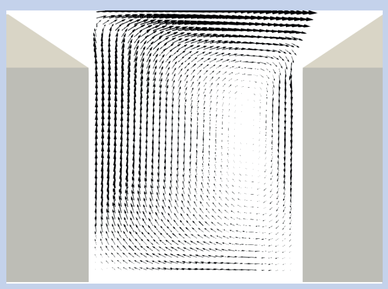
ELMM $\Delta z=H/25$



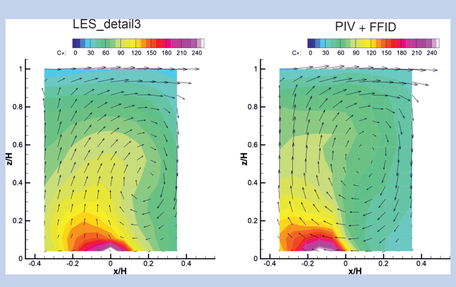
ELMM $\Delta z=H/50$



ELMM $\Delta z=H/100$



OpenFOAM $\Delta z=H/40$



ELMM $\Delta z=H/100$ scalar C^*

- Despite having very incorrect results at $H/20$ we recieve very good correspondence at $H/25$, but for higher resolutions the results worsen.
- Reason not yet determined.
- Little dependence on the subgrid model.
- Small difference when changing discretization order.
- Difference between LES and DNS of a lower Reynolds noticeable.
- Scalar concentrations simulated, but yet to be compared systematically.

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