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VENTILATION OF STREET CANYONS WITH VARIOUS COMPLEXITY OF GEOMETRY

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Abstract: The effect of the geometry complexity on the flow and pollution dispersion in a finite-length street canyon embedded in a street network with courtyards is investigated. The parameters varied are the shape of the roofs (flat/pitched) and the building height (uniform/nonuniform). The flow patern for the pitched roof case significantly differs from the flat roof case and also from a 2D infinite canyon. The actual configuration of buildings of non-uniform heigth can causes large diferences beween individual street canyons.

Key words: *street canyon, large eddy simulation, wind tunnel, turbulent fluxes*

INTRODUCTION

The air polution in city centers is an important problem for the inhabitants. This paper investigates the effects of the shape of buildings of which a street network consists on the concentrations of the passive scalar and scalar fluxes.

STREET NETWORK GEOMETRY

The geometry considered was already described in Nosek et al. 2018. It is a street network where the buildings form blocks with enclosed courtyards. All street canyons have the same equal mean building height H. In addition to Nosek et al. 2018 this paper also considers buildings with flat roofs. The length of every street canyon is 4.8 H and the width is 0.8 H.

The passive scalar source is a line source located on the bottom of the street canyon. In this contribution we only consider the source located within the street canyon only (without any intersection). The previous study discusses the difference from the line source in the whole street.

In total four cases were considered: pitched roofs and uniform height (A1), pitched roofs and variable height (A2), flat roofs and variable height (B1) and flat roofs and variable height (B2). The layout of of case A2 as a representatice example can be found in Figure 4.

NUMERICAL MODEL

This study uses the ELMM (Fuka, 2015) large eddy simulation model. It is set-up with teh second order finite volume method and the third order Runge/Kutta method and the subgrid terms are modelled by the mixed-time-scale model (Inagaki et al., 2005). This setup was validated by Nosek et al. (2018) which also brings more detail about the domain, boundary conditions and other aspects of the numerical simulation setup.

The horizontal boundary conditions were periodic and the flow was driven by a variable pressure gradient, which kept the flow rate constant. The domain consisted of sixteen blocks of buildings.

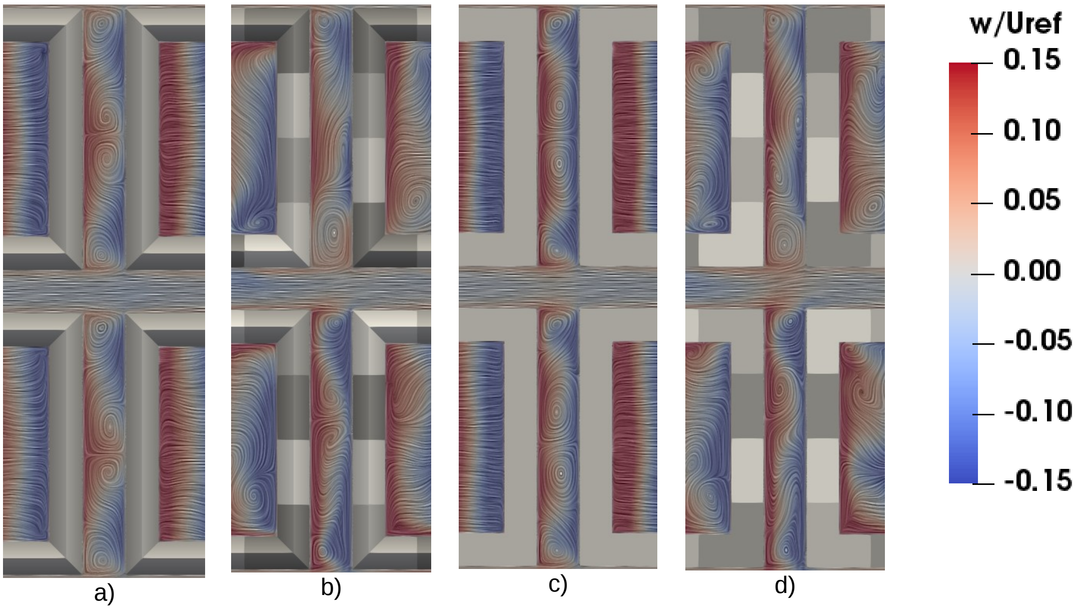

Figure 1 The flow patterns in the street canyons and intersections, streamlines by line integral convolution. The building colour denotes their height (dark 0.8*H*, medium 1*H*, light 1.2*H*). The colour inside the streamlines denotes the vertical velocity *w*. a) A1, b) A2, c) B1, d) B2. Note that for A1 the positive *w* region touches the opposite wall.

RESULTS

The simulated flow in four cases differs considerably. Figure 1 shows the top view of the streamlines at z=0.4 H and Figure 2 the vectors of the flow in the centre of the canyon. It is apparent that for uniform height the main horizontal street conyon vortex is split into two separate vortexes for the pitched roofs while it remains connected for the flat roofs. This is expected to be dependent on the street canyon length. For variable height the flow pattern is more complex.

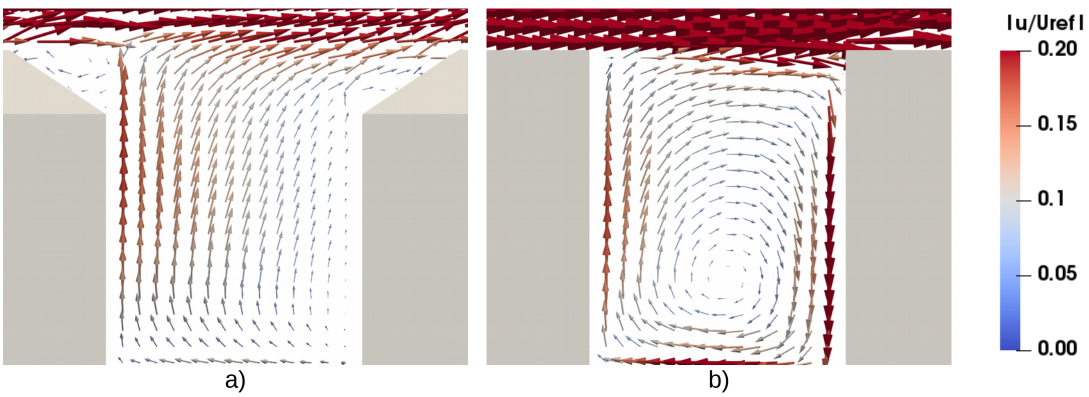

Figure 2 The vector field in the centre of the canyon. a) A1, b) B1.

The flow pattern affects the transport of the scalar within the canyon. Figure 3 presents the mean scalar dimensionless concentrations at z=0.4 H. For the variable height cases it shows two neighbouring canyons as they differ considerably. The dimensionless conentrations are normlized by the mean wind speed in the x direction at z=3H, by the building height and by the source length.

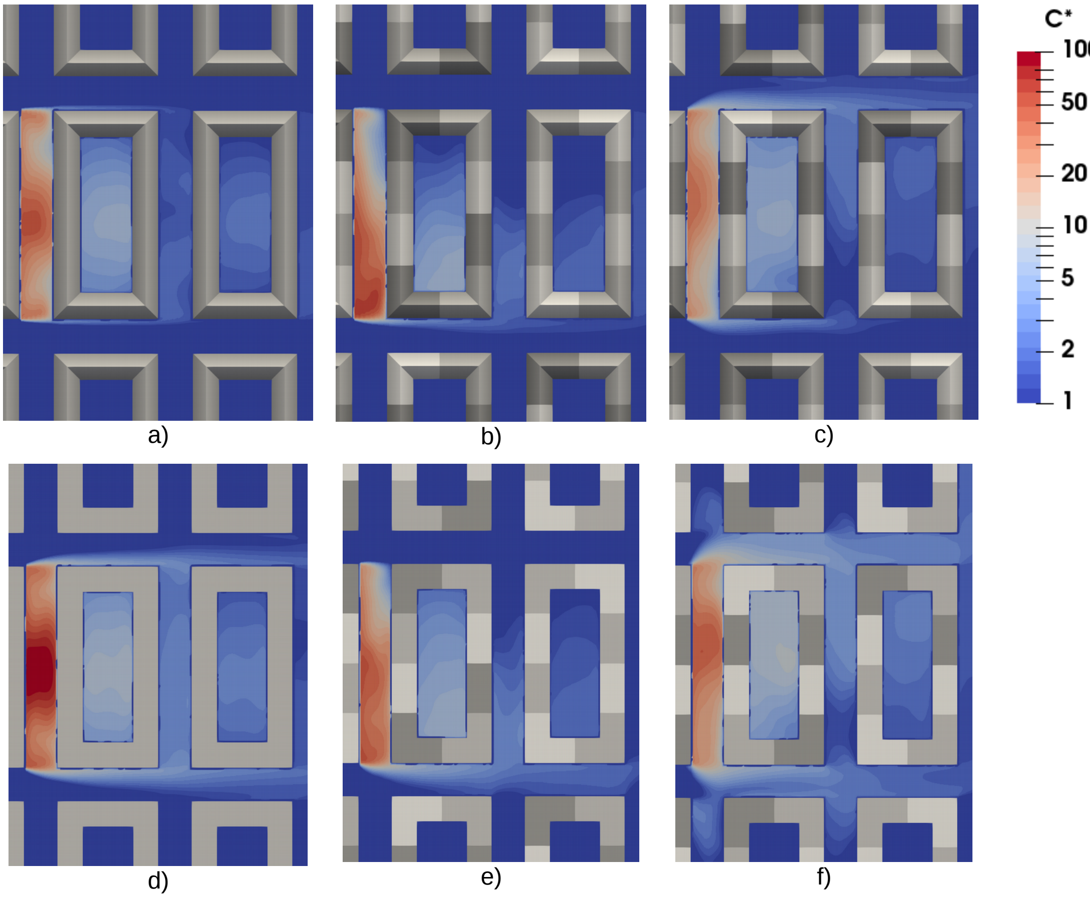

Figure 3 The mean concentrations at z=0.4H. a) A1, b) A2L (left canyon), c) A2R (right canyon), d) B1, e) B2L, f) B2R.

From the mean concentration plots it is apparent that the highest concentrations are achieved for the uniform height and flat roofs. For variable heights the concentration fields in the left canyon are skewed towards the central intersection. That is likely connected with the step-down configuration of the buildings at the intersection. Significant amount of scalar is drawn into the intersection while almost none is drawn into the intersection on the left. For the right canyon the peak of the concentration field is located to the left of the centre of the canyon, but the concentration field is closer to being symmetric.
To compare the concentration levels quantitatively we evaluated the average concentrations within the streat canyon. The top boundary is the heigh of the eaves of the lowest buildings (z=0.6H) for pitched roofs and the height of the lowest buildings (0.8H) for flat roofs variable height andthe top of the buildings for flat roofs uniform height (1H). The results are in Table 1.
The average concentrations follow the differences visible in Fig. 3 with the highest levels occuring with flat roofs and uniform height (B1). For flat roofs and variable heights both canyons (B2L and B2R) have lower concentrations in comparison to the uniform height case. This is not true for pitched roofs. While the right canyon (A2R) has significantly lower concentrations in comparison with the uniform case (A1), this is not true for the left canyon (A2L) which has a slighly higher concentration than the uniform case. The larger integration volume for B1 does not spoil the comparison, because for the part of the canyon up to z=0.8H whe average concentration would be even higher.

canyon	average dimensionless concentration C^*
A1	33.9
A2L	36.0
A2R	22.3
B1	48.1
B1L	30.1
B1R	28.0

Table 1 The average dimensionless concentrations within the canyons. See the text for the averaging domain definition.

To allow more definite conclusions we also integrated the vertical scalar flux (both advective and turbulent) at the top opening of the canyon. The ratio of the integrated flux to the scalar source intensity describes the portion of the scalar that leaves the canyon through the top opening. The remaining part leaves the canyon through the intersections. Direct comparison between different cases is more difficult here because of the necessity to define the integration plane at different heights. The result is more sensitive to this choice than, for example, the mean scalar concentration in the canyon. With raising the plane the side boundary in the intersection changes its area. To avoid additional problematic boundaries in the x direction the plane must be kept below the eaves of the lowest building. One can still compare different canyons in the same simulation (A2 or B2) directly.

canyon	ratio of scalar flux through canyon top
A1	96%
A2L	97%
A2R	84%
B1	63%
B1L	88%
B1R	68%

Table 2 The ratio of the scalar flux integrated over the canyon top opening to the scalar source intensity. The same domain as in Table 1 was used to define the height of the top boundary.

One immediately notices the very low number for the flat uniform B1 case. Even when lowering the plane to z=0.6H it would still be rather low with 84%. That is in a great contrast with the 96% of the A1 configuration. For both roof shape types the left canyon shows higher percantage of the flux through the top. The B2R canyon has a rather low value of this ratio and one can see in Figure 3f that the scalar even enters the neighbouring canyons across the intersection.

CONCLUSION

From the LES results it is clear that the flow and scalar dispersion strongly depend on the details of the biulding layout in the street network. The change from uniform roof height to variable roof height did mostly lower the average concentrations within the canyon, but not uniformly. For the pitched roof shape one of the canyons actually shows higher concentrations. For flat roofs, the difference between the uniform height case and the variable height case is much larger.

The scalar flux through the canyon top opening is significantly lower for the flat roofs. The role of the turbulent and the advective fluxes, as well as other details and established measures for street canyon ventilation will be investigated in subsequent studies.

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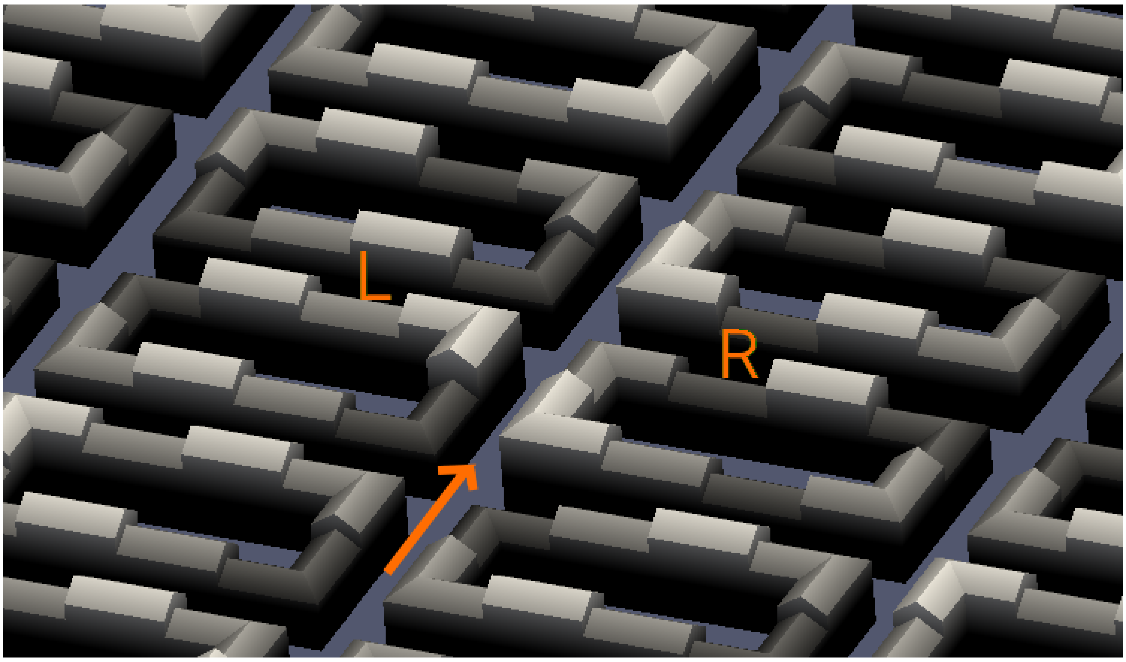

Figure 4 The layout of the buildings in the case A2. The arrow denotes the wind direction and the letters L and R denote the left and the right canyon containing the source.