2017 TRAVEL AWARD FOR YOUNG INVESTIGATORS

CFD MODELLING OF THE IMPACT OF URBAN HEDGEROWS ON AIR QUALITY IN AN IDEALIZED STREET CANYON

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This poster presents a study of the effects of hedges on pollutant dispersion in an idealized street canyon of width-to-building height aspect ratio equal to 2. The dispersion of traffic pollutants is analyzed by CFD simulations and wind tunnel experiments.

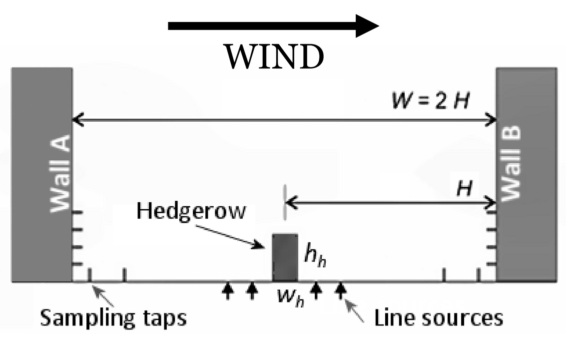
Wind tunnel experiments

(Gromke et al., 2016; Atmospheric Environment, 139, 75-86)

a) Geometry and set-up

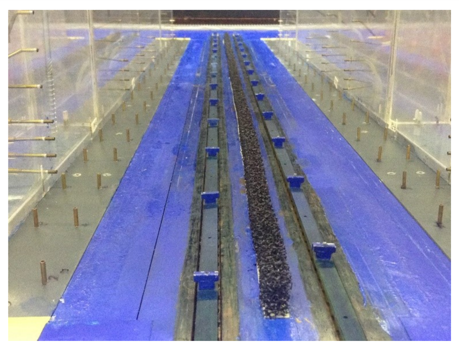
- Wind tunnel model: scale 1:150
- Isolated urban street canyon: length L = 180m, height H = 18m and width W = 36m, i.e. aspect ratios W/H = 2 and L/H = 10
- One central hedgerow placed on the street
- Boundary layer flow: $\frac{U(z)}{U(z_{ref})} = \left(\frac{z}{z_{ref}}\right)^{\alpha_U}$ $\frac{I(z)}{I(z_{ref})} = \left(\frac{z}{z_{ref}}\right)^{-\alpha_I}$

$U(z_{ref}) = u_H$ = 4.65m/s
α_U = 0.30
α_I = 0.36



- Four tracer gas emitting line sources
- Concentration measurement sampling taps at the bottom of the building walls (28 at each wall) and in the reduced traffic zones at pedestrian level (40 at each floor).
- Samples were analysed by Electron Capture Detection (ECD) yielding mean concentrations and normalized according to: $c^+ = \frac{c U_H H}{Q_l}$

c = measured concentration
Q_l = source strength per unit length of the gas emission



b) Vegetation model

- Porous open-cell foam materials, with pore volume fractions - pressure loss coefficient λ :
  - 96.1% - 250m[-1] (1.67m[-1] at full scale)
  - 94.5% - 500m[-1] (3.34m[-1] at full scale)
- Full-scale hedgerows of height either h_h = 1.50m or 2.25m and width w_h = 1.50m

CFD modelling simulations

a) Flow and dispersion set-up

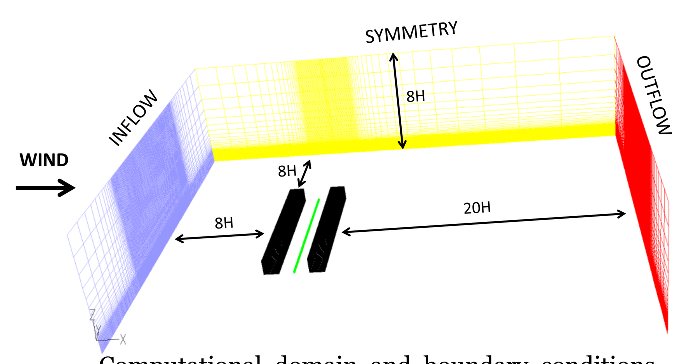
- FLUENT (commercial CFD code)
- RANS-Equations
- turbulence closure scheme
  - standard k-ε
- second order discretization schemes
- grid: hexahedral elements
  - ~ 1,500,000
  - δ_x=0.05H, δ_y=0.05H, δ_z=0.03H
  - expansion rate <1.3
- turbulent Schmidt number Sc_t = 0.3; 0.5; 0.7

$Sc_t = \frac{\nu_t}{D_t}$ $\left(\frac{turbulent\ viscosity}{turbulent\ diffusivity}\right)$

INLET

$$\frac{u(z)}{u_H} = \left(\frac{z}{H}\right)^{\alpha} \quad k = \frac{u_*^2}{\sqrt{C_\mu}}\left(1-\frac{z}{\delta}\right) \quad \varepsilon = \frac{u_*^3}{\kappa z}\left(1-\frac{z}{\delta}\right)$$

u_* =0.52 m/s: friction velocity
κ=0.40: von Kàrmàn constant
C_μ = 0.09



Computational domain and boundary conditions for the perpendicular wind

b) Vegetation model

- Momentum sink term added to standard fluid flow equations

$$S_i = -LAD c_d U u_i$$

where LAD = λ/c_d

u_i = wind velocity component
U = wind speed
c_d = 0.2: drag coefficient for vegetation (dimensionless)
LAD: leaf area density [m[2]m[-3]]

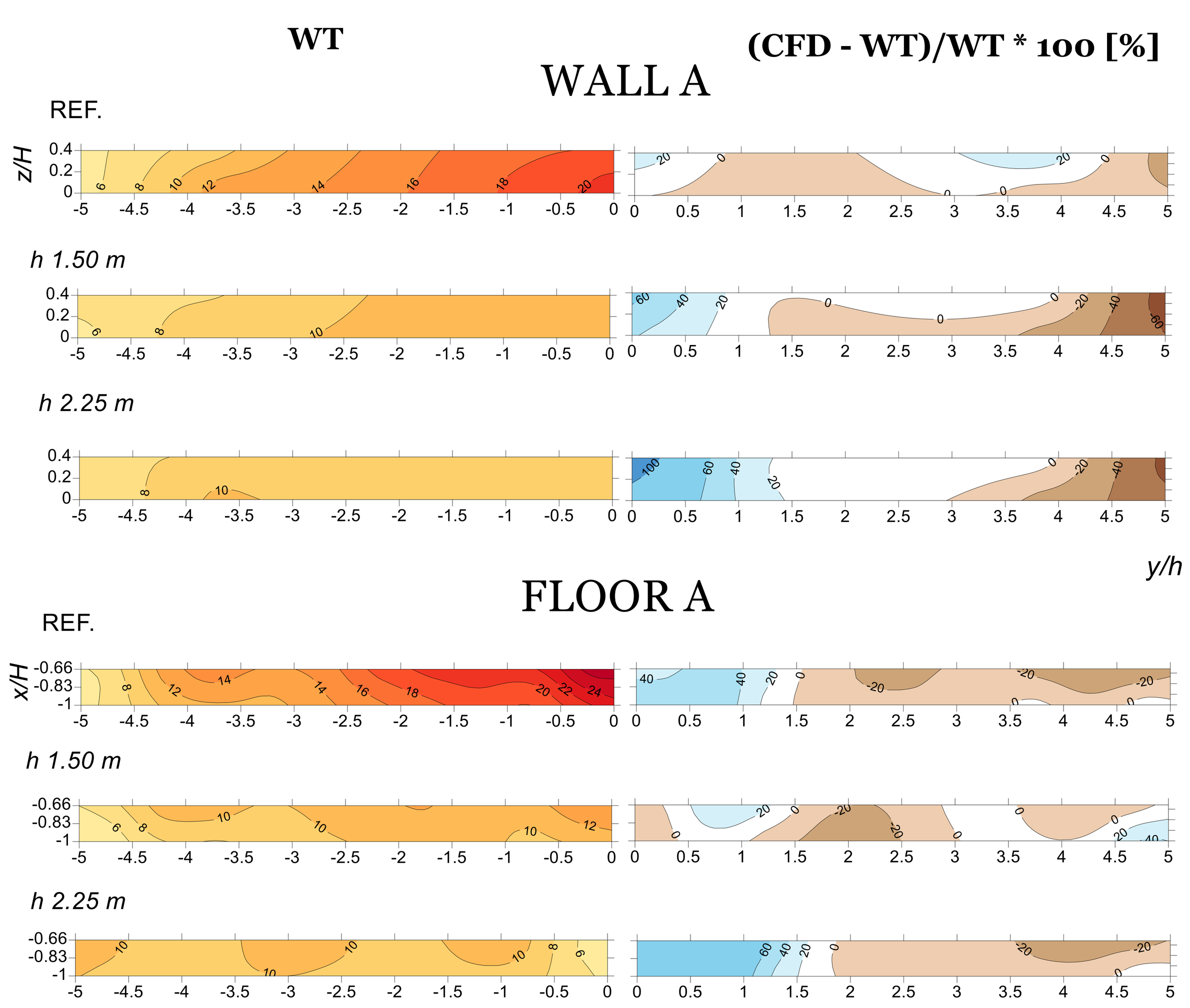
Summary of cases investigated

(dimensions in full scale) by wind tunnel experiments and CFD simulations (Note: n=no; y=yes; ref.=reference case (no hedges)

	Hedge height h_h (m)			Pressure loss coefficient λ (m[-1])			Wind direction (°)	
	1	1.5	2.25	0 (ref.)	1.67	3.34	90 (perp.)	45 (oblique)
WT	n	y	y	y	y	y	y	n
CFD	y							y

Results

Validation (90°, perpendicular)



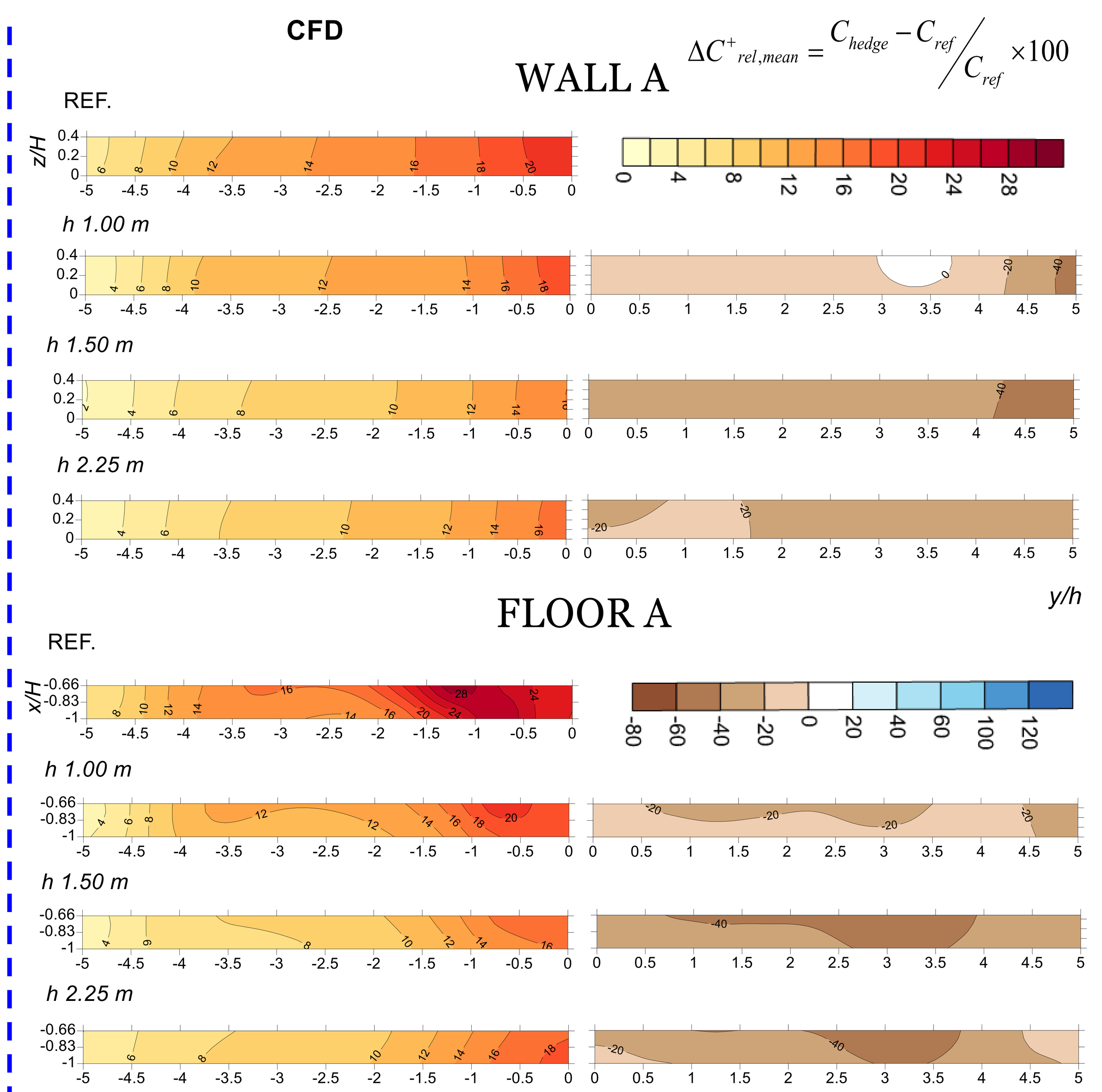
λ (m[-1])	h_h (m)	WALL A		WALL B		FLOOR A		FLOOR B	
		WT	CFD	WT	CFD	WT	CFD	WT	CFD
1.67	1.50	-27	-34	-23	-43	-38	-41	-18	-42
	2.25	-30	-29	-38	-46	-42	-38	-60	-44
3.34	1.50	-38	-33	-40	-44	-48	-41	-40	-43
	2.25	-40	-28	-52	-46	-49	-38	-44	-44

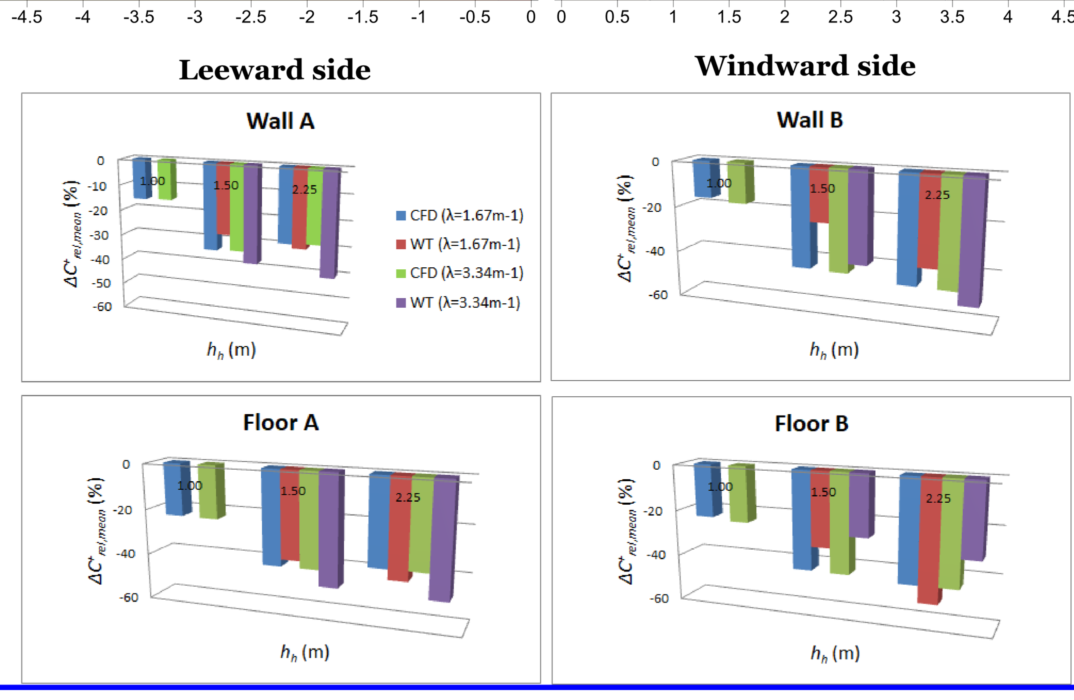
Percentage differences of concentrations for street canyons with hedges referred to the reference case: $(C_{hedge} - C_{ref})/C_{ref}$ *100

Note: Sc_t=0.7 for reference case, Sc_t=0.5 for h_h=1m and Sc_t=0.3 for the other cases

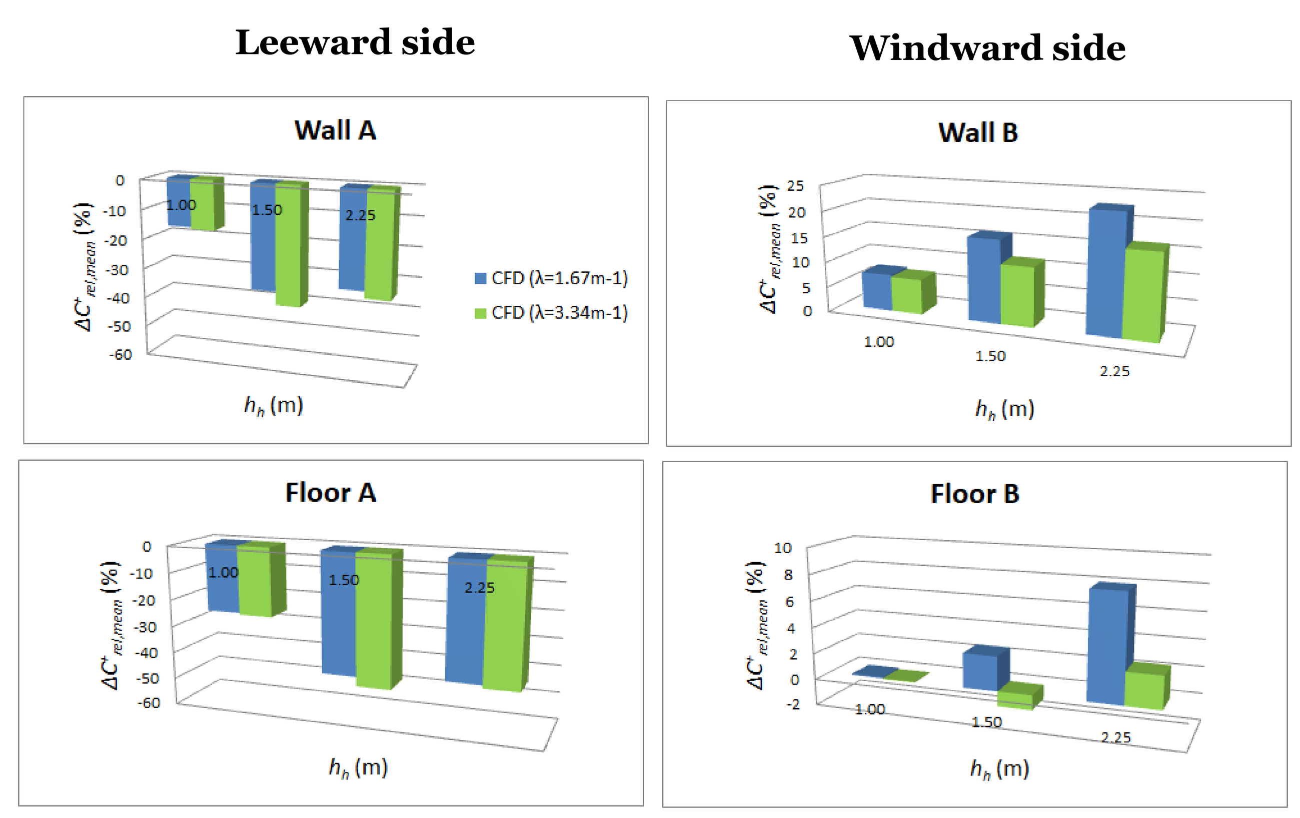
The effect of hedges (90°, perpendicular)

$$\Delta C^+_{rel,mean} = \frac{C_{hedge} - C_{ref}}{C_{ref}} \times 100$$





The effect of hedges (45°, oblique)



Conclusions

- **Perpendicular wind direction (90°)**
  - Percentage differences quantitatively well predicted by the CFD model at both walls and floors
  - Higher hedges require lower values of Sc_t: the higher the hedge, the more the flow field is disturbed
  - The positive impact of hedges increases with increasing (i) hedge height from h_h=1m to h_h=1.50m; and (ii) λ (or LAD), i.e. decreasing hedge porosity
- **Oblique wind direction (45°)**
  - Similar to the perpendicular wind direction case, at the leeward side (side A) the positive impact of hedges increases with increasing height and porosity
  - At the windward side (side B), the impact of hedges turns to be adverse, with percentage increases up to about 20%. The negative impact (i) increases with increasing hedges height from h_h=1m to h_h=1.50m and 2.25m, due to the increased disturbance compared to the reference case; and (ii) decreases with increasing λ (or LAD)
  - Overall, concentrations at the windward side are much lower than those at the leeward side, and thus an overall decrease in concentrations occurs in the street canyon