Annual average impact of trees on air quality in street canyons

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Introduction

The influence of vegetation on the concentrations of traffic pollutants in urban street canyons is examined using numerical simulations with the CFD code OpenFOAM. This **CFD** approach is validated against literature wind tunnel data on traffic pollutant dispersion in street canyons. The impact of avenues of trees is simulated for a variety of vegetation types and the full range of approaching wind directions at 15° interval. All these results are combined in meteostatistical analysis, including effects of seasonal leaf loss, to determine the annual average effect of trees in street canyons. This analysis is performed for two pollutants, elemental carbon (EC) and PM_{10}, using background concentrations and emission strengths for the city of Antwerp, Belgium.

Numerical model

3D steady state simulations to study air quality effects using the **OpenFOAM** CFD package:

The computational domain is shown in figure 1, a regular hexahedral grid is applied with high resolution inside the street canyon (z/H = 0.028 and x/H = y/H = 0.05 with H building height of 18 m). The cell size expands outside the central region and becomes irregular.

- Standard *k-ε model*
- Boundary conditions to reflect atmospheric boundary layer as applied in wind tunnel experiments used as validation target (CODASC, Buccolieri et al. 2009)
- Residuals < 10^{-6}
- Schmidt number, Sc_T, optimised for each wind direction
- *Simplefoam* RANS-solver adapted for vegetation and pollutant dispersion, physical properties of a tree in the simulations are defined through a momentum sink, Cx = LAD * Cd, and deposition term, LADvd = LAD * vd. LAD, Cd and vd represent the leaf area density, the drag coefficient and the deposition velocity.

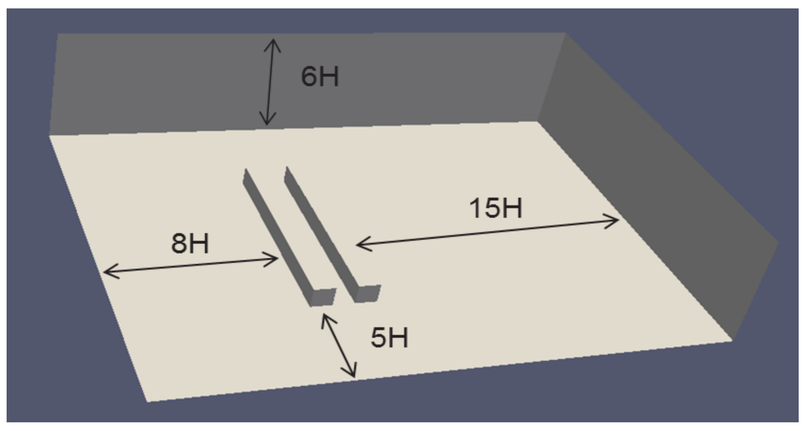

Fig. 1: Computational domain with H the building height and W the canyon width.

CFD model validation

The pollutant dispersion in idealized street canyons with and without trees is simulated, analyzed and validated against the majority of the cases presented in the CODASC databank.

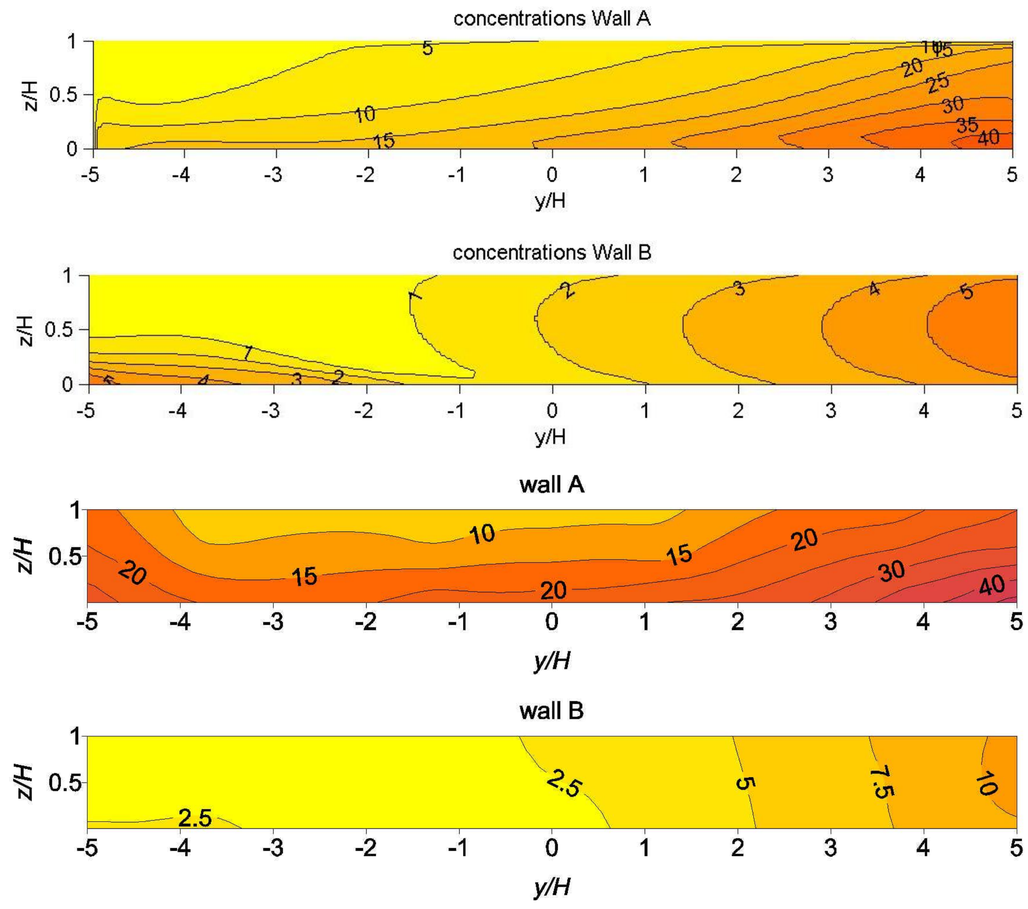

Fig 2: Normalized concentration profiles inside the street canyon near building walls for W/H = 1.0, 45 degrees, no trees. Top two profiles CFD simulations, bottom two reproduced from CODASC.

Table 1: Summary wall average normalized concentrations near the buildings inside the idealized street canyon W/H = 1.0 (left) and W/H = 2.0 (right), presented CFD results vs. the wind tunnel (WT) results (CODACS, 2008). For each case the coefficient of determination of a scatter plot of the simulations against the experimental data and the relative difference (diff.) between the simulation and the exp. value included.

Angle	Wall	No trees				Trees				Effect Trees	
		WT	*CFD*	*diff.*	R^2	*WT*	*CFD*	*diff.*	R^2	*WT*	*CFD*
90°	*A*	19.7	23.0	17%	0.78	32.7	35.0	7%	0.77	66%	52%
90°	*B*	5.34	8.03	50%	0.95	2.69	7.10	169%	0.83	-50%	-12%
45°	*A*	18.4	14.3	-22%	0.81	31.0	21.6	-30%	0.75	69%	51%
45°	*B*	3.70	2.41	-35%	0.80	5.27	11.6	120%	0.27	42%	380%
0°	*A/B*	7.10	7.22	2%	0.88	9.73	12.2	26%	0.88	37%	70%

Angle	Wall	No trees				Trees				Effect Trees	
		WT	*CFD*	*diff.*	R^2	*WT*	*CFD*	*diff.*	R^2	*WT*	*CFD*
90°	*A*	15.0	10.8	-28%	0.68	20.9	19.5	-7%	0.73	40%	81%
90°	*B*	5.14	8.23	60%	0.73	3.46	5.88	70%	0.93	-33%	-29%
45°	*A*	9.84	9.83	0%	0.45	18.4	13.2	-29%	0.80	87%	34%
45°	*B*	0.87	0.89	2%	0.55	3.77	3.28	18%	0.59	218%	269%
0°	*A/B*	1.46	1.16	-21%	0.83	2.10	2.42	15%	0.82	44%	109%

Annual average effects of trees on air quality

Validated OpenFOAM CFD model applied to study year round effects of trees in broader street canyons (W/H = 2.0):

- Wind directions at 15 degree interval - 10 different types of trees
- Annual statistics (hourly meteo 2012 Antwerp Belgium, seasonal leaf loss)
- PM_{10} and EC emissions busy urban street canyon (Frankrijklei, Antwerp, Belgium)
- Background concentrations Antwerp, Belgium
- 4 different canyon orientations (N-S, E-W, NW-SE, NE-SW)

Conclusions

The presented results agree with prior studies that the positive effect of street canyon vegetation on pollutant deposition is surpassed by the flow disturbance limiting the ventilation. The annual effects prove however fairly small, 0.2% to 2.6% increase for PM10 concentrations and 1% to 13% for EC, depending on the type of vegetation. Urban vegetation has several positive environmental impacts, traffic pollutant exposure mitigation for street canyons is however not one of them. We like to stress urban trees are not the source of increased pollutant concentrations in street canyons, as this is the local traffic.

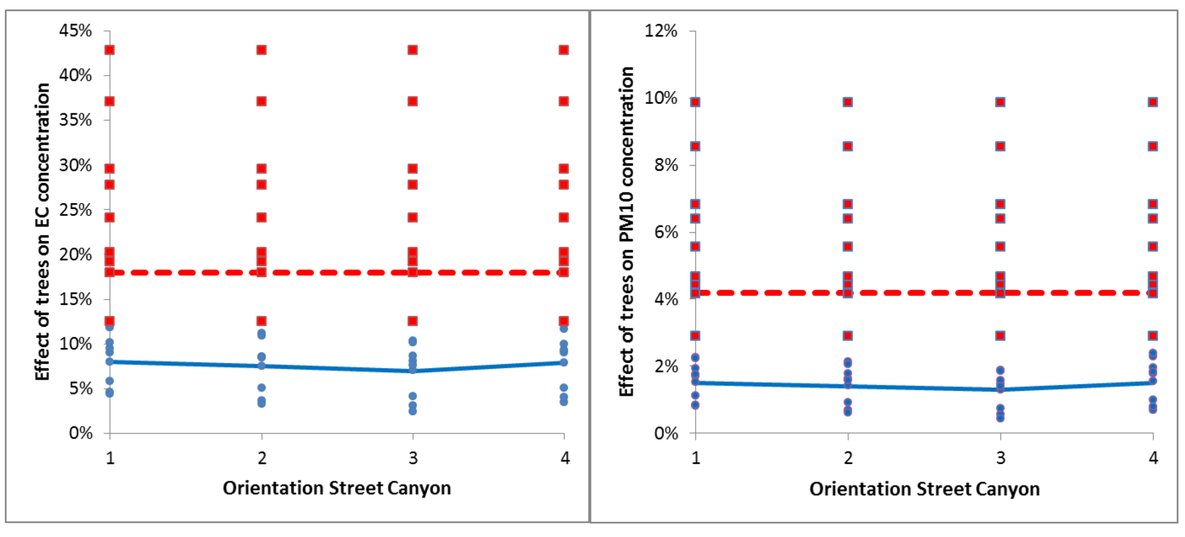

Fig 3: The annual effect of trees on EC and PM10 concentrations in an urban street canyon, for each street canyon orientation (N-S, W-E, NE-SW, NW-SE) data for 9 different vegetation types (blue dots) are presented and an average Belgian vegetation type is shown by the full line. Red squares represent worst-case-scenario of perpendicular wind direction and full-leaved trees, the dashed line indicates worst-case-influence for average vegetation.

REFERENCES:

CODASC, 2008. Concentration data of street canyons. Internet Database. Karlsruhe Institute of Technology KIT, Germany. www.codacs.de.

Buccolieri, R., Gromke, C., Di Sabatino, S., Ruck, B., 2009. Aerodynamic effects of trees on pollutant concentration in street canyons. Sci. Total Environ. 407, 5247–56.

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