SUPPLEMENTAL MATERIAL to:

A Comparison of Different Approaches to Estimate Small Scale Spatial Variation in Outdoor NO_2 Concentrations.

M. Dijkema, U. Gehring, R. van Strien, S. van der Zee, P. Fischer, G. Hoek, B. Brunekreef

Index:

Supplemental Material, Figure 1 2
Supplemental Material, Figure 2 2
Supplemental Material, Figure 3 3
Supplemental Material, Figure 4 3
Supplemental Material, Figure 5 4
Supplemental Material, Figure 6 5
Supplemental Material, Annex A - Land Use Regression: Databases used 6
Supplemental Material, Annex B - CAR dispersion model 7
References 11

Supplemental Material, Figure 1

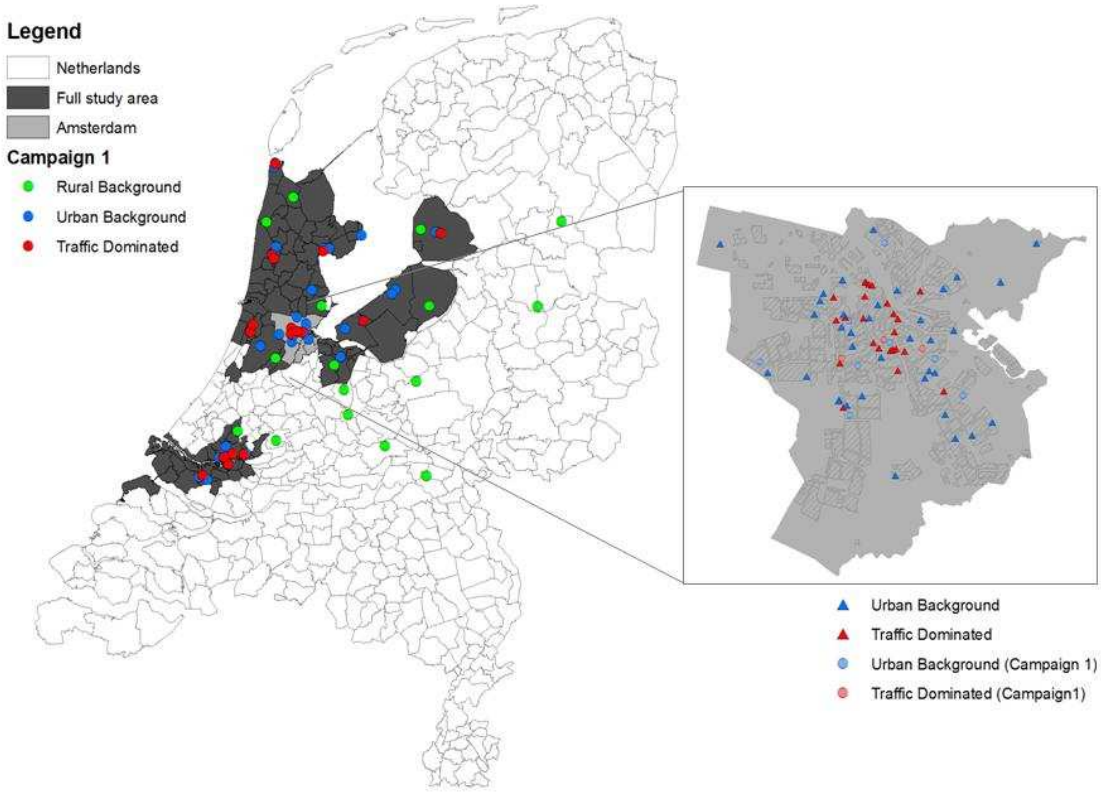


Figure 1: Maps and measurement locations for the large area LUR model (campaign 1, N=60) and the city specific LUR model (campaign 2, N=62)

Supplemental Material, Figure 2

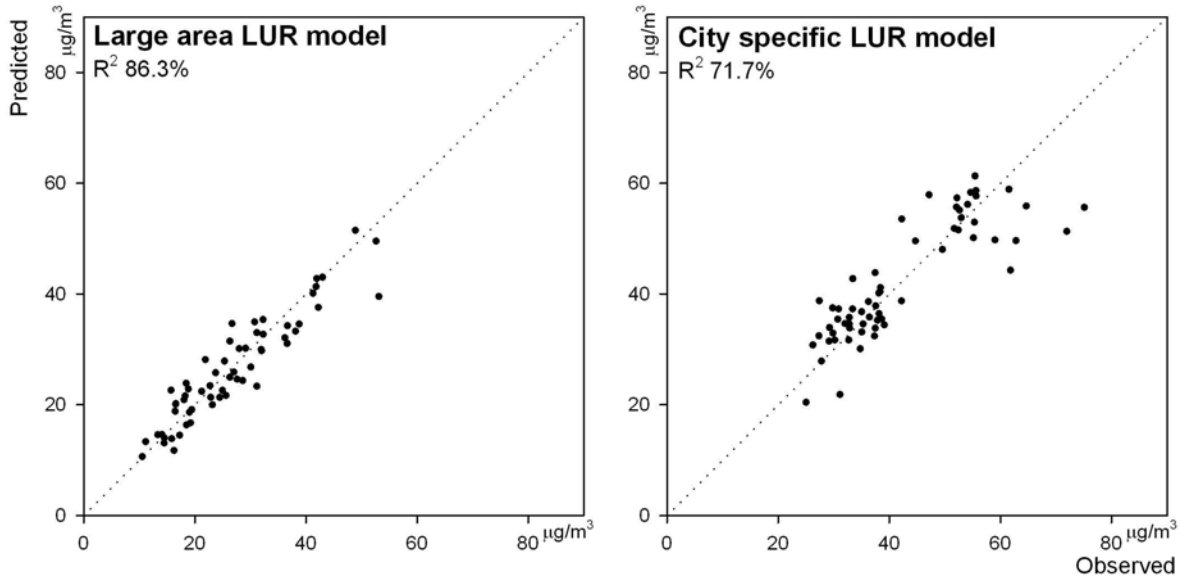


Figure 2: Observed and predicted NO_2 concentrations for the large area (N=60) and city specific campaigns (N=62). The dotted line is where observed equals predicted concentration.

Supplemental Material, Figure 3

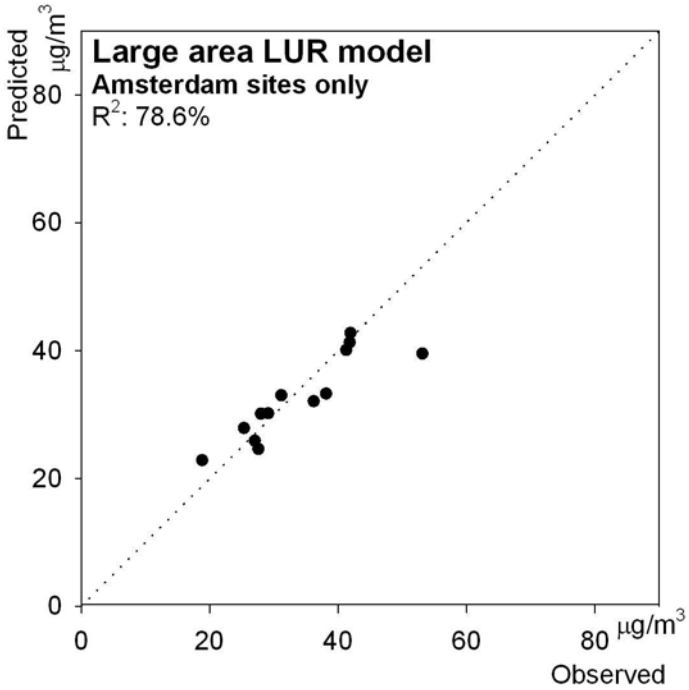


Figure 3: Observed and predicted NO_2 concentrations for the Amsterdam sites of the large area campaign (n=13). The dotted line is where observed equals predicted concentration.

Supplemental Material, Figure 4

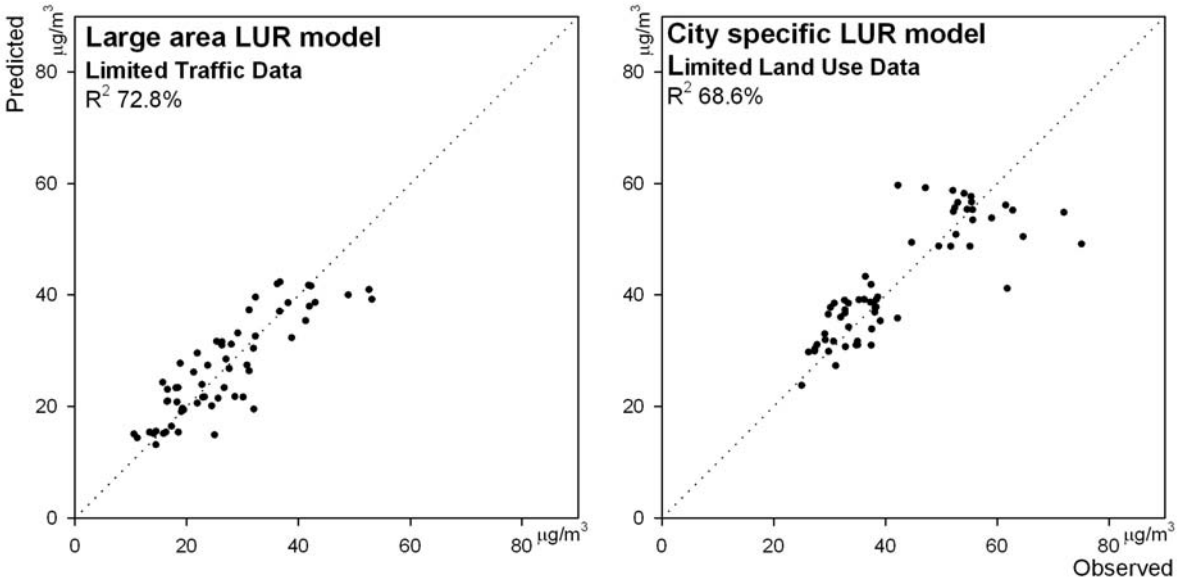


Figure 4: Observed and predicted NO_2 concentrations for the recalculated large area (limited traffic data, R^2 72.8%, adjusted R^2 71.3%) and city specific (limited land use data, R^2 68.6, adjusted R^2: 67.0) LUR models.

Supplemental Material, Figure 5

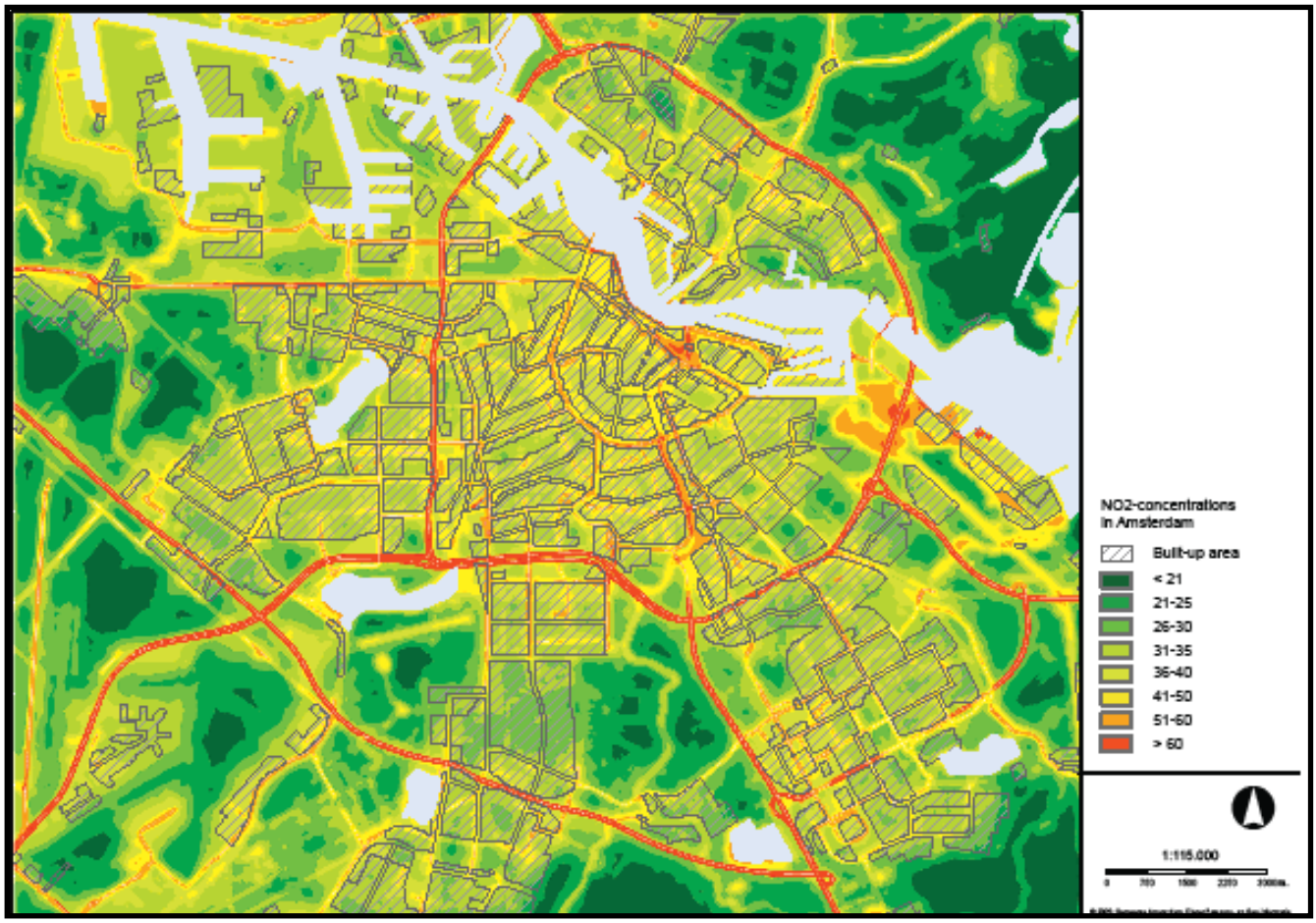
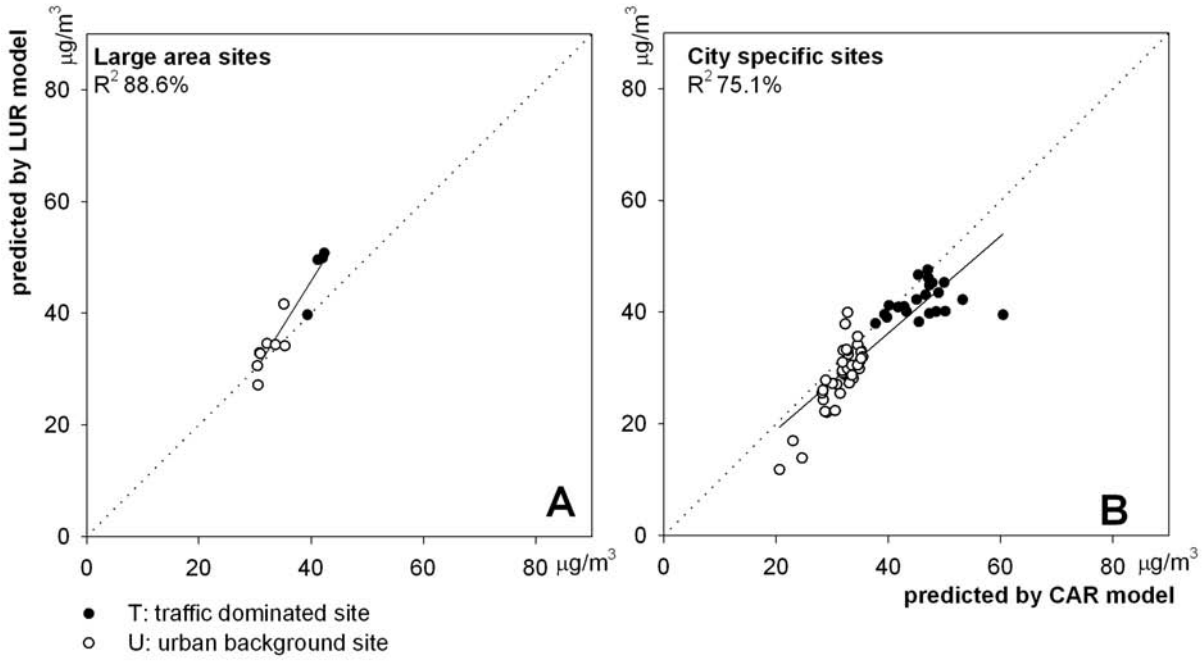


Figure 5: Predicted NO_2 concentrations by the city specific LUR model in Amsterdam

Supplemental Material, Figure 6



A: CAR vs. City specific LUR at large area sites
B: CAR vs. Large area LUR at city specific sites

Figure 6: Predicted concentration from CAR dispersion model vs. predicted concentration from both LUR models, for sites of the campaigns not used to develop the LUR models.

Supplemental Material, Annex A - Land Use Regression: Databases used

Air quality

ACN: Geocoding of measurement locations

Adres Coordinaten Nederland (translation: Address Coordinates Netherlands) 2005. Apeldoorn, the Netherlands, Kadaster, 2005.

Traffic data

NWB: Digital road map to which traffic infomation was linked

Nationaal Wegen Bestand (translation: National Road Database) 2006. Den Haag, the Netherlands, Ministerie van Verkeer en Waterstaat (Dutch ministry of Transport), 2006.

Land use data

CORINE: European land use (grid 100*100m)

Coordination of information on the environment (Corine) Land Cover 2000. Copenhagen, Denmark, European Environmental Agency, 2006.

KBKA: Amsterdam land use (grid 5*5m)

Kadastrale Basiskaart Amsterdam (translation: Cadastral Base Map Amsterdam) 2006. Amsterdam, the Netherlands, Dienst Geo- en Vastgoedinformatie, Gemeente Amsterdam (translation: Amsterdam Municipal Service for Geo- and Real Estate Information), 2007.

National population density database

CBS. National Population Database 2006. Heerlen, the Netherlands, Centraal Bureau voor de Statistiek (translation: Dutch Central Bureau of Statistics), 2006.

Supplemental Material, Annex B - CAR dispersion model: Model Description and Details from the manual

Model Description

In this study, the Dutch modeling tool CAR (Eerens et al. 1993; Velders and Diederen 2009) was used, which is the model to be used in built up areas of the Netherlands according to Dutch air quality regulations to calculate traffic-related air pollution. CAR is an empirical dispersion model derived from the more comprehensive traffic model developed at TNO (Utrecht, the Netherlands), which is a Gaussian dispersion model, adapted to calculate air quality near roads based on an extensive program of wind tunnel experiments covering many different street configurations including street canyons (Vardoulakis et al. 2003). The model adds a local traffic contribution on top of a large scale concentration map calculated with the Operational Priority Substances (OPS) dispersion model (Van Jaarsveld 2004; Van Jaarsveld and De Leeuw 1993) and updated every year (Velders et al. 2008). This large scale concentration map (at a 1*1km grid) is calculated from measurement data of the National Air Quality Monitoring Network (NAQMN, Bilthoven, the Netherlands) and modeling contributions of sources in the Netherlands and other European countries excluding local traffic. The OPS model calculates annual average concentrations based on emissions and their dispersion, transport, chemical conversion and deposition. The model uses a Gaussian plume for dispersion on a local scale and a Lagrangian trajectory for long-distance transport of compounds. The model calculates 5*5km concentrations, which have been interpolated to 1*1km grids.

The traffic contribution is calculated by multiplying the traffic emissions with a dispersion factor. The traffic emissions are calculated from traffic intensity, - composition and default speed-dependent national emission factors. The dispersion factor depends on street configuration (buildings, trees), distance to the center of the road and on average annual wind speed which is estimated on a 1x1 km basis (see 'Details from the manual'). The model calculates the NO_x concentration, which is transformed into NO_2 concentrations based on the fraction of directly emitted NO_2 and the transformation of NO to NO_2, using an empirical formula including the background ozone concentration (see 'Details from the manual'). The CAR model is updated yearly including updated traffic emission factors, meteorology and the updated map of large-scale concentrations. The CAR model has been calibrated using measurements from 14 NAQMN stations in busy streets for the period 2003-2006 (Wesseling

and Sauter 2007). The CAR model can be applied to a maximum distance of 60 meters. A further discussion of the CAR model and its relation to other dispersion models is found in (Vardoulakis et al. 2003).

CAR version 6.1.1 was used to predict 2006 annual mean NO_2 concentrations in this study for both sets of monitoring locations, using meteorology for the year 2006. The information included in the model was: exact geo coded location, traffic flow (vehicles per 24 hours) and composition (percentage of cars, vans, trucks and busses), distance to the center of the road (m) and categorical information on driving speed, road type and the presence of trees.

Details from the manual

Details on the CAR dispersion model can be found in the model software user manual in Dutch. Here the main formulas are presented to calculate the street contribution.

1. Concentration

Concentration contribution from traffic in the street itself is calculated using formula 1.

(1)

$$C_{jm-bijdrage} = E \cdot \theta \cdot F_b \cdot F_{regio}$$

Where	$C_{jm\text{-}bijdrage}$	=	Annual traffic contribution
	E	=	Emission (2)
	θ	=	Dilution factor (3)
	F_b	=	Tree factor (4)
	F_{regio}	=	Regional factor concerning meteorology and windspeed (yearly updated and included in the model automatically, based on geographic coordinates)

The annual NO_x concentration contribution is calculated using function (1). The concentration of NO_2, is calculated using an empirical relationship including NOx, the background ozone concentrations and the fraction of directly emitted NO2 (formula 1a)

(1a)

$$C_{NO2-jm} = F_{NO2} \cdot C_{NOx-jm} + \frac{B \cdot C_{achtergrond\_O3} \cdot C_{NOx-jm} \cdot (1 - F_{NO2})}{C_{NOx-jm} \cdot (1 - F_{NO2}) + K} + C_{achtergrond\_NO2}$$

where	$C_{NO2\text{-}jm}$	=	annual NO2 concentration contribution
	F_{NO2}	=	weight fraction of directly emitted NO_2
	$C_{NOx\text{-}jm}$	=	annual NOx concentration contribution (1)
	$C_{achtergrond\_O3}$	=	background concentration of O_3[1]
	$C_{achtergrond\_NO2}$	=	background concentration of NO_2[1]
	B, K	=	empirical derived conversion factor, for NO to NO_2 (B=0.6, K=100)

2. Emission:

Emission is calculated from traffic intensity, traffic composition and default emission factors for the Dutch car fleet (formula 2). Emission factors are speed dependent.

(2)

$$E = N \cdot ((1 - (F_m + F_v + F_b)) \cdot E_p + F_m \cdot E_m + F_v \cdot E_v + F_b \cdot E_b) \cdot \frac{1000}{24 \cdot 3600}$$

where	*E*	=	Emission (µg/m/s)
	N	=	Number of vehicles per 24 hours ($24hrs^{-1}$)
	Fm	=	fraction 'medium heavy' traffic (i.e. vans)
	Fv	=	Fraction of heavy traffic (i.e. trucks)
	Fb	=	Fraction of busses
	Ep	=	Emission factor for cars
	Em	=	Emission factor for 'medium heavy' traffic (i.e. vans)
	Ev	=	Emission factor for heavy traffic (i.e. trucks)
	Eb	=	Emission factor for busses

All emission factors are yearly updated based on roller bank measurements of vehicles.

[1]: derived from the yearly updated large scale background map, based on geographical coordinates

3. Dilution Factor:

Dilution factors are differently derived for different road types. In CAR roads are categorized as:

1) Road through open terrain, incidental buildings or trees within a radius of 100m

2) Basic type, all roads not categorized in any of the other categories

3a) Buildings along both sides of the road, distance road-axis to building façade is smaller than three and larger than 1.5 times the building height.

3b) Street canyon: Buildings along both sides of the road, distance road-axis to building façade is smaller than 1.5 times the building height.

4) Buildings along one side of the road, at a distance smaller than three times the building height.

For road type 1 the dilution factor is derived from the following function:

(3a)

$$\theta = a \cdot S^{b\frac{S+e}{S}} \cdot (c \cdot S + d)$$

For road type 2, 3a, 3b and 4 the factor function is:

(3b)

$$\theta = a \cdot S^2 + b \cdot S + c$$

where θ = Dilution factor

S = Distance to road-axis

a, b, c, d, e = Road type specific parameters (from table below)

Parameter	wegtype				
	1	2	3a	3b	4
a	0,725	$3,1 \cdot 10^{-4}$	$3,25 \cdot 10^{-4}$	$4,88 \cdot 10^{-4}$	$5,00 \cdot 10^{-4}$
b	-0,77	$-1,82 \cdot 10^{-2}$	$-2,05 \cdot 10^{-2}$	$-3,08 \cdot 10^{-2}$	$-3,16 \cdot 10^{-2}$
c	-0,0011	0,33	0,39	0,59	0,57
d	1,20	n.v.t.	n.v.t.	n.v.t.	n.v.t.
e	2,70	n.v.t.	n.v.t.	n.v.t.	n.v.t.

4. Tree Factor:

Trees are included to take into account limited dispersion in case of high tree density in streets.

1	No trees at all, or an occasional tree
1.25	One or more rows of trees, less than 15 meters apart, openings between crowns
1.5	Crowns are touching and covering at least one third of the road with

References

1. Eerens HC, Sliggers CJ, an den Hout KD. 1993. The CAR model: the Dutch method to determine city street air quality. Atmospheric Environment 27B:389-399.

2. Van Jaarsveld JA. The Operational Priority Substances Model. RIVM report no. 500045001.2004. Bilthoven, the Netherlands, Institute of Public Health and the Environment.

3. Van Jaarsveld JA, De Leeuw FAAM. 1993. An operational atmospheric transport model for priority substances. Environmental Software 8:93-100.

4. Vardoulakis S, Fisher BEA, Pericleous K, Gonzales-Flesca N. 2003. Modelling air quality in street canyons: a review. Atmospheric Environment 37:155-182.

5. Velders G, Aben J, Blom W, Van Dam J, Elzenga H, Geilenkirchen G et al. Large-scale air quality concentrations maps in the Netherlands, Report 2008. 500088002.2008. Milieu- en Natuur Planbureau (MNP), Bilthoven, The Netherlands.

6. Velders G, Diederen HSMA. 2009. Likelihood of meeting the EU limit values for NO2 and PM10 concentrations in the Netherlands. Atmospheric Environment 43:3060-3069.

7. Wesseling JP, Sauter FJ. Calibration of the program CAR II using measurements of the national measuring network of the RIVM. RIVM report 680705004/2007.2007. Bilthoven, the Netherlands, Institute of Public Health and the Environment.