The Role of Vegetation in Traffic Emission Dispersion and Air Quality in Urban Street Canyons

13th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

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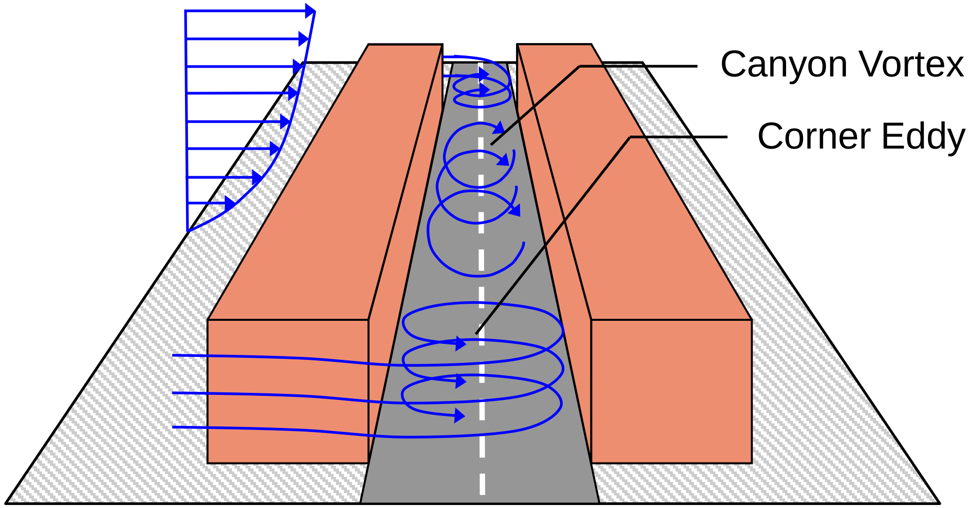
Basics of Flow and Pollutant Dispersion in Street Canyons

Long street canyon ($L/H > 7$ and $0.7 \leq W/H \leq 2.2$)

urban street canyon



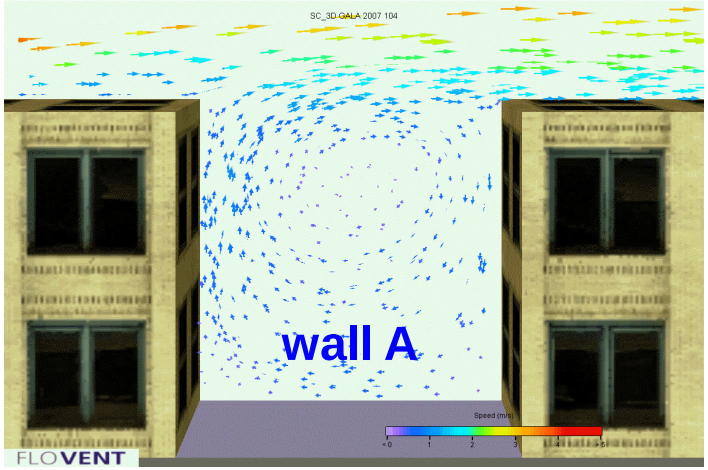
idealized street canyon

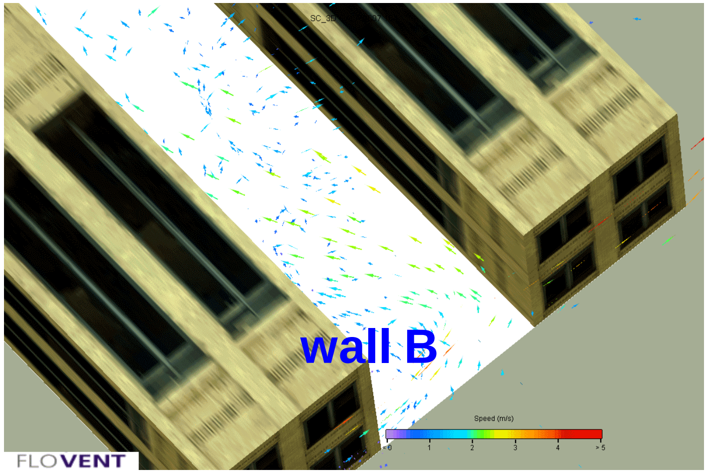
approaching wind perpendicular to street axis

- two dominating large scale vortex structures
  - Canyon Vortex
  - Corner Eddy
- superposition at street canyon ends

Basics of Flow and Pollutant Dispersion in Street Canyons

long street canyon, incident flow $\alpha = 90°$





Canyon Vortex

Corner Eddy

numerical simulation with k-ε turbulence closure scheme

Urban Street Canyons with Avenue-like Tree Planting

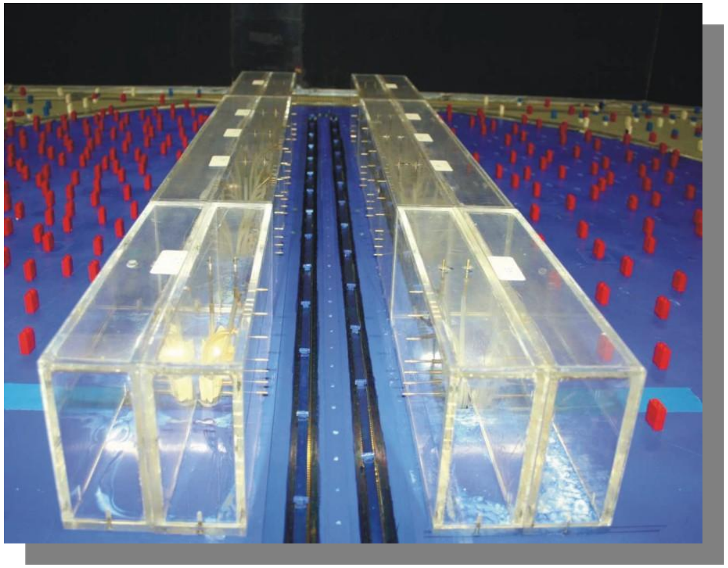
Implications of Trees on Flow and Pollutant Dispersion?

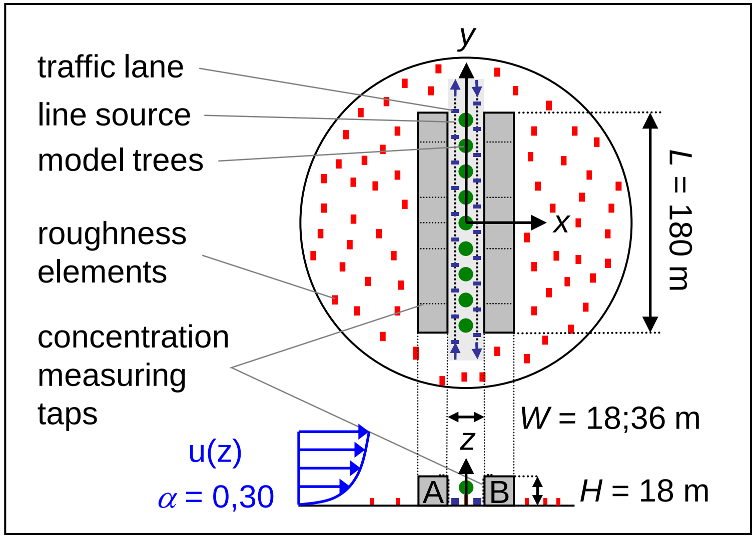
Approach

Street Canyon Model and Boundary Layer Wind Tunnel

Street canyon model (scale 1:150)

- isolated long street canyon (L/W = 10, W/H = 1;2)
- line source at street level
- tracer gas (sulfur hexafluoride SF_6)
- 126 measurement taps at canyon walls
- traffic induced turbulence



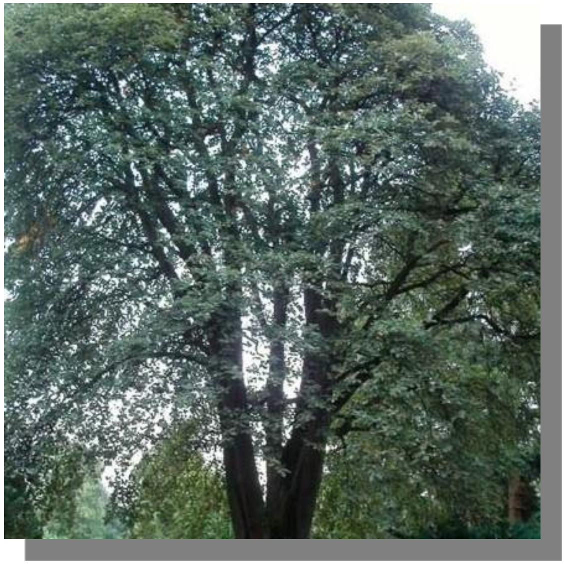


Boundary layer wind tunnel

- closed-circuit BLWT
- vortex generators and roughness elements
- adjustable ceiling
- power law profile exponent α = 0.30
- u_δ = 7 ms^{-1}, u_H = 4.65 ms^{-1}
- Reynolds-No. Re = 37.000

Wind Tunnel Trees – Modeling Approach

Aerodynamic of trees



is governed by crown porosity

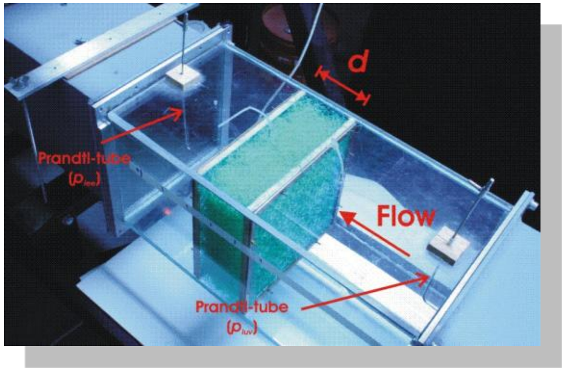
- permeable for wind
- form and skin drag (volume specific surface)
- wake characteristics

Characterization of crown porosity/permeability

- pressure loss coefficient *λ*

$$\lambda = \frac{\Delta p_{stat}}{p_{dyn}\, d} = \frac{p_{luv} \quad p_{lee}}{1/2\, \rho\, u^2\, d} \qquad [m^{-1}]$$

integral measure for flow resistance

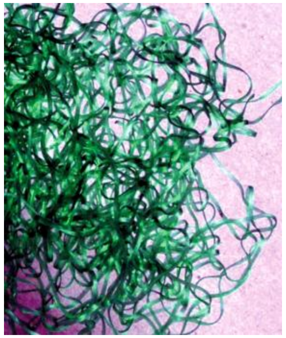


Similarity requirement

$$\left.\frac{\Delta p}{p_{dyn}}\right|_{model} = \left.\frac{\Delta p}{p_{dyn}}\right|_{field} \Leftrightarrow [\lambda\, d]_{model} = [\lambda\, d]_{field} \Leftrightarrow \frac{\lambda_{field}}{\lambda_{model}} = \frac{d_{model}}{d_{field}} = M$$

Wind Tunnel Trees – Modeling Approach

Realization of model trees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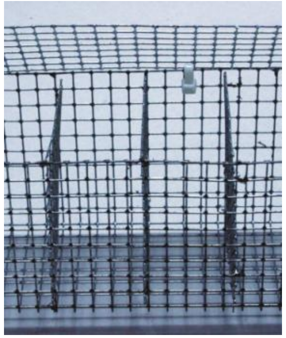
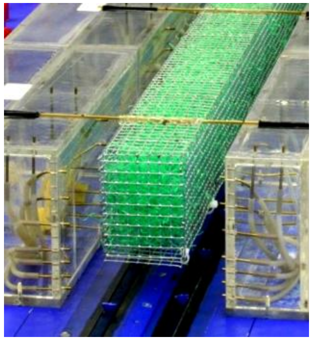


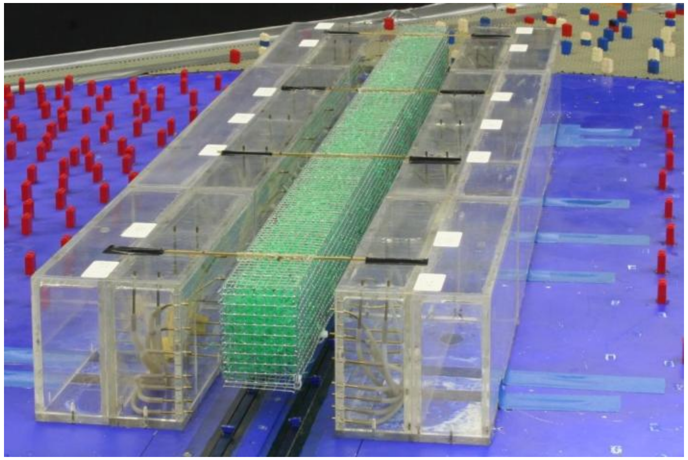
Modeling of trees/avenue-like tree planting

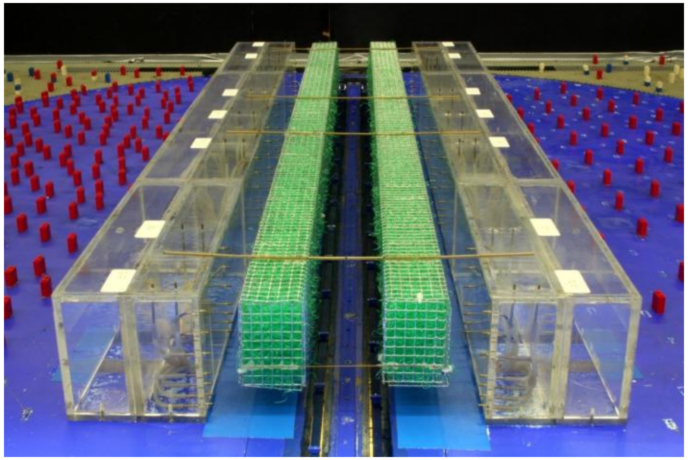
- crown porosity/permeability
  - P_{Vol} = 97.5 … 96%
  - λ_{model} = 80 … 250 m^{-1}
- planting density (#trees/unit length)
- similarity criterion

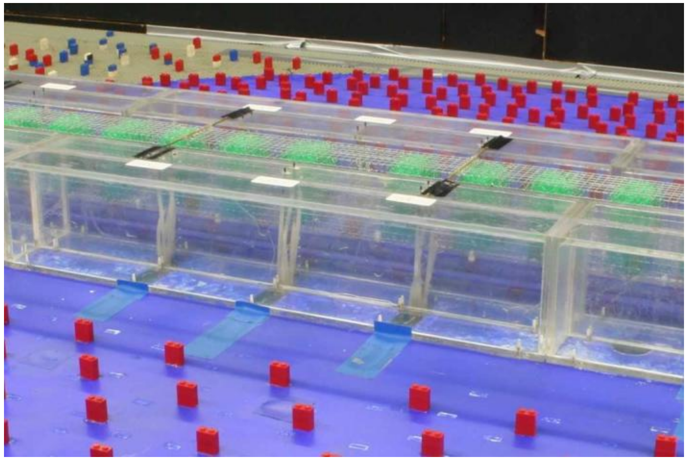
Application of similarity criterion

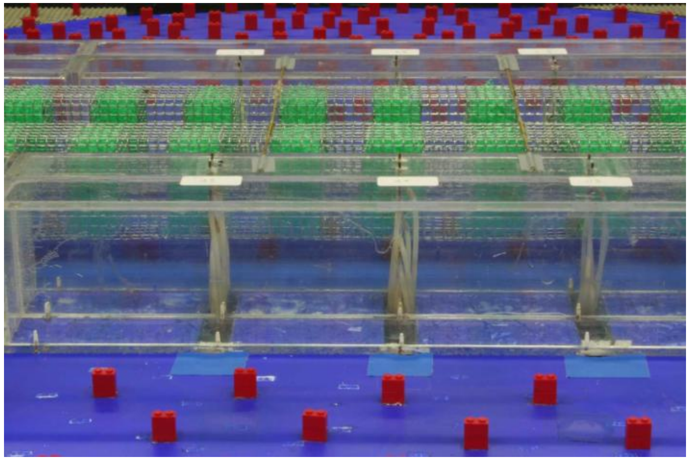
- λ of tree crowns not available
- λ of vegetation shelterbelts (Grunert et al. 1984)
  - λ_{field} = 0.4 … 13.4 m^{-1}
- Similarity criterion: $\lambda_{field} / \lambda_{model} = M$
  - λ_{model} = 60 … 2000 m^{-1}

Street Canyon with Model Trees









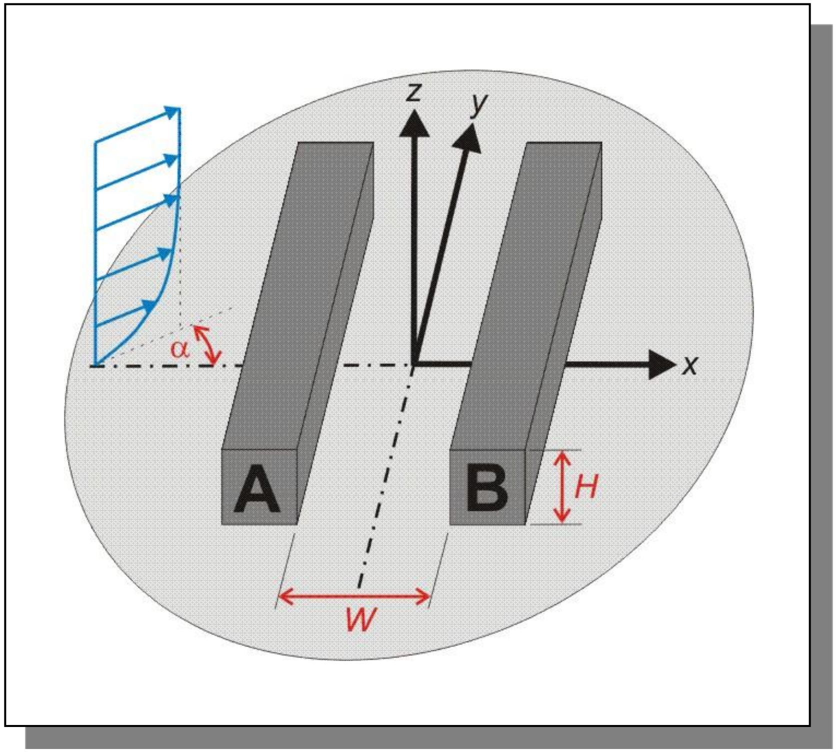
Overview: Wind Tunnel Experiments

Parameter study comprising 40 experiments

Variation of

- street width to building height ratio *W/H*
- angle of approaching flow α
- planting density ρ_b
- crown permeability λ (crown porosity P_{Vol})
- tree rows

  (closed or open tree crown canopy)
- traffic situation



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(**Co**ncentration **Da**ta of Street **Ca**nyons)

Overview: Wind Tunnel Experiments

Parameter study comprising 40 experiments

Variation of

- street width to building height ratio *W*/*H*
- angle of approaching flow α
- planting density ρ_b (#trees/unit length)
- crown permeability λ (crown porosity P_{Vol})
- tree rows

  (closed or open tree crown canopy)
- traffic situation

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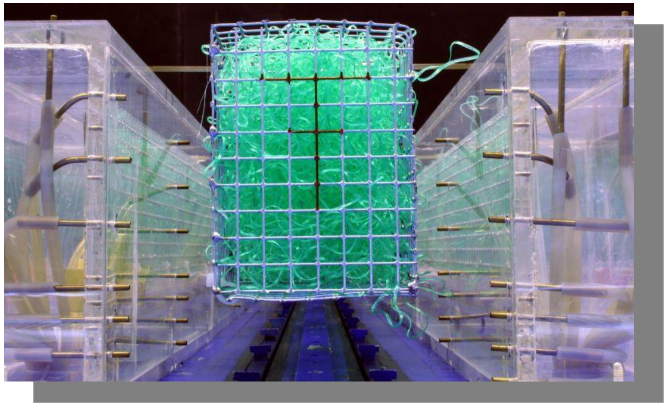
(**Co**ncentration **Da**ta of **S**treet **Ca**nyons)

Overview: Wind Tunnel Experiments

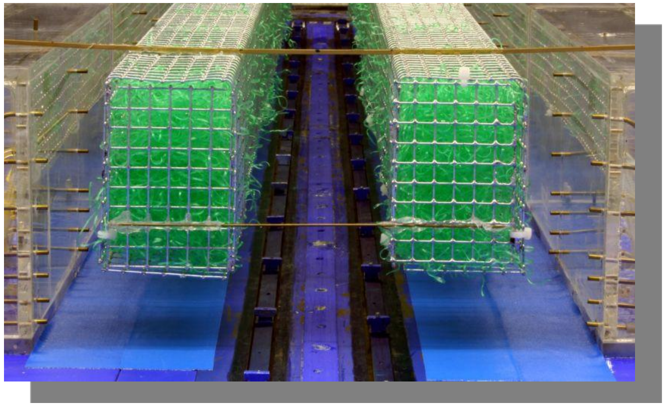
Parameter study comprising 40 experiments



Variation of

- street width to building height ratio *W*/*H*
- angle of approaching flow α
- planting density ρ_b
- crown permeability λ (crown porosity P_{Vol})
- tree rows

  (closed or open tree crown canopy)
- traffic situation



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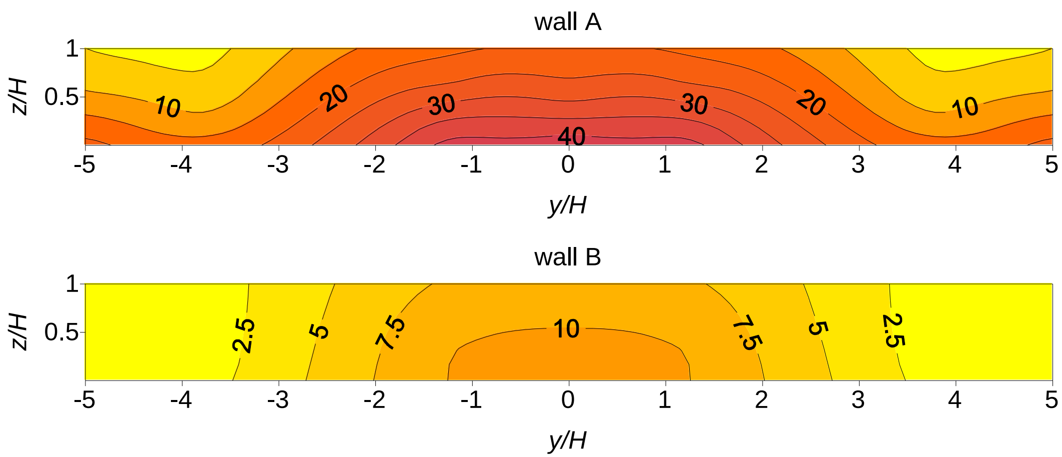
(**Co**ncentration **Da**ta of Street **Ca**nyons)

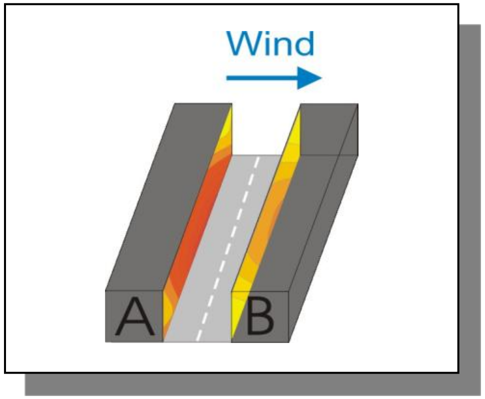
Measurement Results

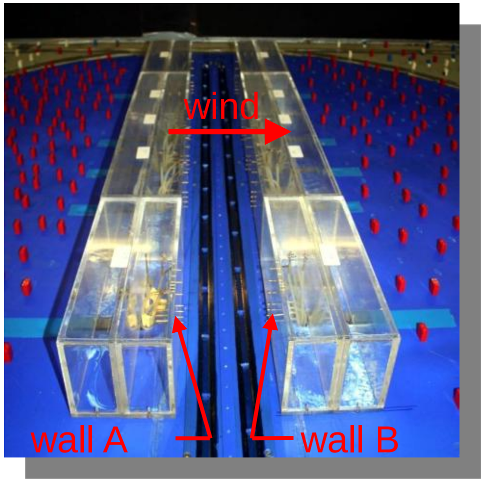
Pollutant Concentrations in narrow Street Canyon ($W/H = 1$, $\alpha = 90°$)

Tree-free street canyon with wind approaching perpendicular



normalized concentrations c^+ [-]



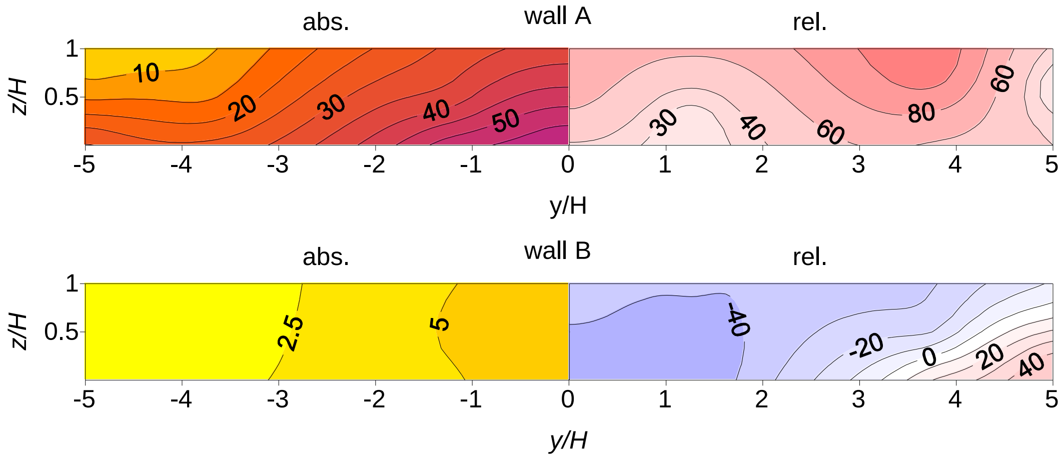


- max. concentrations in central part of wall A close to the ground
- concentrations at leeward wall A > windward wall B
  (in wall average by 3.6)
- concentration decreases towards street ends
- concentration gradients give evidence for vortex structures

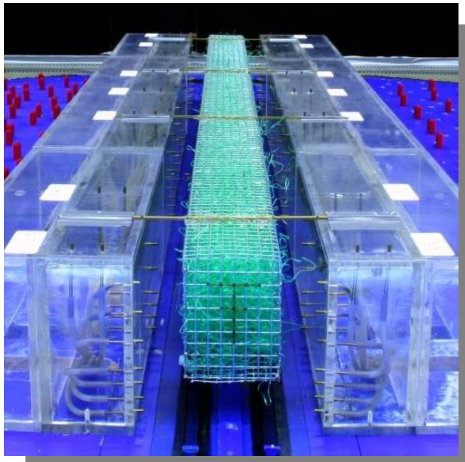
Pollutant Concentrations with Avenue-like Tree Planting (W/H = 1, α = 90°)

Single-row tree planting

- high planting density ρ_b = 1.0, high crown porosity λ = 80 m^{-1} (P_{Vol} = 97.5%)



$$\text{rel. change } \delta_c^+ = (c_{tree}^+ - c_{ref}^+)/c_{ref}^+$$



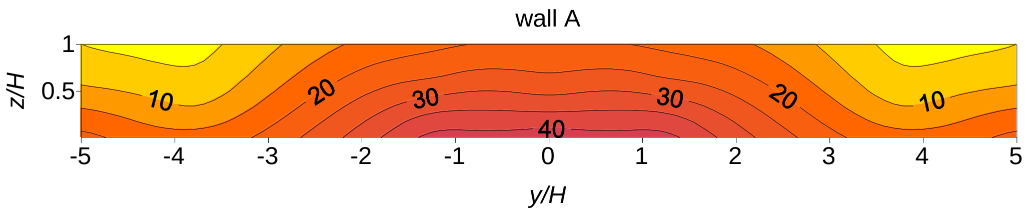
in comparison to tree-free street canyon

- increase in concentrations at wall A (wall average: +41%)
- decrease in concentrations at wall B (wall average: -38%)
- in total: concentration increase

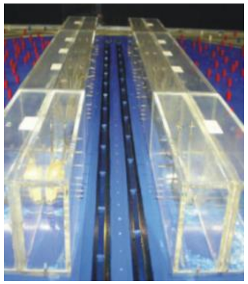
Pollutant Concentrations with Avenue-like Tree Planting (W/H = 1, α = 90°)

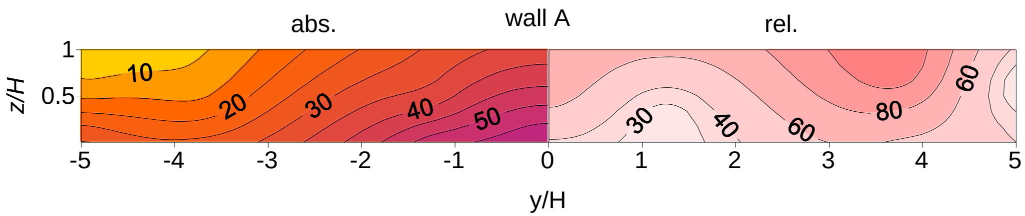
Influence of decreased crown porosity/permeability

- high planting density ρ_b = 1.0

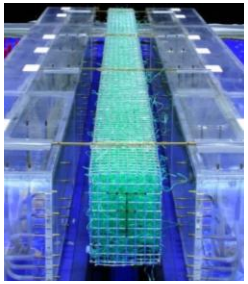


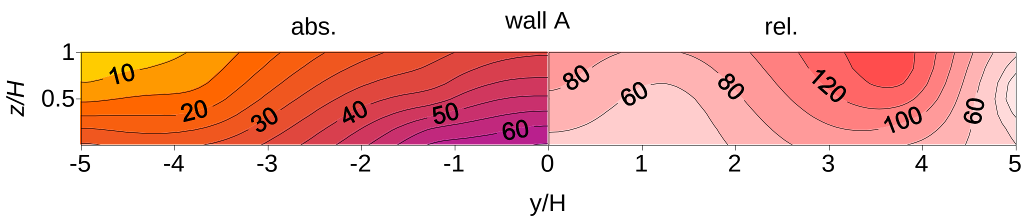
tree-free





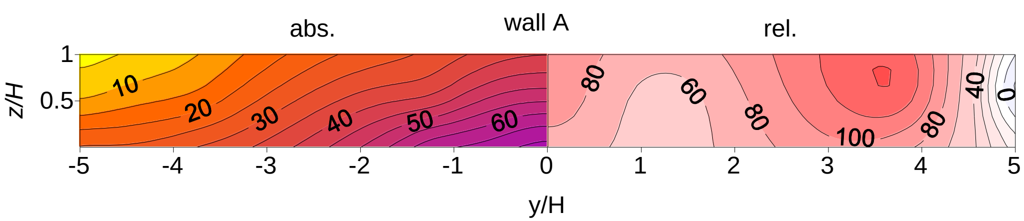
λ = 80m^{-1}
P_{Vol} = 97.5%



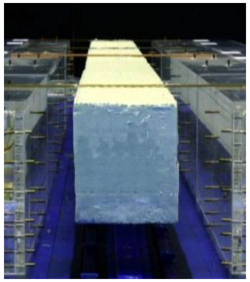


λ = 200 m^{-1}
P_{Vol} = 96%

- P_{Vol}
+ λ

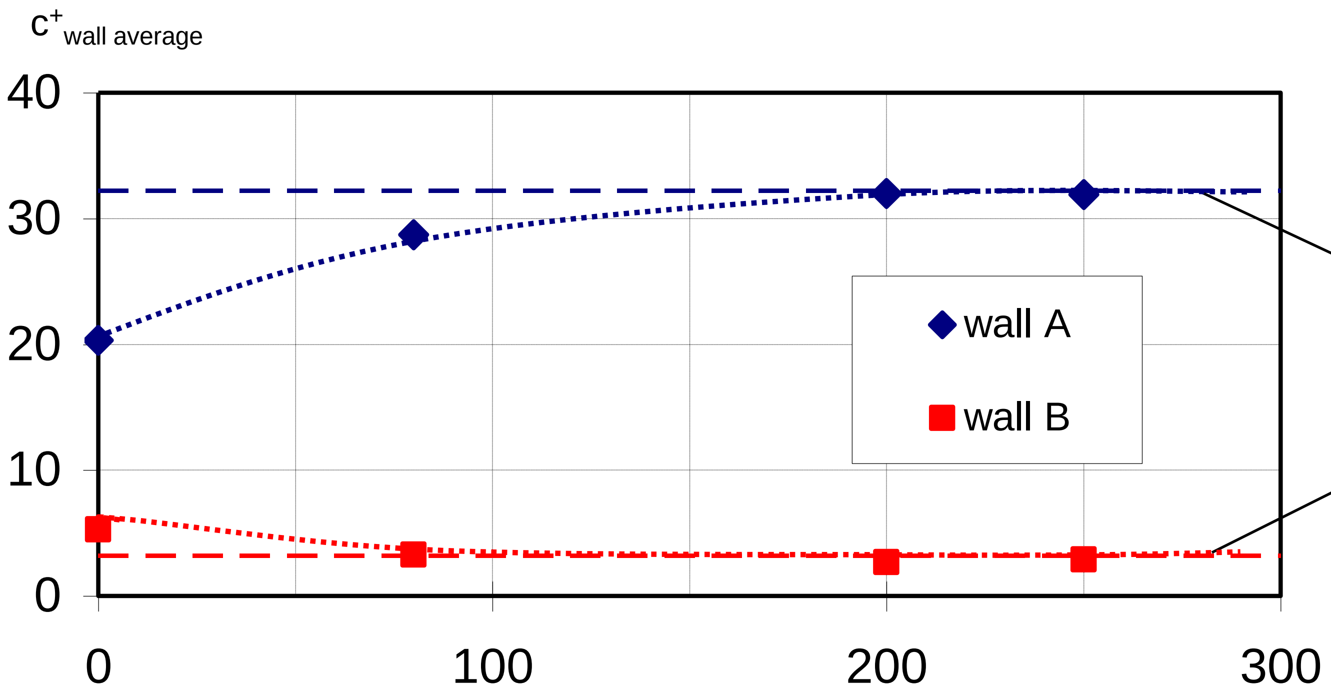


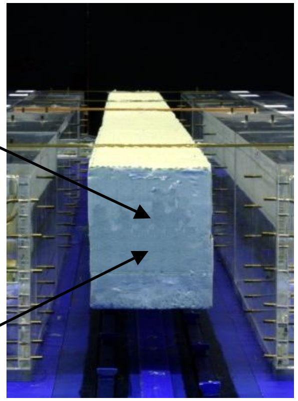
λ = ∞
P_{Vol} = 0%



Parameter Study on the Influence of Crown Permeability λ

Single-row tree planting (W/H = 1, α = 90°, high planting density ρ_b = 1)





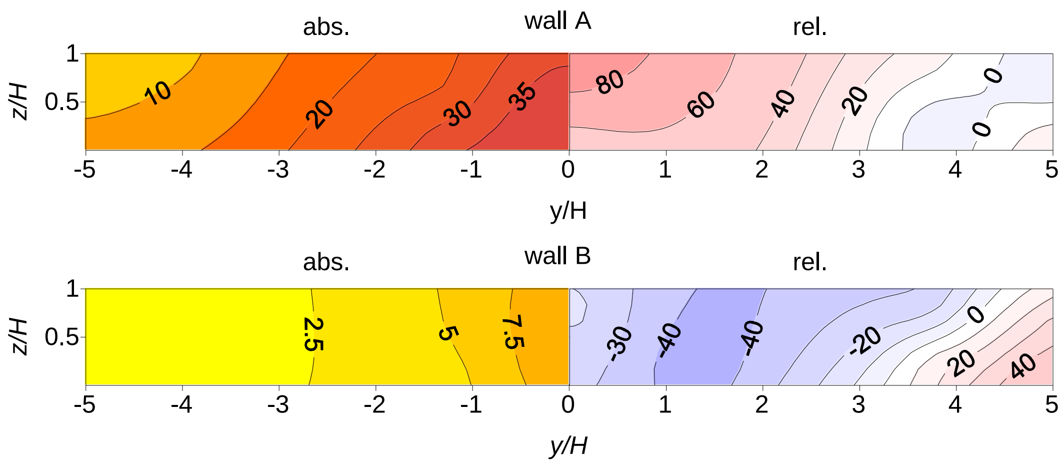
"impermeable" tree crown ($\lambda = \infty$)

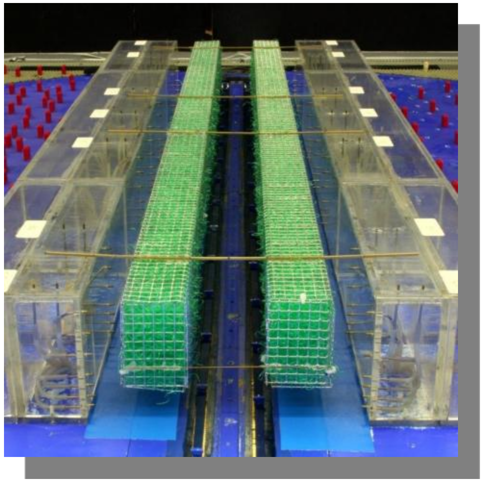
- wall A: increase of c^+_{wall} increasing λ, max. change +60%
- wall B: decrease of c^+_{wall} increasing λ, max. change -50%
- asymptotic limit

Pollutant Concentrations in Broad Street Canyon (*W*/*H* = 2)

Two-row tree planting (*W*/*H* = 2, *α* = 90)

- high planting density ρ_b = 1.0, low crown porosity λ = 200 m^{-1} (P_{Vol} = 96.0 %)





in comparison to tree-free street canyon (*W*/*H* = 2)

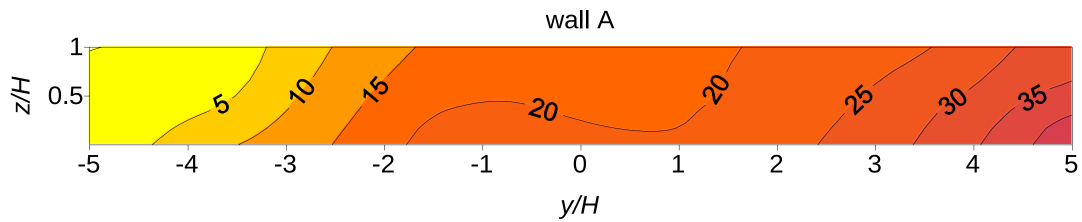
- increase in concentrations at wall A (wall average: +41 %)
  - max. increases in the canyon center
- decrease in concentrations at wall B (wall average: -32 %)

→ implications analog to narrow street canyon (*W*/*H* = 1)

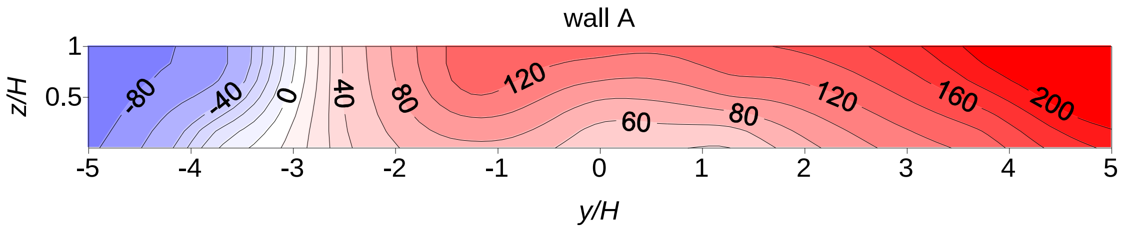
Pollutant Concentrations for Inclined Approaching Flow (W/H = 2, α = 45°)

Two-row tree planting (W/H = 2, α = 45)

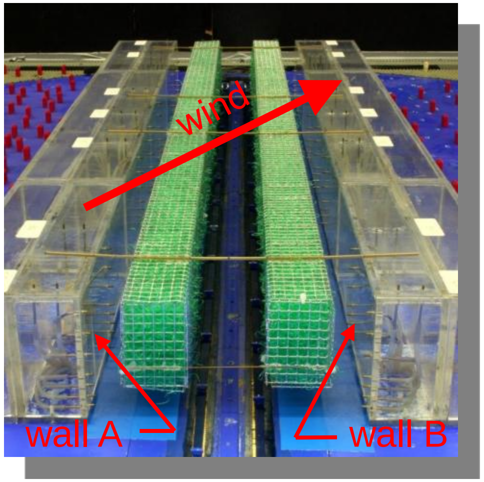
- high planting density ρ_b = 1.0, low crown porosity λ = 200 m^{-1} (P_{Vol} = 96.0 %)



norm. concentrations c^+ [-]



rel. changes δ_c^+ [-]



- increases/decreases of concentrations at wall A (average: +88 %)
- increases in concentration at wall B
- accumulative traffic pollutant transport along street canyon axis
- max. pollutant concentrations at canyon end
- max. rel. changes in concentration for inclined approaching flow

Maximum Pollutant Concentration

Maximum Pollutant Concentration at Canyon Wall

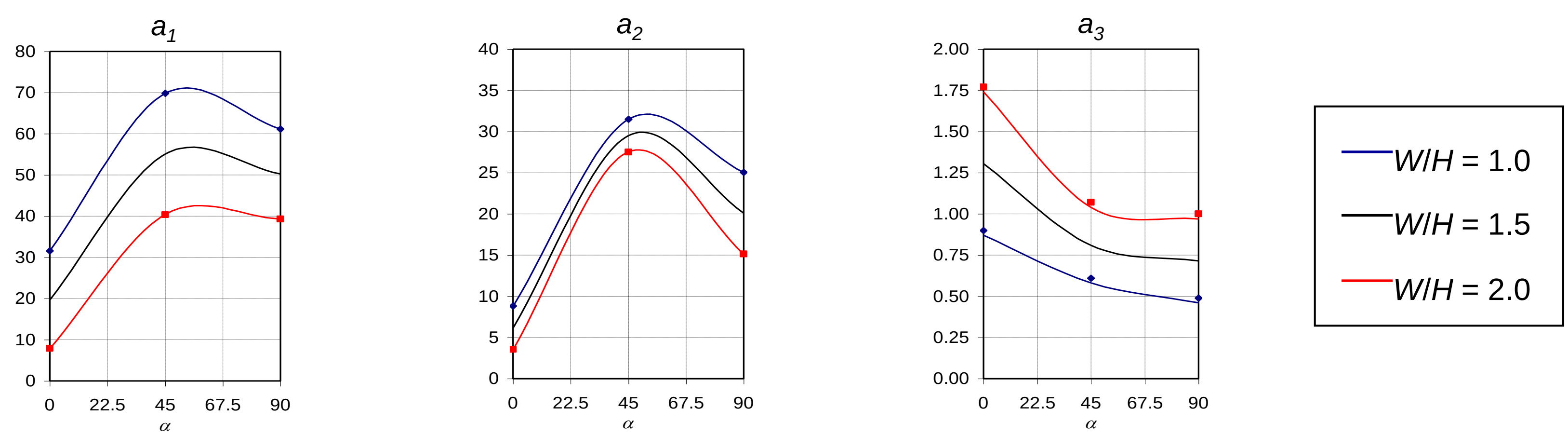
Estimate for maximum traffic pollutant concentration c^+_{max} was derived based on

- 40 wind tunnel experiments
- dimensional analysis

$$c^+_{max} = f\left(\frac{W}{H}, \rho_b, P_{Vol}, \alpha\right)$$

$$c^+_{max} = a_1 - a_2\, e^{-a_3 \{\rho_b (100 - P_{Vol})\}}$$

$$a_i = f\left(\frac{W}{H}, \alpha\right)$$

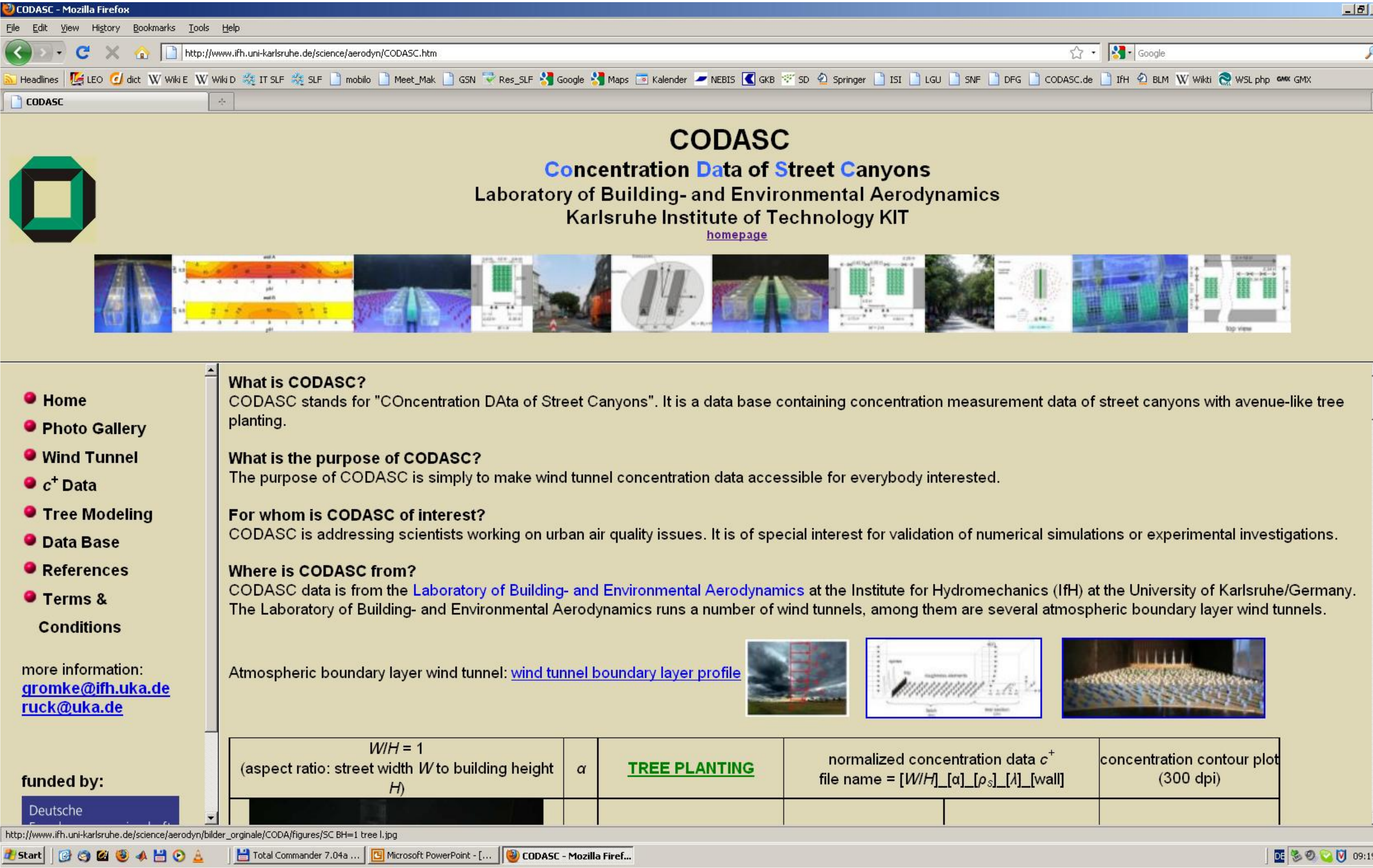


CODASC

CODASC

CODASC - Concentration Data of Street Canyons

- Internet data base
- collection of wind tunnel concentration data
- comprises more than 40 street canyon/tree planting configurations
- contains also information on
  - approaching flow characteristics
  - street canyon geometry
  - vegetation/tree modeling approach
- purpose: serve for the validation of numerical models and simulations



CODASC - Mozilla Firefox

http://www.ifh.uni-karlsruhe.de/science/aerodyn/CODASC.htm

CODASC

Concentration Data of Street Canyons

Laboratory of Building- and Environmental Aerodynamics
Karlsruhe Institute of Technology KIT
homepage

- Home
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- Wind Tunnel
- c^+ Data
- Tree Modeling
- Data Base
- References
- Terms & Conditions

more information:
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ruck@uka.de

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Deutsche

What is CODASC?
CODASC stands for "COncentration DAta of Street Canyons". It is a data base containing concentration measurement data of street canyons with avenue-like tree planting.

What is the purpose of CODASC?
The purpose of CODASC is simply to make wind tunnel concentration data accessible for everybody interested.

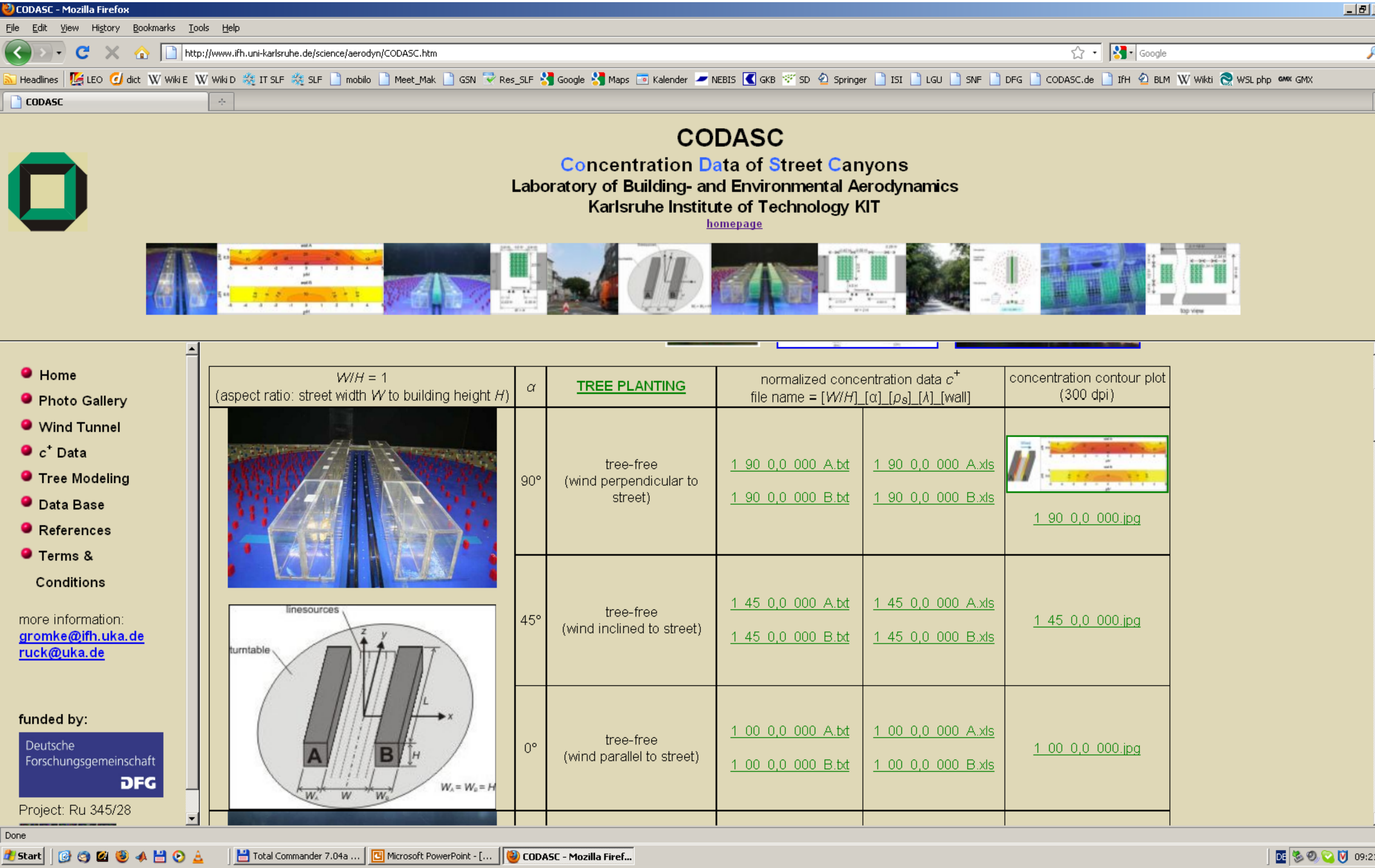
For whom is CODASC of interest?
CODASC is addressing scientists working on urban air quality issues. It is of special interest for validation of numerical simulations or experimental investigations.

Where is CODASC from?
CODASC data is from the Laboratory of Building- and Environmental Aerodynamics at the Institute for Hydromechanics (IfH) at the University of Karlsruhe/Germany. The Laboratory of Building- and Environmental Aerodynamics runs a number of wind tunnels, among them are several atmospheric boundary layer wind tunnels.

Atmospheric boundary layer wind tunnel: wind tunnel boundary layer profile

W/H = 1 (aspect ratio: street width *W* to building height *H*)	*α*	TREE PLANTING	normalized concentration data c^+ file name = [*W/H*]_[α]_[ρ_S]_[*λ*]_[wall]	concentration contour plot (300 dpi)

http://www.ifh.uni-karlsruhe.de/science/aerodyn/bilder_orginale/CODA/figures/SC BH=1 tree l.jpg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more information:
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funded by:
Deutsche Forschungsgemeinschaft DFG
Project: Ru 345/28
W/H = 1 (aspect ratio: street width W to building height H)
α
TREE PLANTING
normalized concentration data c+ file name = [W/H]_[α]_[ρs]_[λ]_[wall]
concentration contour plot (300 dpi)
90°
tree-free (wind perpendicular to street)
1_90_0,0_000_A.txt
1_90_0,0_000_B.txt
1_90_0,0_000_A.xls
1_90_0,0_000_B.xls
1_90_0,0_000.jpg
45°
tree-free (wind inclined to street)
1_45_0,0_000_A.txt
1_45_0,0_000_B.txt
1_45_0,0_000_A.xls
1_45_0,0_000_B.xls
1_45_0,0_000.jpg
0°
tree-free (wind parallel to street)
1_00_0,0_000_A.txt
1_00_0,0_000_B.txt
1_00_0,0_000_A.xls
1_00_0,0_000_B.xls
1_00_0,0_000.jpg
linesources
turntable
A
B
Done
Start
Total Commander 7.04a ...
Microsoft PowerPoint - [...
CODASC - Mozilla Firef...
09:21

CODASC

CODASC

Concentration Data of Street Canyons

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Summary and Conclusions

Summary and Conclusion

- **Vegetation/Tree modeling approach for wind tunnel studies**

  - accounts for the porosity/permeability of tree crowns/vegetation
  - is based on similarity criterion
  - proofed to give reasonable results in wind tunnel dispersion studies

- **Tree planting and traffic pollutant concentrations**

  - tree planting resulted in higher/lower concentrations at the leeward/windward wall
  - overall increase in traffic pollutant concentrations
  - max. concentrations for flow approaching inclined

- **Maximum pollutant concentration**

  - for regulatory purposes in dispersion modeling
  - can be used by town planers to estimate the implications of trees on pollutant concentrations

- **CODASC – Concentration Data of Street Canyons**

  - comprises more than 40 wind tunnel experiments
  - is a useful tool for validation of CFD codes and numerical simulations

Appendix

Related Journal Papers

Buccolieri, R., Gromke, C., Di Sabatino, S., Ruck, B. (2009) Aerodynamic effects of trees on pollutant concentration in street canyons, Science of the Total Environment, Vol. 407, No. 19, pp. 5247-5256.

Gromke, C., Ruck, B., (2009) Effects of trees on the dilution of vehicle exhaust emissions in urban street canyons, International Journal of Environment and Waste Management, Vol. 4, No. 1/2, pp. 225-242.

Balczó, M., Gromke, C., Ruck, B. (2009) Numerical modeling of flow and pollutant dispersion in street canyons with tree planting, Meteorologische Zeitschrift, Vol. 18, pp. 197-206.

Gromke, C., Ruck, B. (2009) On the impact of trees on dispersion processes of traffic emissions in street canyons, Boundary-Layer Meteorology, Vol.131, pp. 19-34.

Gromke, C., Buccolieri, R., Di Sabatino, S., Ruck, B. (2008) Dispersion modeling study in a street canyon with tree planting by means of wind tunnel and numerical investigations - Evaluation of CFD data with experimental data, Atmospheric Environment, Vol. 42, pp. 8640-8650.

Gromke, C., Ruck, B. (2008) Aerodynamic modeling of trees for small scale wind tunnel studies, Special Issue on Wind and Trees in Forestry, Vol. 81, No. 3, pp. 243-258.

Gromke, C., Ruck, B. (2007) Influence of trees on the dispersion of pollutants in an urban street canyon – experimental investigation of the flow and concentration field, Atmospheric Environment, Vol. 41, pp. 3387-3302.

Under Review

Gromke, C., Ruck, B. () Wind-tunnel study and dimensional analysis on traffic pollutant concentrations in urban street canyons with trees, submitted to Boundary-Layer Meteorology.

Buccolieri, R., Di Sabatino, S., Salim, M. S., Ielpo, P., Gennaro de, G., Piacentino, C. M., Chan, A., Gromke, C. () Influence of tree planting on flow and pollutant dispersion in urban street canyons in Bari (Italy), submitted to Atmospheric Environment.

Measurement Instrumentation

Concentration Measurements

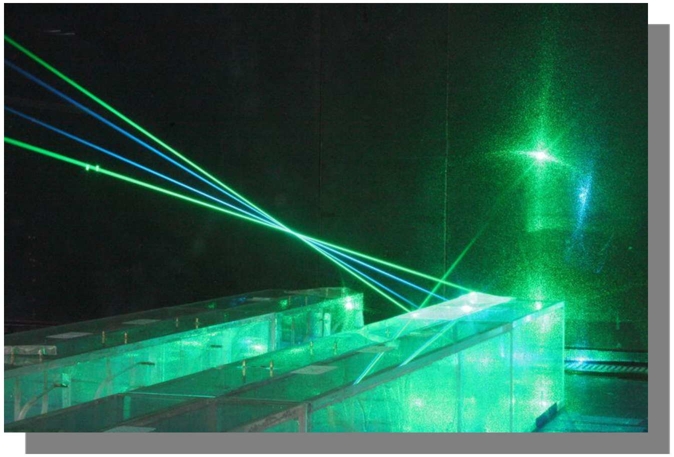
- Electron Capture Detector (ECD) model Meltron LH 108
- measurement of mean tracer gas concentrations (sulfur hexafluoride SF_6)
- determination of dimensionless concentrations c^+ according to

$$c^+ = \frac{c_m \; u_{ref} \; L_{ref}}{Q_T / l}$$

c_m measured concentration
u_{ref} reference velocity
L_{ref} reference length
Q_T/l strength of line source

Velocity Measurements

- Laser Doppler Velocimetry (LDV)
- 4 W Argon-Ion Laser
- 2-component LDV-system
- Bragg-cells 40 MHz
- backscatter system
- sampling frequency 50 Hz



Dimensional Analytical Considerations

Estimate for the max. pollutant concentration

$$c_{max} = f_1(H, B_A, B_B, L, W, x_{ls,i}, z_{ls,i}, \mathbf{x}_{k,j}, \mathbf{K}_j, P_{Vol,j}, u_H, \alpha, \nu, Q_l)$$

14 parameters

geometric

- H, B_A, B_B	building length scales
- L, W	street length scales
- $x_{ls,i}$, $z_{ls,i}$	source positions
- $\mathbf{x}_{K,j}$, $\mathbf{K}_j$,	tree positions and length scales
- $P_{Vol,j}$	crown porosity

kinematic

- u_H	char. velocity
- α	angle of approaching flow
- ν	kinematic viscosity
- Q_l	source strength

Dimensional Analytical Considerations

Elimination of parameters

- which have not been varied for the wind tunnel study
  - B_A, B_B building width
  - L street canyon length

- are considered not to vary strongly in typical urban street canyons
  - $x_{Lq,i}$, $z_{Lq,i}$ source positions
  - $x_{K,j}$, K_j positions and length scales of trees

- Buckingham π theorem
  - elimination of 2 more parameters
  - dimensionless π parameters

→ $$c_{max} = f_2\left(\frac{W}{H}, \rho_b, P_{Vol}, \alpha, Re, \frac{Q_l}{u_H H}\right)$$ (6 parameters)

Dimensional Analytical Considerations

$$c_{max} = f_2\left(\frac{W}{H}, \rho_b, P_{Vol}, \alpha, Re, \frac{Q_l}{u_H H}\right)$$

(6 parameters)

Further considerations

- π_5 Reynolds No. $Re = u_H H / \nu$
  - sharp-edged geometries → critical Reynolds number similarity Re_{crit} > 10.000
  - experimental evidence

=> c_{max} can be considered to be independent of *Re*

- π_6 dimensionless source strength $Q_l/(u_H H)$
  - $c_{max} \sim Q_l$ (twofold source strength → twofold concentration)

=> c_{max} is linear in $Q_l/(u_H H)$

→

$$c^+_{max} = f_3\left(\frac{W}{H}, \rho_b, P_{Vol}, \alpha\right)$$

(4 parameters)

Dimensional Analytical Considerations

$$c^{+}_{max} = f_3\left(\frac{W}{H}, \rho_b, P_{Vol}, \alpha\right)$$

(4 parameters)

- ρ_b planting density
- P_{Vol} crown porosity

} describe the avenue-like tree planting

Idea: combination of ρ_b und P_{Vol} to a single **"alley parameter" *AP*** which is a measure for the amount of vegetation (solid crown material)

General approach: $AP = (\rho_b)^{c_1} \bullet (100 - P_{Vol}[\%])^{c_2}$ $\quad c_i > 0$

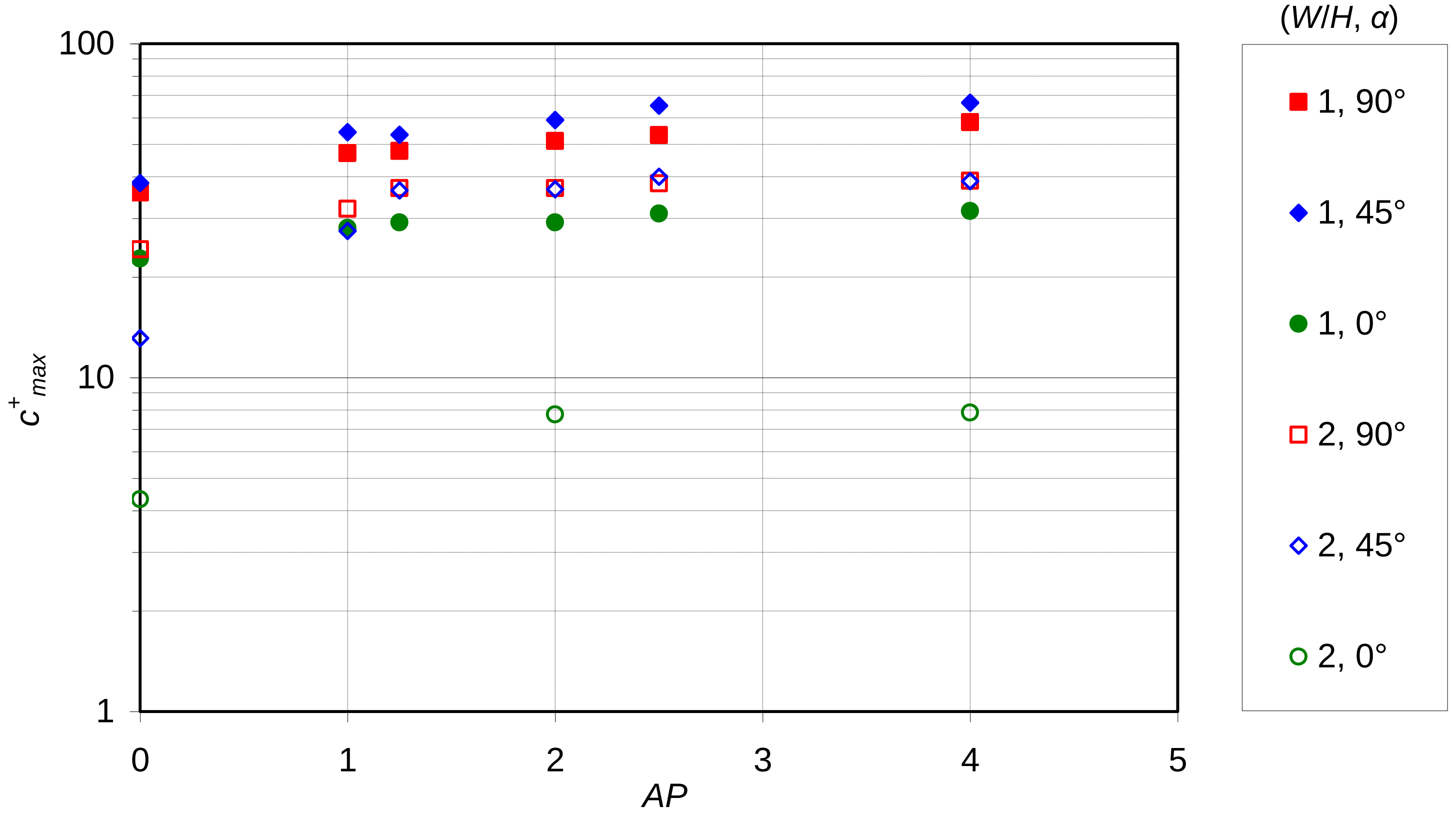
- *AP* increases with increasing vegetation
- determination/choice of values for c_1 and c_2 remains (moist obvious choice: $c_1 = c_2 = 1$)

➡ $$c^{+}_{max} = f_4\left(\frac{W}{H}, AP, \alpha\right)$$

("3" parameters)

Relationship

c^+_{max} from experimental results for $c_1 = c_2 = 1$ => $AP = (\rho_b) \bullet (100 - P_{Vol}[\%])$



=> exponential relationship between c^+_{max} und *AP*

Relationship

Requirements to the relationship between c^{+}_{max} and *AP*

- exponential dependency
- asymptotically approach c^{+}_{max} for $AP \rightarrow \infty$

General approach:

$$c^{+}_{max} = a_1 - a_2 \exp(-a_3 AP) \qquad a_i > 0, \qquad a_i = f\left(\frac{W}{H}, \alpha\right)$$

- determination of a_i by regression analyses in dependency of *W*/*H* and *α*

Meaning of a_i

- a_1 largest possible maximum concentration ($AP \rightarrow \infty$)
- a_2 range of maximum concentrations (tree-free – $AP \rightarrow \infty$)
- a_3 stretching factor

Dimensional Analytical Considerations

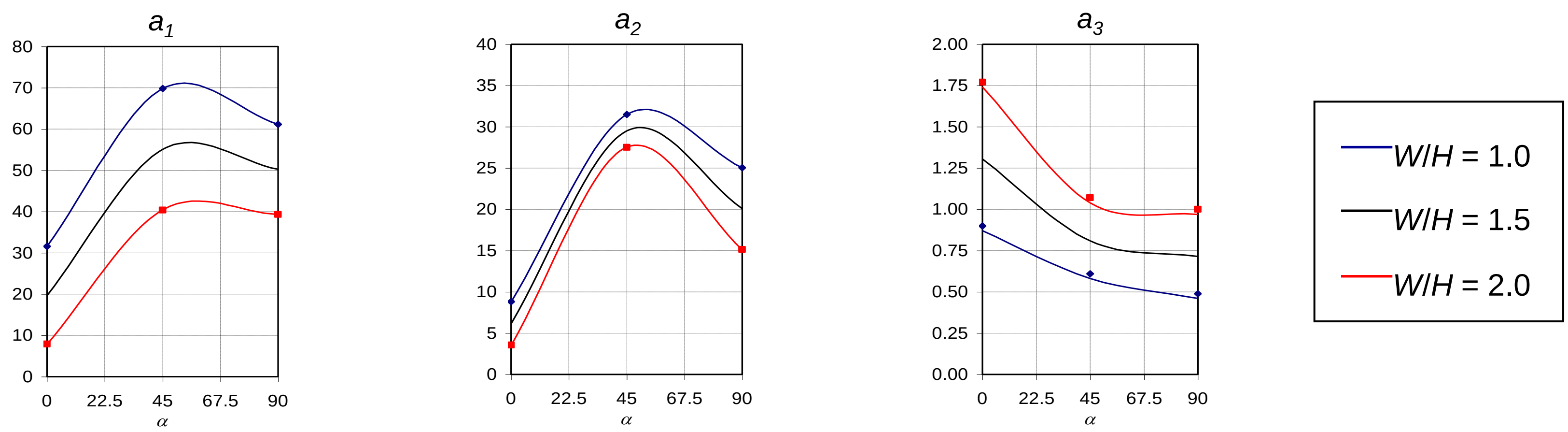
Functional relationship for c^+_{max}

- asymptotically approaches limit case $\lambda \rightarrow \infty$

$$c^+_{max} = a_1 - a_2 \exp\left\{-a_3\left[\rho_b \bullet (100 - P_{Vol}[\%])\right]\right\}$$

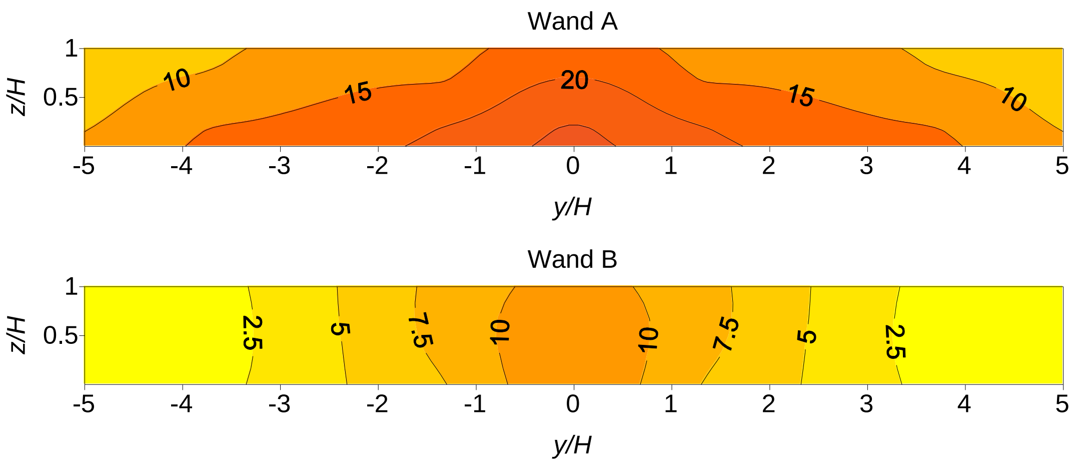
$$a_i = f\left(\frac{W}{H}, \alpha\right)$$

- determination of a_i by regression analyses in dependency of W/H and α

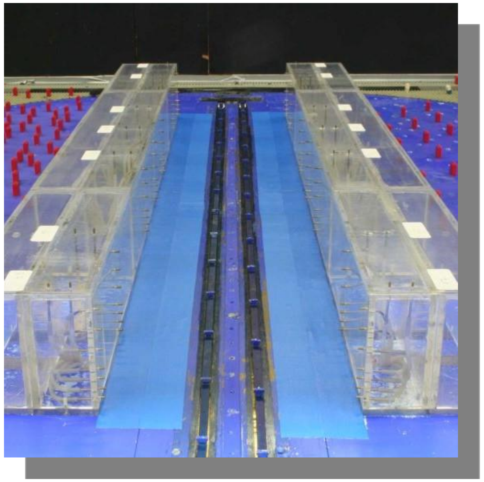


Konzentrationen in "breiter" Straßenschlucht (B/H = 2, α = 90°)

Baumfreie Straßenschlucht (Referenzfall)



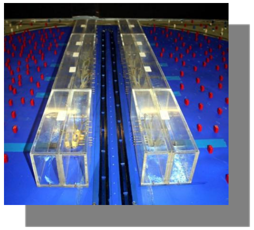
normierte Konzentrationen c^+ [-]



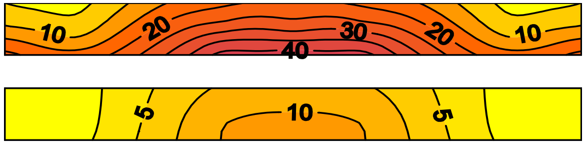
im Vergleich zur engen Straßenschlucht (*B*/*H* = 1)

- geringere Konzentrationen an der leeseitigen Wand A (im Wandmittel: -24 %)
- ähnliche Maximalbelastung an Wand B
- vergleichbare Verteilung der Konzentrationen

$\Rightarrow$ Strömungsregime ähnlich, Schadstoffbelastung unkritischer

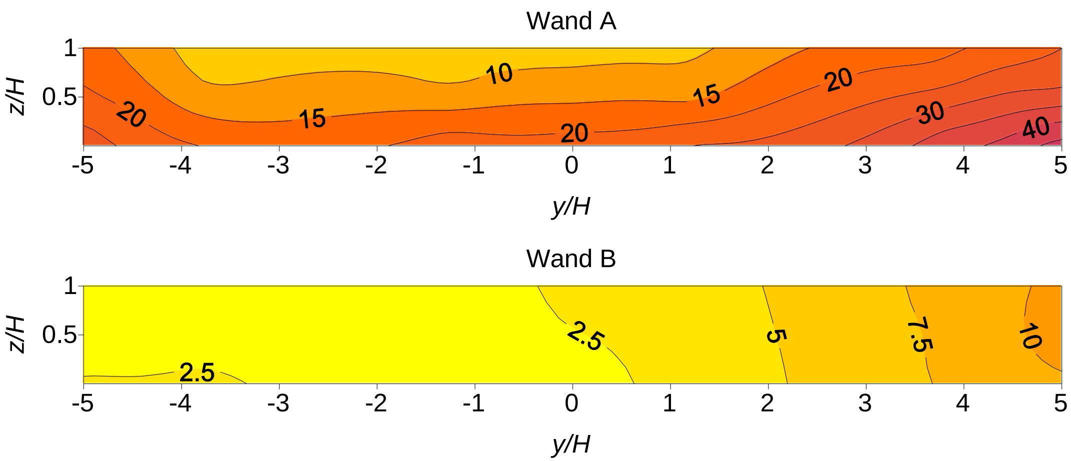


"enge" Straßenschlucht (B/H = 1)

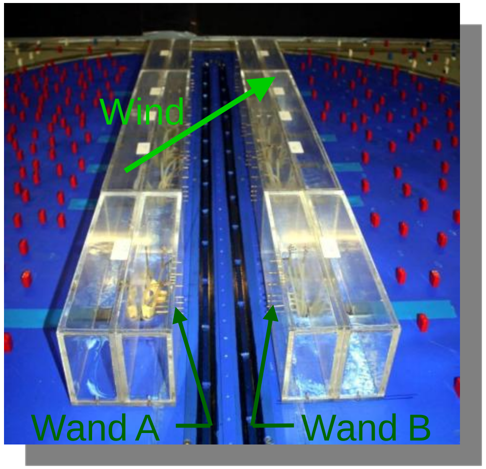


Konzentrationen bei Schräganströmung (*B*/*H* = 1, *α* = 45°)

Baumfreie Straßenschlucht (Referenzfall) bei Schräganströmung



normierte Konzentrationen c^{+} [-]



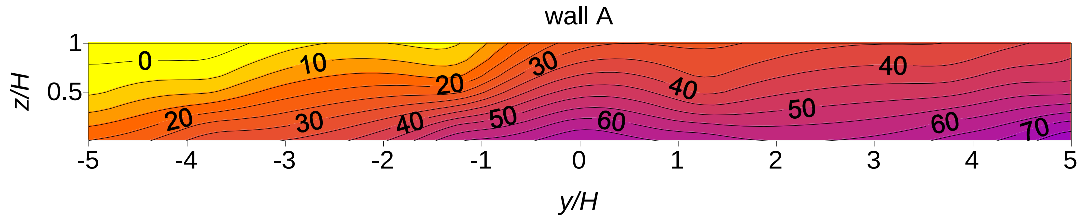
bei schräger Anströmung

- Konzentrationen an Wand A deutlich höher als an Wand B
- helixartige Wirbelstruktur (Überlagerung von Canyon Vortex und Paralleldurchströmung)
- Totwassergebiet an Einströmseite von Wand A
- max. Konzentrationen am Straßenschluchtende
- akkumulativer Schadstofftransport entlang der Straßenlängsachse
- kritisch bei längeren Straßenschluchten (*L*/*H* > 10)

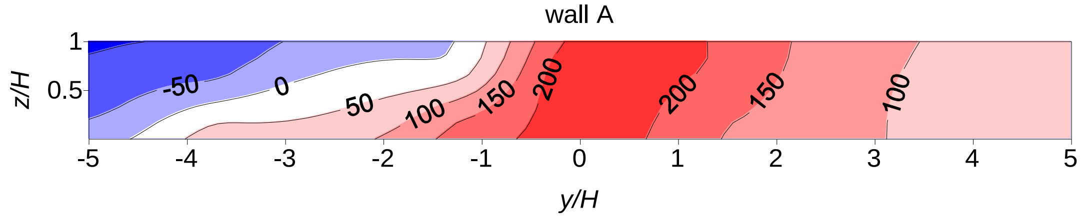
Pollutant Concentrations for Inclined Approaching Flow ($W/H = 1$, $\alpha = 45°$)

Single-row tree planting

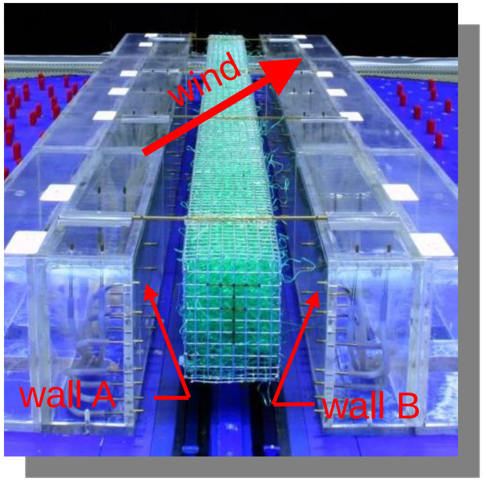
- high planting density $\rho_b = 1.0$, high crown porosity $\lambda = 80\ m^{-1}$ ($P_{Vol} = 97.5\%$)



norm. concentrations c^+ [-]



rel. changes δ_c^+ [-]

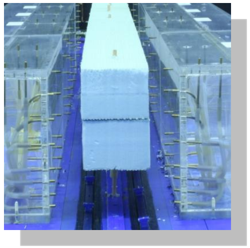


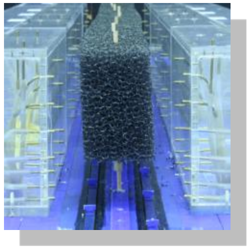
- increases and decreases of concentrations at wall A (wall average: +91 %)
- decreases in concentration at wall B (wall average: -49 %)
- accumulative traffic pollutant transport along street canyon axis
- max. rel. changes in concentration for inclined approaching flow
- max. pollutant concentrations at canyon end

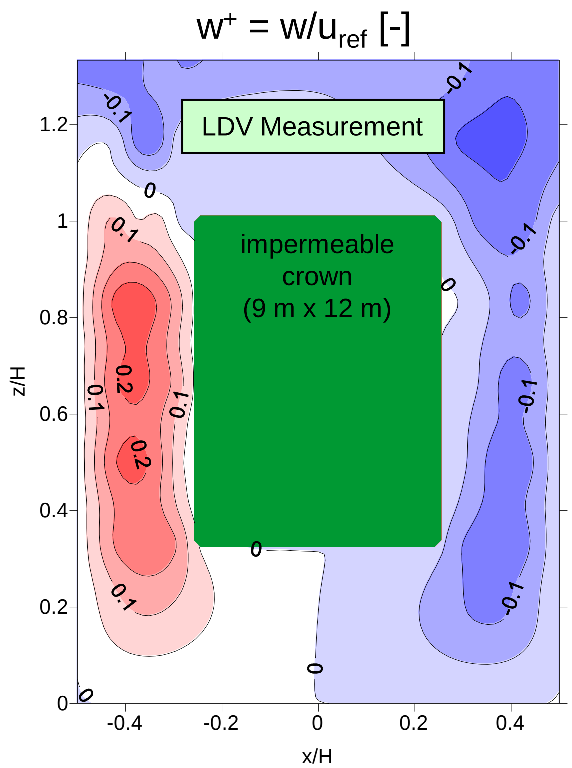
Influence of Crown Porosity on Velocity Field

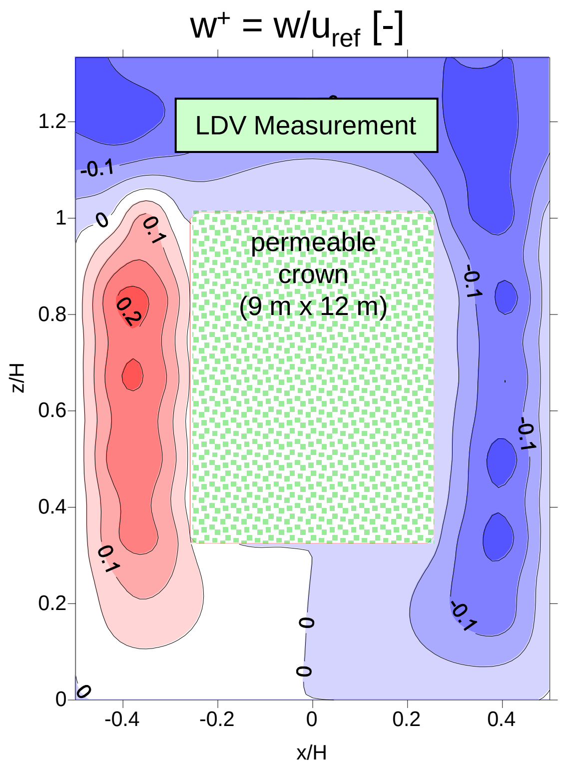
Comparison of impermeable and permeable tree crown

- continuous block-shaped permeable crown
  (97 % pore volume, λ = 250 Pa Pa^{-1}m^{-1})









impermeable - permeable

- vertical velocities are similar
- volume flux at z/H = 0.7 differs only by 8 %
- no significant influence of crown permeability on flow field

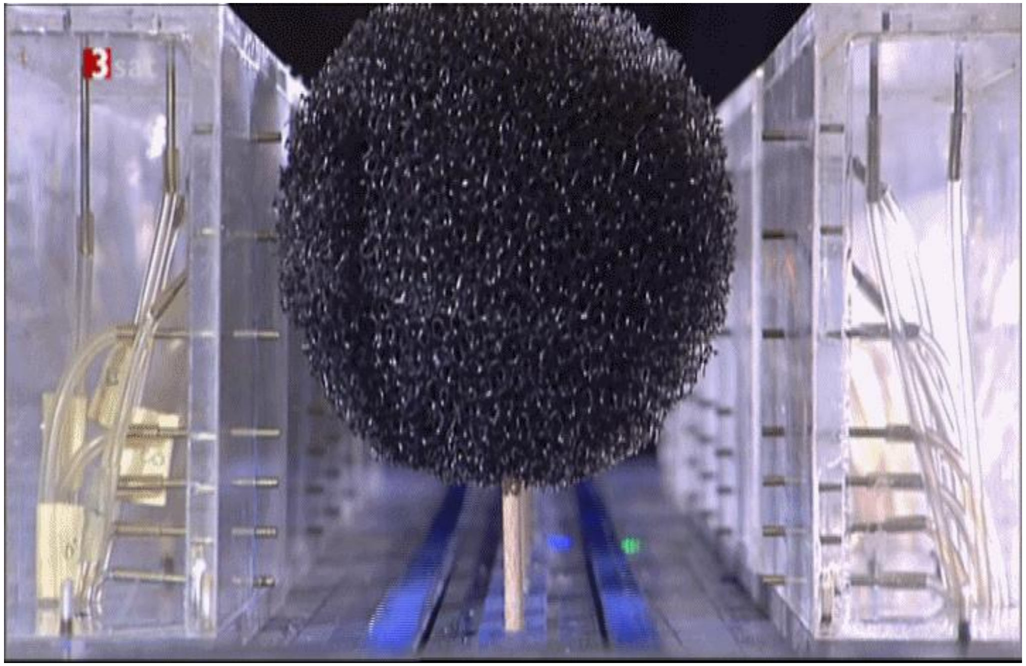
Traffic induced Turbulence

Turbulence production ratio T_P

$$T_P = P_T / P_W$$

Similarity is given when:

$$T_{P,Model} = T_{P,Nature}$$



$$P_T = \frac{\rho\, c_D\, n_T\, F_T\, u_T^3}{W\,H}$$

turbulence production by moving traffic assumption
(total kin. energy of traffic is transformed into TKE)

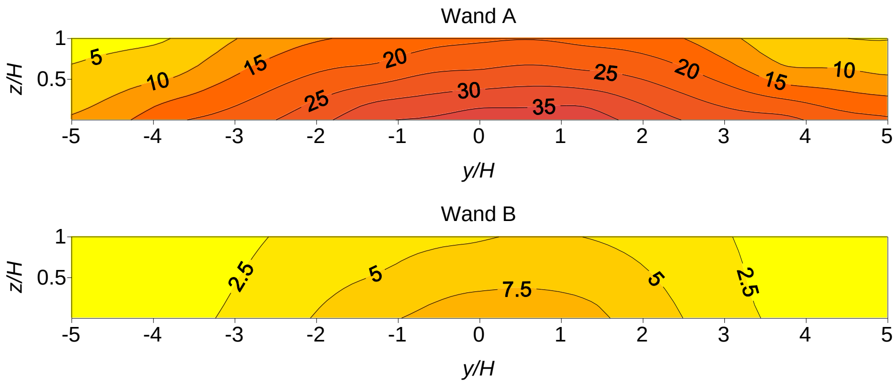
$$P_W \propto \frac{\rho\, c_f\, u_\delta^3}{H}$$

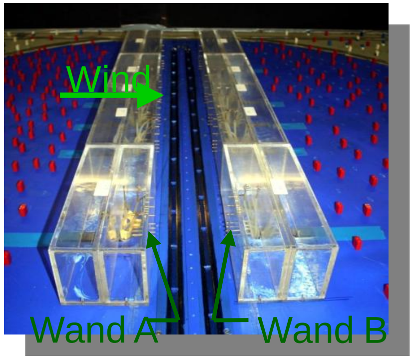
turbulence production by interaction of
building environment with atmospheric wind

Konzentrationen bei Berücksichtigung Verkehrsinduzierter Turbulenz

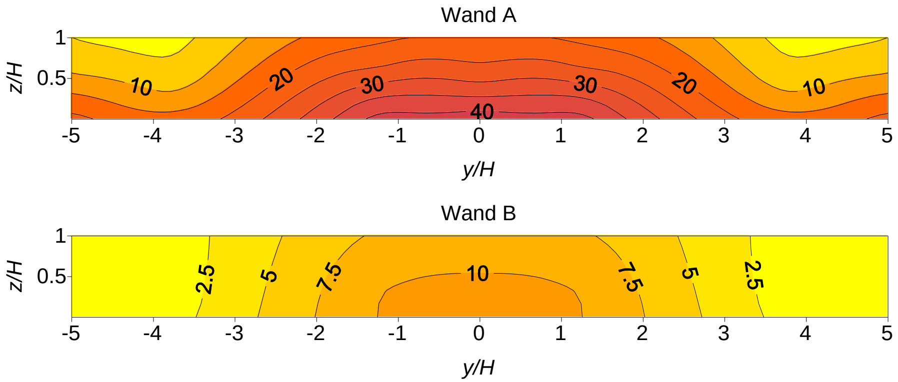
Referenzfall: Baumfreie Straßenschlucht *B*/*H* = 1 bei senkrechter Anströmung

mit Verkehr





ohne Verkehr

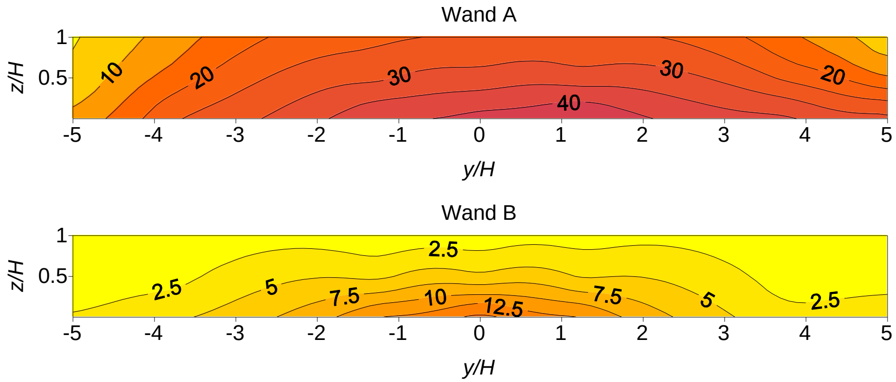


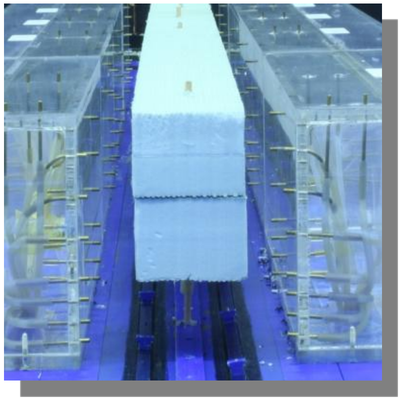
- Gegenverkehr, u_v = 40 km/h
- Verkehrsstärke n_v = 37 Kfz/km
- $c_f = 0.02$ ($c_f = \rho u_*^2/(0.5\,\rho U_\delta^2)$)
- Turbulenzproduktion $P_W \approx 10\,P_T$
- Konzentrationsabnahmen
  - Wand A: 2 %
  - Wand B: 31 %

Konzentrationen bei Berücksichtigung Verkehrsinduzierter Turbulenz

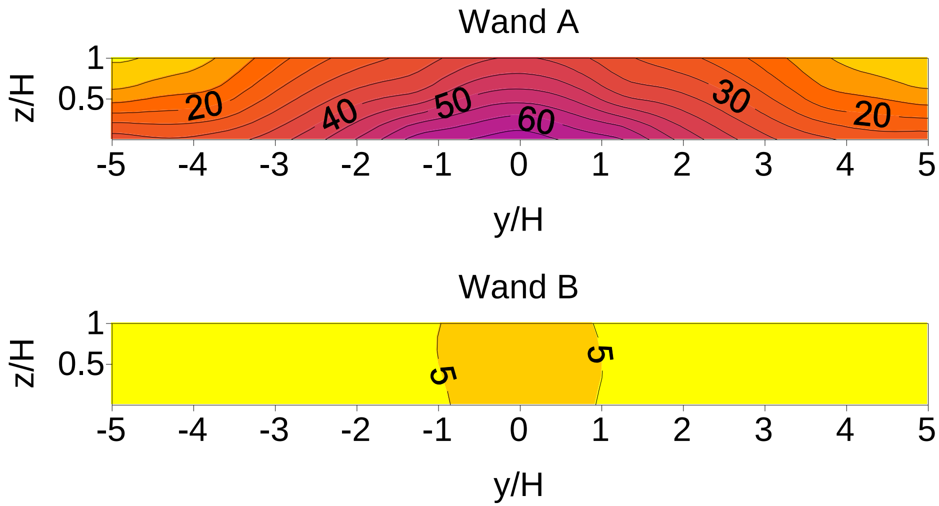
Straßenschlucht mit impermeabler Baumpflanzung (*B*/*H* = 1, *α* = 90)

mit Verkehr





ohne Verkehr



- Gegenverkehr, u_v = 40 km/h
- Verkehrsstärke n_v = 37 Kfz/km
- $c_f = 0.02$ ($c_f = \rho u_*^2/(0.5\,\rho U_\delta^2)$)
- Konzentrationsänderungen
  - Wand A: -23 %
  - Wand B: +19 %

Dimensionsanalytische Betrachtung

Aufstellen der Dimensionsmatrix

	c	H	B	ρ_b	P_{Vol}	u_H	α	v	Q_l	x	y	z
L	0	1	1	0	0	1	0	2	2	1	1	1
T	0	0	0	0	0	-1	0	-1	-1	0	0	0

Elimination der Basisgröße Länge [L] durch Einflussgröße Gebäudehöhe *H*

	c	B/H	ρ_b	P_{Vol}	u_H/H	α	v/H^2	Q_l/H^2	x/H	y/H	z/H
L	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	-1	0	-1	-1	0	0	0

Elimination der Basisgröße Zeit [T] durch Einflussgrößenkombination H/u_H

	π_1	π_2	π_3	π_4	π_5	π_6	π_7	π_8	π_9	π_{10}
	c	B/H	ρ_b	P_{Vol}	α	$v/(u_H H)$	$Q_l/(u_H H)$	x/H	y/H	z/H
L	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0

Funktionaler Zusammenhang

Regressionsanalysen zur Bestimmung der Parameter a_i

2.) Beschreibung der Parameter a_i in Abhängigkeit der **Π** Gruppen B/H und α mittels

gemischt quadratischer Polynomansatz für funktionalen Zusammenhang $a_i = f(B/H,\alpha)$

$$a_i = \sum_{j=0}^{2} c_{B/H,j}\left(\frac{B}{H}\right)^j \cdot \sum_{j=0}^{2} c_{\alpha,j}\alpha^j$$

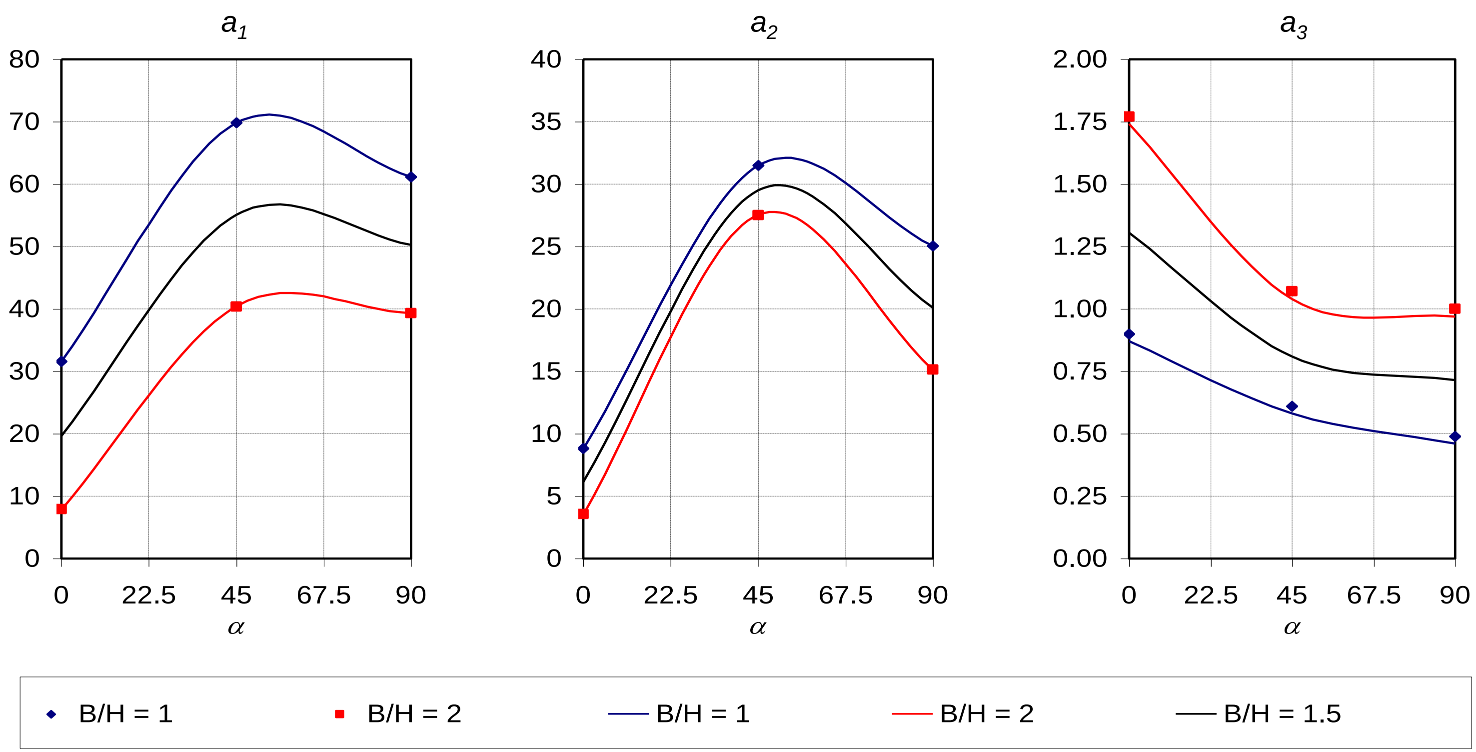
$$a_i = c_{i0} + c_{i1}\left(\frac{B}{H}\right) + c_{i2}\alpha + c_{i3}\left(\frac{B}{H}\right)^2 + c_{i4}\alpha^2 + c_{i5}\left(\frac{B}{H}\right)\alpha + c_{i6}\left(\frac{B}{H}\right)^2\alpha + c_{i7}\left(\frac{B}{H}\right)\alpha^2 + c_{i8}\left(\frac{B}{H}\right)^2\alpha^2$$

3.) Regressionsanalyse zur Bestimmung der Parameter c_i

	c_{i0}	c_{i1}	c_{i2}	c_{i3}	c_{i4}	c_{i5}	c_{i6}	c_{i7}	c_{i8}
i = 1	55.3	-23.8	94.2	0.0	-48.7	-15.5	0.0	10.7	0.0
i = 2	14.1	-5.3	41.0	0.0	-17.6	6.4	0.0	-6.0	0.0
i = 3	0.0	0.9	0.3	0.0	-0.2	-0.8	0.0	0.4	0.0

Funktionaler Zusammenhang

Gegenüberstellung berechneter und aus Windkanalversuchen resultierenden Parametern a_i



- 1.0 < *B*/*H* < 2.0 Zwischenwerte liegen im physikalischen sinnvollen Bereich (*B*/*H* = 1.5)
- höchst mögliche Maximalkonzentrationen bei schräger Anströmung ($\alpha \approx 50$ … 55)