Air Exchange Mechanism in 3-D Complex Array

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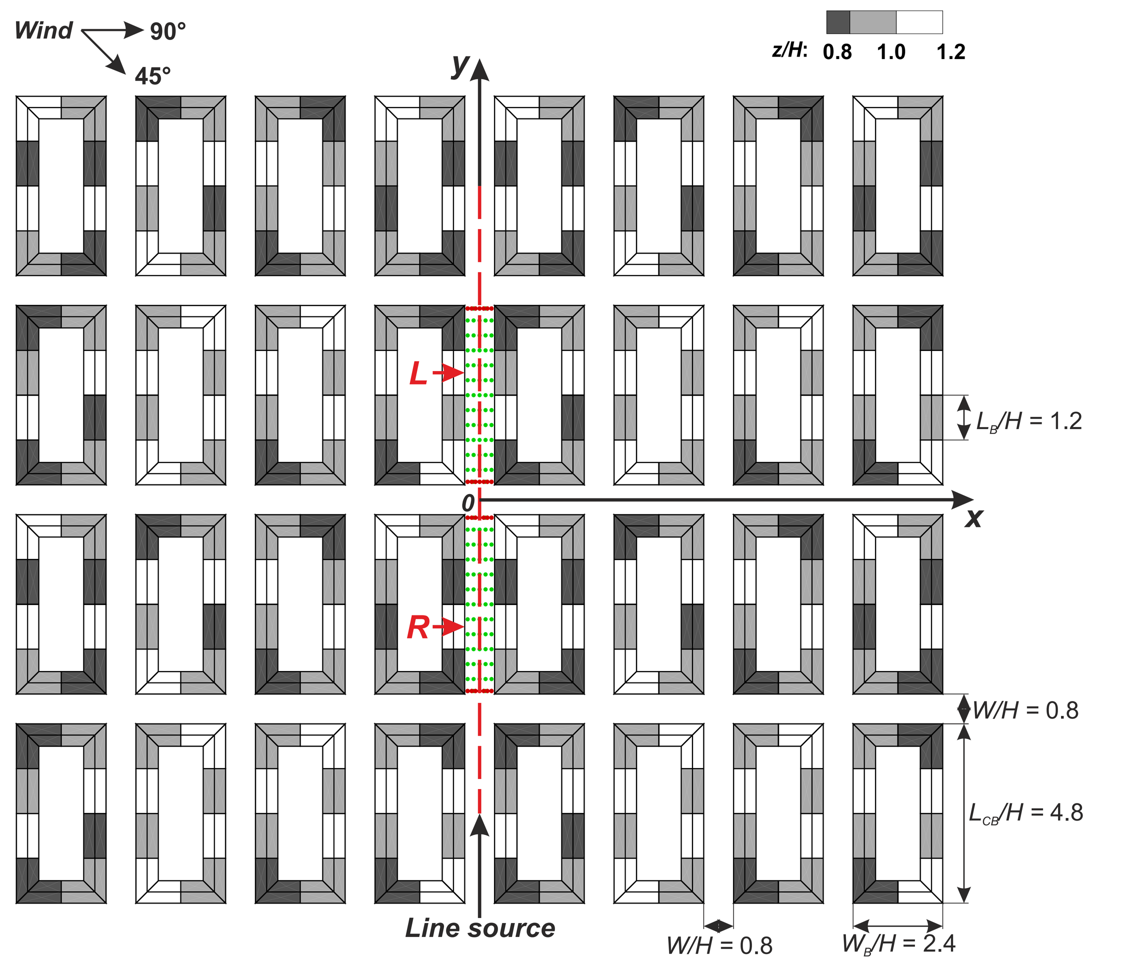
Highlights

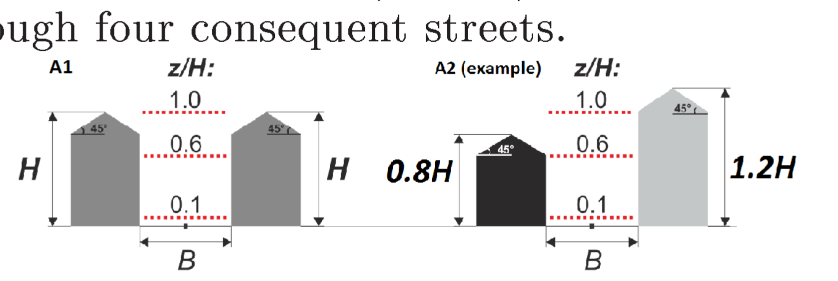
- Wind-tunnel simultaneous measurement of wind speed and tracer concentration in a street canyon with a ground-level line source.
- Tracer flux balance of the non-uniform street canyons shows a significance of the local roof-height non-uniformities for their ventilation.
- The step-down building arrangement causes flow convergence and entraining air from intersection, the step-up arrangement causes flow divergence.

Urban array model

The experiments were conducted in a wind tunnel.The approaching atmospheric boundary layer corresponded to the flow above very rough terrain in the scale of 1:400.



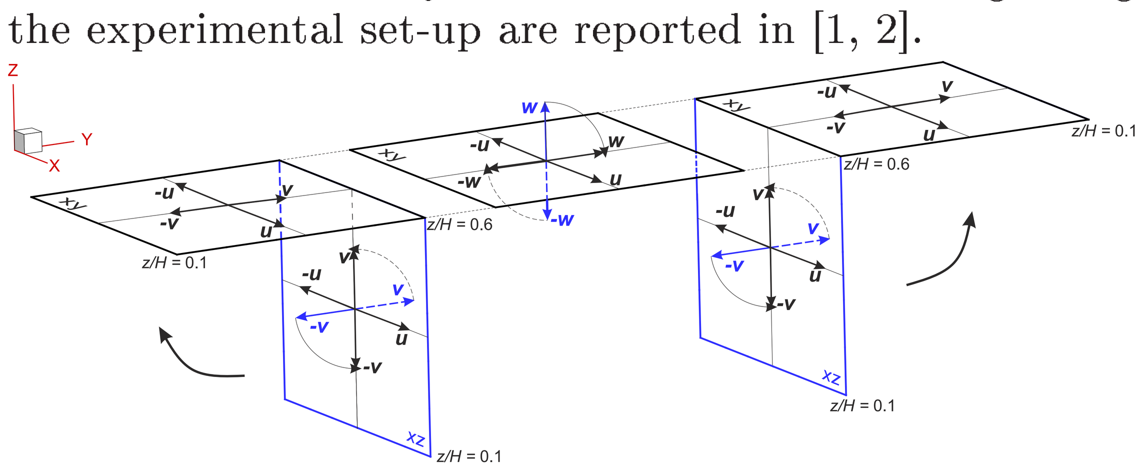
Two idealized models were formed by courtyard building blocks. The difference between the models consisted of the heights of the pitched roofs. The reference urban model A1 had a constant roof height ($H = 62.5$ mm, i.e., 25 m at full scale), the A2 model had arbitrarily distributed roof heights among the buildings. Ground-level line source emitted the tracer (ethane) homogenously and it ran through four consequent streets.



Measurement technique

The simultaneous point measurements of two velocity components and tracer concentration was performed using a Dantec Laser Doppler Anenometry probe and a probe of a Cambustion HFR400 fast-response flame ionization detector. The probes were assembled together on a 3D traverser system approx. 2 mm aside. For both urban-array models we simulated two wind directions: perpendicular and oblique (45°) to the line source.

Horizontal measurement plane was set at the height of $0.6H$ to ensure that this plane is below the building eave for all building heights. The vertical planes were measured at the street-canyon ends. Further details regarding the experimental set-up are reported in [1, 2].



To show the results at all measured planes together, the transformation of coordinates and vectors was used and it is depicted in the figure. For the mean total tracer flux fields we used the dimensionless form: $\langle c^* w\rangle/U_{ref}$ for the total vertical and $\langle c^* v\rangle/U_{ref}$, for the total lateral tracer fluxes, where w and v are the instantaneous vertical a lateral velocity components, respectively, and c^* is the instantaneous dimensionless concentration computed as

$$c^* = \frac{cL_S U_{ref} H}{Q}$$

where c is the measured concentration, L_S is the length of the line source, U_{ref} is the reference velocity, and Q is the tracer volume flow rate from the line source.

Acknowledgements

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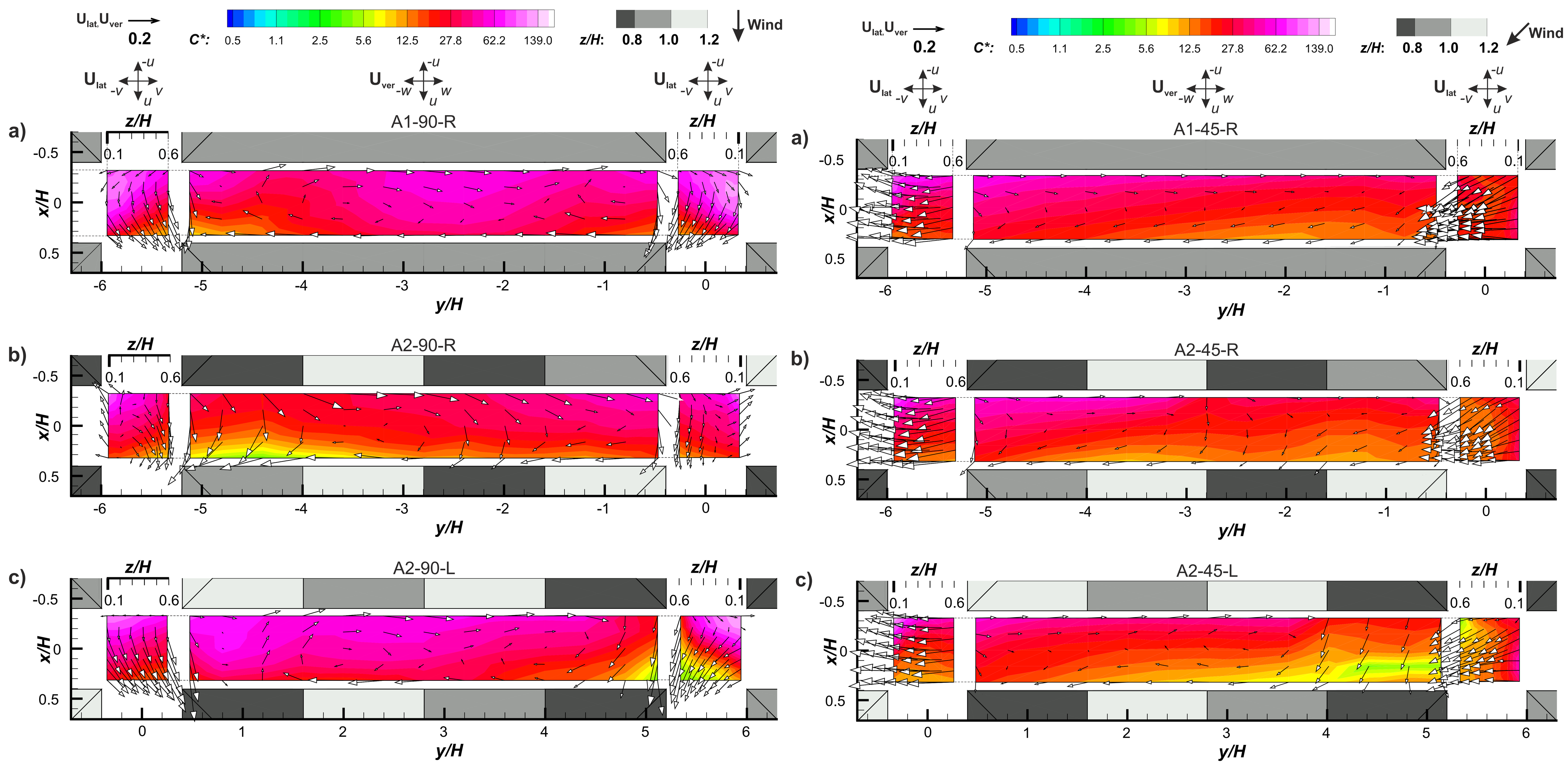
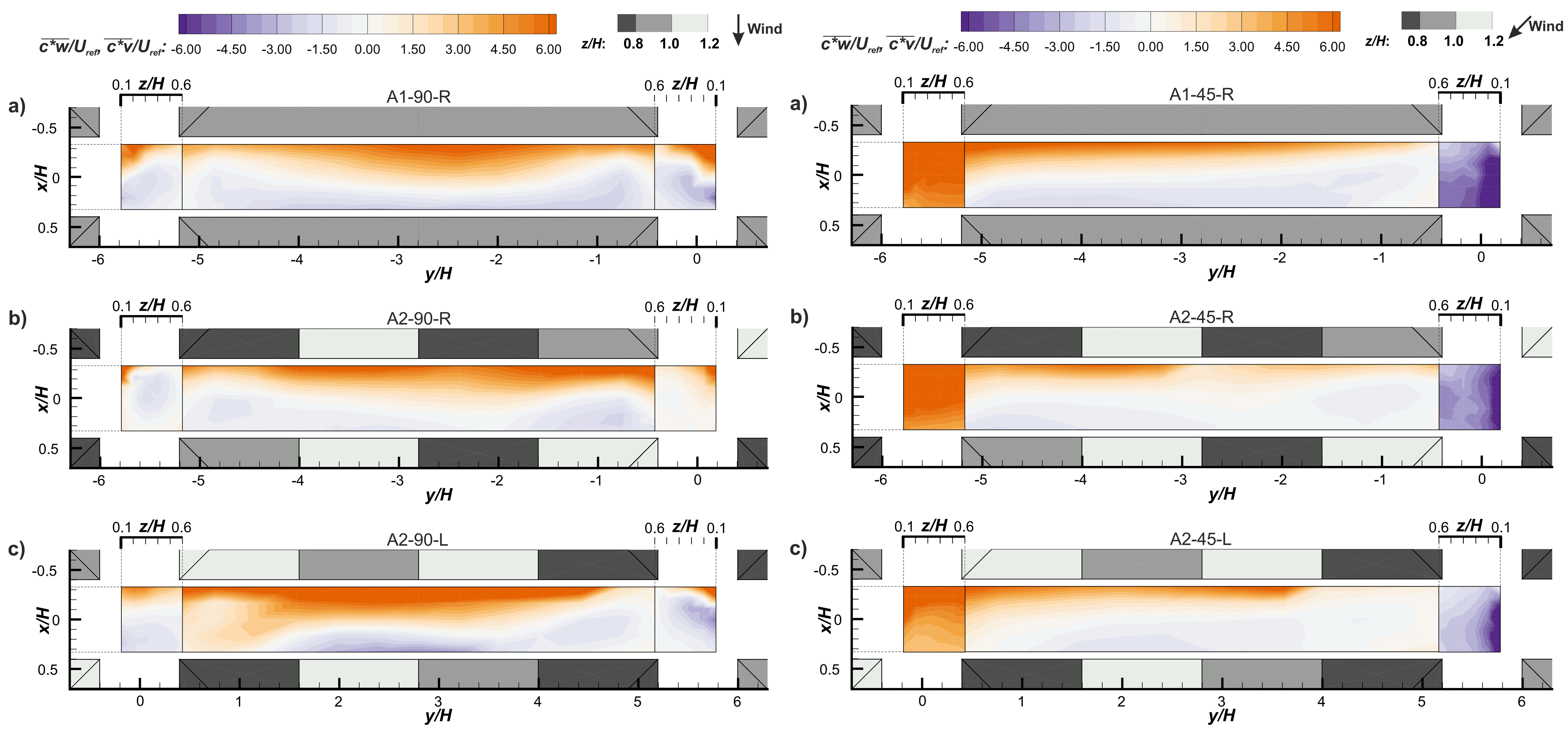
Tracer concentration and flow field



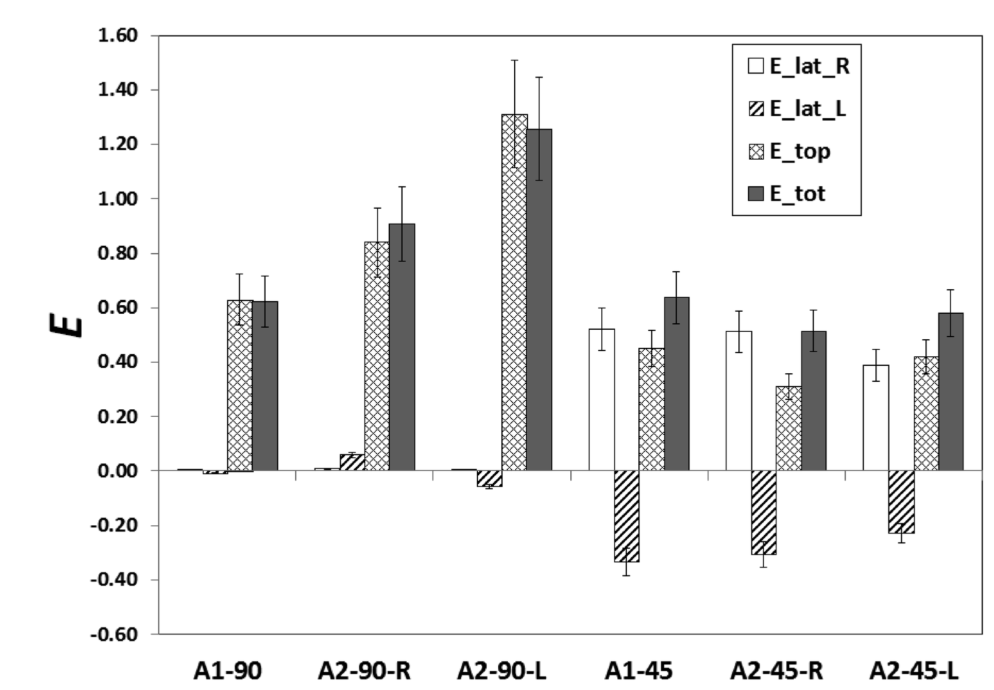
Mean dimensionless velocity vector and concentration fields for the uniform canyons (the first row) and the non-uniform canyons (the second and third rows). Perpendicular wind direction is on left, 45° wind direction is on right. The grey contour represents the dimensionless height z/H of the buildings. The figures are adapted from [2].

Passive tracer flux



The dimensionless lateral and vertical tracer flux fields. Negative values represent the incoming flux, positive values represent the outgoing flux to the street canyon. The fluxes nearby the walls (up to $0.08H$) were not investigated due to probe constrains.

Tracer flux balance



The surface integrals of the normal dimensionless tracer flux for each plane are presented in the figure.

E_lat_R the relative flux through the right street-canyon end;
E_lat_L the relative flux through the left street-canyon end;
E_top the relative flux through the horizontal plane at $0.6H$;
E_tot the flux sum for the whole street-canyon box.

An ideal pollution flux balance should sum up to the flux from the source, Q, (i.e. E_tot=1). Our balances differed from the ideal balance significantly because of the unmeasured fluxes close to walls. Due to the measurement constrains nearby the building walls and floor, the investigated area covered only 77% of the total area. Extension of measured areas is currently tested.

The local step-down building arrangement (A2-L) causes flow convergence and thus entraining air from intersection (which might be polluted in the case of traffic line going through the intersection) and venting it upward. The local step-up (A2-R) arrangement causes flow divergence and enhances the air exchange with the above-roof flow.

References

[1] Nosek, Š., Kukačka, L., Kellnerová, R., Jurčáková, K., Jaňour, Z.: *Ventilation processes in the three-dimensional street canyon.* Boundary-Layer Meteorol, 159, 259-284 (2016)
[2] Nosek, Š., Kukačka, L., Jurčáková, K., Kellnerová, R., Jaňour, Z.: *Impact of roof height non-uniformity on pollutant transport between a street canyon and intersections.* Environmental Pollution 227, 125-138 (2017)