Impact of Avenue-trees and Hedgerows on Traffic Pollutant Dispersion in Urban Street Canyons

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Webinar Series: Air Pollution Mitigation using Passive Techniques in the Built Environment: Sharing International Best Practice

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Basics of flow and pollutant dispersion in urban street canyons

Part I: Avenue-trees

Part II: Hedgerows
Long street canyon (L/H > 7 and 0.7 ≤ W/H ≤ 2.2)

- two dominating large scale vortex structures
  - canyon vortex
  - corner eddy
- superposition at street canyon ends
long street canyon, incident flow $\alpha = 90^\circ$

Canyon Vortex

Corner Eddy

numerical simulation with k-\(\varepsilon\) turbulence closure scheme
Urban Street Canyons with Avenue-Trees or Hedges
Part I:

Effects of Avenue-Trees on Pollutant Dispersion in Street Canyons
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 \(\text{SF}_6\))
- 126 measurement taps at canyon walls
- traffic induced turbulence

**Boundary layer wind tunnel**

- closed-circuit BLWT
- vortex generators / roughness elements
- adjustable ceiling
- power law profile exponent \(\alpha = 0.30\)
- Reynolds-No. \(Re = 37,000\)
Realization of tree models

Modeling of trees / avenue-trees

- fiber material packed into grid cages
- crown porosities
  - $P_{\text{Vol}} = 97.5 \ldots 96\%$
  - (permeability $\lambda_{rs} = 80 \ldots 250\ m^{-1}$)
- tree density (#trees/unit length)

→ approach based on geometric and dynamic similarity criteria
Literature on tree modeling:

A vegetation modeling concept for Building and Environmental Aerodynamics wind tunnel tests and its application in pollutant dispersion studies

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Wind tunnel model of the forest and its Reynolds number sensitivity

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Street Canyons with Tree Models
Tree-free reference street canyon ($W/H = 1, \alpha = 90^\circ$)

- max. concentrations in central part of wall A close to 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
Single-row avenue-trees (W/H = 1, α = 90°)
- high tree density $\rho_b = 1.0$, high crown permeability $\lambda = 80 \text{ m}^{-1}$ ($P_{\text{Vol}} = 97.5\%$)

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
Parameter Study Crown Permeability $\lambda$

**Influence of crown porosity / permeability** ($W/H = 1, \alpha = 90^\circ$)
- high tree density $\rho_b = 1.0$

- $\lambda = 80 \text{m}^{-1}$
  - $P_{\text{Vol}} = 97.5\%$

- $\lambda = 200 \text{m}^{-1}$
  - $P_{\text{Vol}} = 96\%$

- $\lambda = \infty$
  - $P_{\text{Vol}} = 0\%$

Tree-free
Single-row avenue-trees \((W/H = 1, \alpha = 90^\circ, \text{high tree density } \rho_b = 1)\)

- wall A: increase of \(c^+_{wall}\) increasing \(\lambda\), max. change +60%
- wall B: decrease of \(c^+_{wall}\) increasing \(\lambda\), max. change -50%

- larger vertical velocities $w$ in street canyon without trees
- reduced passage width between crown and facades
  - less air volume is rotating (- 64 %)
  - increase in concentration at wall A
**Two-row avenue-trees** ($W/H = 2, \alpha = 90^\circ$)

- high tree density $\rho_b = 1.0$, low crown permeability $\lambda = 200 \text{ m}^{-1}$ ($P_{\text{Vol}} = 96.0\%$)

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%)  
  $\rightarrow$ effects analog to narrow street canyon ($W/H = 1$)
Two-row tree planting \((W/H = 2, \alpha = 45^\circ)\)
- high tree density \(\rho_b = 1.0\), low crown permeability \(\lambda = 200\ \text{m}^{-1}\) \((P_{\text{Vol}} = 96.0\%)\)

- increases / decreases in conc. at wall A (average: +88%)
- increases in concentration at wall B (not shown here)
- max. concentrations at canyon end \(\rightarrow\) accumulative transport
- max. rel. changes in conc. for inclined approaching flow
Recommended literature:

Dispersion study in a street canyon with tree planting by means of wind tunnel and numerical investigations – Evaluation of CFD data with experimental data
Christof Gromke a,*, Riccardo Buccolieri b, Silvana Di Sabatino b, Bodo Ruck a

On the Impact of Trees on Dispersion Processes of Traffic Emissions in Street Canyons
Christof Gromke · Bodo Ruck

Pollutant Concentrations in Street Canyons of Different Aspect Ratio with Avenues of Trees for Various Wind Directions
Christof Gromke · Bodo Ruck
What is CODASC?
CODASC stands for "COncentration DATA of Street Canyons". It is a database containing concentration measurement data of street canyons with and without tree planting.

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

For whom is CODASC of interest?
CODASC is addressing scientists working on urban air quality issues. It is of special interest to urban planners and traffic engineers who need concentration data for 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

<table>
<thead>
<tr>
<th>$W/H$ = 1</th>
<th>$\alpha$</th>
<th>TREE PLANTING</th>
<th>normalized concentration data $c^+$ file name = $[W/H]<em>{[\alpha]}</em>{[\rho]}<em>{[\theta]}</em>{[\text{wall}]}$</th>
<th>concentration contour plot (300 dpi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aspect ratio: street width $W$ to building height $H$</td>
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Part II:

Effects of roadside Hedges on Pollutant Dispersion in Street Canyons
Street Canyon Model

- generic isolated street canyon model
- aspect ratios: W/H = 2 and L/H = 10 (H: building height, W: street width, L: street length)
- model scale M = 1:150 (full-scale dimension: H = 18 m, W = 36 m, L = 180 m)
- atmospheric boundary layer flow typical for urban environment
- perpendicular approach wind
Hedge Arrangements and Configurations

eccentric arrangement
- two sidewise hedges -

central arrangement
- one central hedge -
Realization of hedge models

- open porous foam materials
- characterized by number of pores per inch (PPI-#)
  - PPI-10 ($P_h = 96.1 \text{ vol}\%$)
  - PPI-20 ($P_h = 94.5 \text{ vol}\%$)
- pressure loss coefficients determined in forced flow experiments
  - PPI-10: $\lambda = 250 \text{ m}^{-1} \rightarrow \lambda_{fs} = 1.67 \text{ m}^{-1}$
  - PPI-20: $\lambda = 500 \text{ m}^{-1} \rightarrow \lambda_{fs} = 3.34 \text{ m}^{-1}$

\[ \rightarrow \text{ similarity criterion } \checkmark \]
Presentation of results

- normalized concentrations
  \[ C^+ = \frac{C_{\text{meas}} U_{\text{ref}} L_{\text{ref}}}{Q_T/l} \]

- relative differences in concentrations [%]
  \[ \Delta C_{\text{rel}}^+ = \frac{C_{\text{hedge}}^+ - C_{\text{no-hedge}}^+}{C_{\text{no-hedge}}^+} \]
Results – Hedge-free Street Canyon

- concentrations highest in middle part
- \( C^+_{\text{side-A}} > C^+_{\text{side-B}} \) (4 and 6 times higher)
- focus on side A
Results – Eccentric Hedgerows ($h_h = 1.50$ m, $\lambda_h = 3.34$ m$^{-1}$)

- **wall A:**
  - reductions in middle part, beneficial since here max. concentration
  - increases in outer part
  - in average reductions of 1.1%

- **floor A:**
  - reductions, greatest in middle part where max. concentrations
  - in average reductions of 20.0%
Results – Central Hedgerow \((h_h = 2.25 \text{ m}, \lambda_h = 3.34 \text{ m}^{-1})\)

- **wall A / floor A:**
  - qualitative changes similar as for eccentric hedgerows
  - reductions are greater
  - at wall A: largely reductions
  - in average reductions of
    - 28.0% at wall A
    - 36.1% at floor A
Partitioning of street canyon into areas

- based on dominating flow / vortex structures for perpendicular approach wind
  - canyon vortex
  - corner eddy

<table>
<thead>
<tr>
<th>Area</th>
<th>y/H Range</th>
<th>Description</th>
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<tbody>
<tr>
<td>area I</td>
<td>(-2.0 &lt; y/H &lt; +2.0) (middle part)</td>
<td></td>
</tr>
<tr>
<td>area II</td>
<td>(\pm 2.0 &lt; y/H &lt; \pm 3.5) (intermediate part)</td>
<td></td>
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<tr>
<td>area III</td>
<td>(\pm 3.5 &lt; y/H &lt; \pm 5.0) (outer part)</td>
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Area-averaged rel. differences in concentrations at side A

- area I: largest reductions, larger at floor
  - reductions ↑ with permeability ↓ (i.e. with λ ↑)
- area II: in general reductions at floor and increases at wall
- area III: in general increases
- discontinuous hedgerow leads to increases
Results – Overview: Central Hedgerow

**Area-averaged rel. differences in concentrations at side A**

- reductions in all areas, largest in area I (middle part), larger at floor
- clear tendency: reductions ↑ with permeability ↓ (i.e. with λ ↑), → solid wall
- weak tendency: reductions ↑ with height ↑
- reductions are larger than with two eccentric hedgerows
Modification of flow field in street canyon and resultant traffic pollution dispersion (hypothesis)
Influence of roadside hedgerows on air quality in urban street canyons

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Impact of avenue-trees on air flow and traffic pollutant dispersion

- lower wind speeds in urban street canyons with trees
- overall increase in traffic pollutant concentrations
- higher / lower traffic pollutant concentrations at the leeward / windward wall

Impact of hedgerows on traffic pollutant dispersion

- hedgerows affect flow and pollutant dispersion at the bottom / lower street canyon part
- one central hedgerow is more beneficial than two eccentric (sidewise) hedgerows
- hedgerows reduce concentrations in most polluted street canyon part (middle part, side A)
References


