EXPERIMENTS WITH AN HOURLY STREET CANYON DISPERSION MODEL

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Abstract: Based on wind tunnel experiments and the yearly average calculating CAR model (Jonkers 2007) a new hourly average calculating street canyon dispersion model is derived. With this hourly model, dispersion can be calculated for different types of street configurations, varying in aspect ratio and building configuration. The model outcome is compared with measured concentrations from the TRAPOS campaign. After applying linear regression, a correlation coefficient between the hourly measured and the hourly modelled concentrations of 0.64 was found, the systematic error was 1.13.

Key words: Street canyon, Road traffic, Air quality modelling, Hourly basis

1. INTRODUCTION

In the Netherlands, the CAR model is the standard model to calculate the contributions of road traffic in city streets (Jonkers, 2007) However, CAR only calculates yearly averaged concentrations. In order to check threshold values exceeding daily or hourly concentrations, empirical relations are applied. CAR therefore excludes the possibility to assess the effects of most typical air quality measures, such as traffic regulation, rush hour charging and velocity measures.

For this reason, TNO has developed a dispersion model on hourly basis. The model is based on new wind tunnel studies in combination with the CAR model. The wind tunnel studies are used to determine the dependence of the dispersion on the wind direction. From the CAR model, the dependence of the dispersion on road - receptor dependence is used. The hourly model can be applied to different street canyon configurations.

Here we will present the model, the wind tunnel experiments on which part of the model is based, and a comparison with the TRAPOS data set (Berkowicz, 1998).

2. MODEL CONCEPT AND DESCRIPTION

The hourly model dispersion functions are based on the CAR model. Hence, we start from the CAR formula that calculates the annually averaged concentration contribution C_{car} [µgm^{-3}]:

$$C_{CAR} = 0.62 \cdot E \cdot \theta \cdot F_b \cdot F_r \qquad (1)$$

In which E [µgms^{-1}] is the traffic emission, F_b [-] is a factor that accounts for the influence of trees and F_r [-] a factor that scales for the annually averaged wind speed. θ [sm^{-2}] is the dependence of dispersion on road - receptor distance, given by

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

In which S is the mid road - receptor distance and a, b and c are parameters depending on street type.

In the hourly model, formula 1 is expanded with a factor to account for hourly wind direction and - speed: F_{wd} [-] and F_{ws} [-] .

$$C = 0.62 \cdot E \cdot \theta \cdot F_b \cdot F_{wd} \cdot F_{ws} \qquad (3)$$

The annually averaged wind speed factor in CAR is thus replaced by F_{ws} [-], and is given by

$$F_{ws} = \frac{5}{u_{hour}} \qquad (4)$$

Since the relationship between wind speed and dispersion is not clear for low wind speeds (Ketzel et al., 2002), hourly wind speeds smaller than 3 ms^{-1} are set to 3 ms^{-1}.

A function for the wind direction factor was derived from wind tunnel studies, as explained in the next section.

3. WIND TUNNEL EXPERIMENTS

To determine F_{wd}, experiments are performed for 3 street canyon configurations and a configuration with a building block at only one side of the street. In Table 1, the different street types are shown.

Table 1. geometric properties of the different street types.

Type	Building height [m]	Street width [m]	Aspect ratio[1]
1: Narrow street canyon	20	20	1:1
2: Normal street canyon	20	40	1:2
3: Broad street canyon	20	60	1:3
4: Single side buildings	20	20	1:1

[1] building height: street width

Concentrations were measured at 4 receptor points, which were located at different distances from the building facade. In figure 1a the building-road-receptor configuration for street types 1, 2 and 3 is shown. In Figure 1b, the configuration for street type 4 is shown.

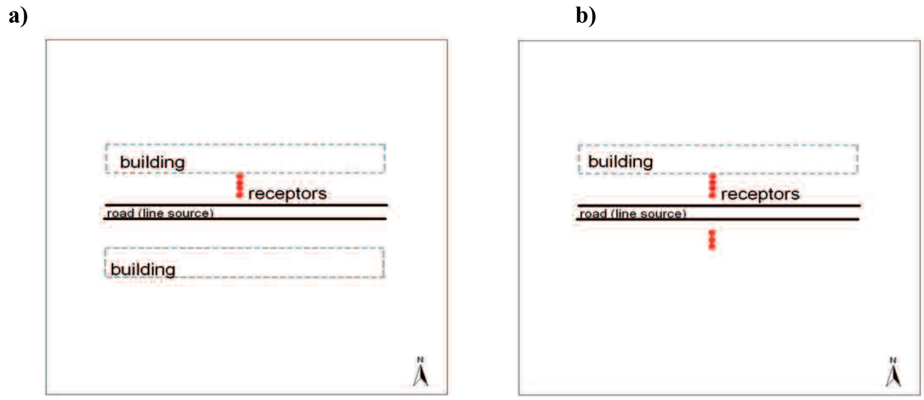

Figure 1. a (left): building-road-receptor configuration for street types 1, 2 and 3 and b (right): building-road-receptor configuration for street type 4.

Concentration measurements were carried out for different wind directions. Results are shown in Figure 2. Since the wind direction dependence did not vary much for the different receptor distances, average F_{wd} values are plotted.

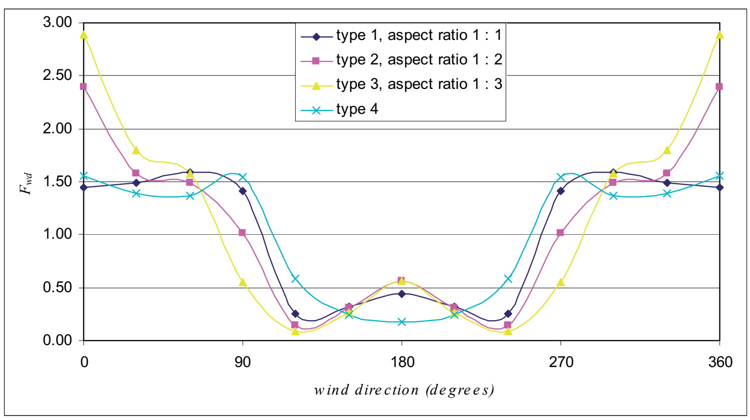

Figure 2. The mapping of F_{wd} for different wind directions. The mapping of F_{wd} is symmetric in 180 degrees (wind direction from the direction opposite to the receptors, i.e. wind from southern direction in figure 1). The values of F_{wd} are normalised with the average over all wind directions.

From Figure 2, the dependence of F_{wd} on the wind direction is clear. It can be seen that the values of F_{wd} are highest when the above roof level wind direction (with respect to the road orientation) is from the same side as where the receptors are located (Fig. 1). When the wind direction is more parallel to the street (between 120^o and 240^o), F_{wd} gives lower values.

Because wind direction plays a minor role for lower wind speeds, when traffic induced turbulence becomes important (Ketzel et al., 2002), the wind direction factor is set to 1 for wind velocities below 2 ms^{-1}.

4. COMPARISON WITH THE TRAPOS DATASET

The output of the hourly model is compared with field measurement from the TRAPOS campaign (Berkowicz et al., 1998). The TRAPOS dataset provides hourly values of concentrations and emissions of NO_X, as well as meteorological data in 3 different street canyons (Jagtvej, Schildhornstrasse and Goettingerstrasse). In this paper, results are compared to measurements carried out in the Goettingerstrasse in Hannover over a one-year period. The width of this street canyon is 25 m and the height of the buildings is estimated at 20 m. In Figure 3 the linear regression of hourly modelled and measured concentrations of NO_X is shown.

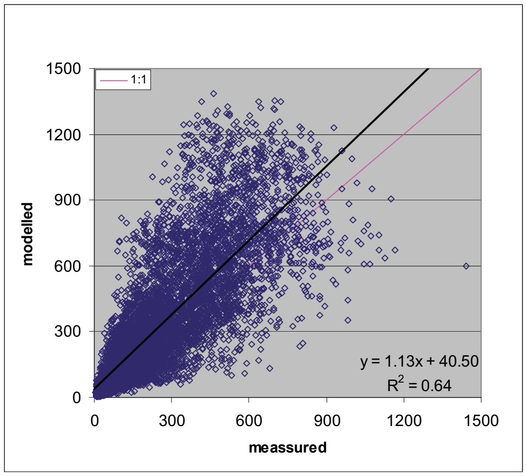

Figure 3. Linear regression of the measured NO_X contribution and the modelled contribution for the Goettingerstrasse in Hannover.

As can be seen from Figure 3, the modelled and measured concentrations have a correlation coefficient of 0.64, which is reasonable. However there is a systematic mismatch of 1.13.

In addition, daily profiles were calculated from the measurements and the model results. Figure 4 shows a systematic positive mismatch (modelled>measured) during daytime and a slightly negative mismatch during nighttime.

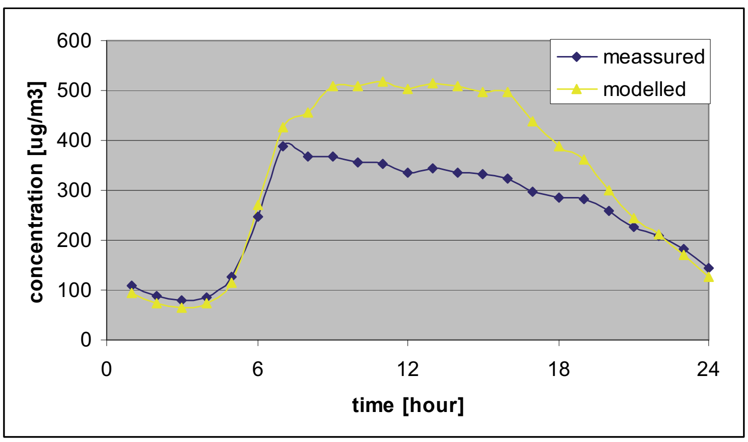

Figure 4. The measured and modelled average daily profiles of NO_x for the year 1994.

5. OUTLOOK

Before the hourly model can be applied to traffic regulation studies, it needs further development and validation. Therefore, results will also be compared to measured concentrations at the other TRAPOS locations (Jagtvej and Schildhornstrasse). This will elucidate the systematic mismatch problem some more. After this, the analysis will be performed for NO_2 as well.

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