4.26 A COMPARISON OF FIELD DATA, NUMERICAL CALCULATIONS AND WIND TUNNEL MEASUREMENTS IN AN URBAN ENVIRONMENT

Joost Wesseling, Peter Builtjes, Gerard Visser
TNO-MEP, PO Box 342, 7300 AH APELDOORN, The Netherlands
Corresponding author: J.P.Wesseling@mep.tno.nl

INTRODUCTION

During the last twenty years TNO has been active in performing environmental impact studies in the Netherlands. These studies deal both with dispersion of pollutants from road traffic and dispersion from industrial stacks. When studies are necessary for complex road or building structures, where numerical modelling is subject to large uncertainties, wind tunnel experiments are performed. In 2002 and 2003 tests were performed on the environmental impact of a strictly enforced 80 km/h speed limit on a highway through the city of Rotterdam. Total emissions of the traffic were expected (and indeed found) to decrease substantially. In order to verify the effect of the speed measure on ambient air quality, extensive field measurements and numerical air quality studies were performed. As a further extension of the available data, TNO has modelled a relevant part of the city of Rotterdam (the area "Overschie") in her wind tunnel. With the availability of numerical modelling, physical modelling and field experiments a comparison of results obtained with different methods and thus a validation of methods and models becomes possible.

EXPERIMENTS

Measurements in the city of Overschie were performed by DCMR (Rijnmond Environmental Protection Agency) and TNO during the period from April 2001 until April 2003. Three measurement stations were located around the A13 highway in the "Overschie" area of Rotterdam. One station (E3) was located some 400 meters west of the A13 highway and served as a background station. The other two stations (E1 and E2) were located 50 and 200 meters to the east of the A13 highway, respectively. The prevailing wind direction in the coastal parts of the Netherlands is south-western. At all three measuring stations hourly values of NO_x, NO_2, O_3, PM_{10}, BTX and CO concentrations were measured and stored. The NO_x/NO_2 measurements were performed by means of NO_x chemoluminescence analyzers (Thermo Electron model 42). During some months, small corrections were necessary to correct relative drift of the apparatus. The uncertainties in the measured concentrations are estimated at several $\mu g/m^3$ for each station. For the experiments, meteorological data were obtained from the nearby (2 km) Rotterdam Airport. Using the turbulence sub models of the numerical model and the available hourly data the horizontal and vertical dispersion parameters were calculated. No height dependence of the concentrations was measured in the field, only the concentrations at a height of z=2.25 meters. The experimental setup is briefly described in (Wesseling, 2002a).

WIND TUNNEL EXPERIMENTS

For the wind tunnel measurements the atmospheric boundary layer wind tunnel of TNO-MEP was used. The wind tunnel is an open Eifel type; it has a cross section of 2x3 meters. The test section is 11.5 meters long but can be extended to 20 meters. TNO can simulate many different atmospheric boundary layers in the wind tunnel, varying from a boundary layer above sea to one above a metropolitan area. The scale at which experiments are performed varies from 1:1 up to 1:2500. The wind velocity in the test section can be set between 0.2 and 20 m/s. A stretch of highway through "Overschie", 750 meters long was modelled in the wind tunnel, at a scale of 1:350. The relevant environmental details were also modelled. Whereas wind tunnel experiments can simulate the dispersion of pollutants from a (road) source with great precision they cannot determine the initial distribution of the pollutants. Pollutants emitted from the exhaust of a car are immediately mixed as a result of traffic-induced turbulence. A description of literature on these effects has been presented in (Wesseling, 2002b). In a previous study the traffic-induced turbulence modelling in the Traffic Model was checked against other models (Wesseling, 2003). In the wind tunnel model the principal measuring locations were selected at the same locations as were used in the field experiments, labelled "E1" and "E2". Furthermore three groups of measuring locations were modelled creating concentration profiles perpendicular to the highway. Two profiles were measured in a part of the city with relatively low (1-3 story) buildings whereas parts of another profile were just before and behind a building of medium height (15 meters) located very close to the highway. These measuring locations were selected in order to determine the influence of the buildings on the concentrations behind the buildings.

NUMERICAL DISPERSION MODEL

The TNO Traffic Model for calculating pollutant concentrations around highways was developed in 1988 with the use of extensive wind tunnel experiments (Hout, 1988). The TNO Traffic Model can calculate concentrations due to traffic emissions on an hourly basis. However, the numerical model uses discrete stability classes instead of calculating the atmospheric turbulence from hourly meteorological data. Especially when hourly averaged concentrations have to be calculated a more dynamic treatment of atmospheric stability is more appropriate. When yearly averaged concentrations are calculated the difference between results from a method using discrete stability classes and a method that calculates the atmospheric turbulence from hourly meteorological data is not very substantial. In the period 2001-2003 the more recent TNO Gaussian dispersion model "PLUME PLUS" was expanded with additional modules for traffic emissions, thus creating a new model: the HEAVEN model, named after the 'HEAVEN' project (Healthier Environment through the Abatement of Vehicle Emissions and Noise), the European Fifth Framework Program. A brief description of the model and initial validation experiments is available in (Wesseling, 2002a). The initial validation tests were performed in an open field type situation. With the present datasets a comparison between calculated and measured data in an urban situation is possible.

RESULTS

In order to check the effect of the reduced traffic emissions on ambient air quality the hourly measured NO_2 concentrations in the field were averaged over one year. For the same period hourly NOx and NO_2 concentrations were calculated with the numerical model. With the emission estimates that were input to the dispersion model the wind tunnel measurements were used to estimate hourly NOx and NO_2 concentrations for the same period. The values of the dispersion model as well as as the wind tunnel values were also averaged to yield yearly averaged concentrations. The results of the calculations and wind tunnel experiments were compared to field data obtained during <u>crosswind</u> situations as in that case the background concentrations can be corrected for. The resulting concentration contributions are shown in figure 1. There is a very satisfactory agreement between the field data, wind tunnel data and numerical dispersion calculations. From the wind tunnel results it could furthermore be concluded that a long 15 meter high building, situated parallel to the highway, results in a reduction of the yearly average NO_2 concentration behind the building of roughly 5 $\mu g/m^3$.

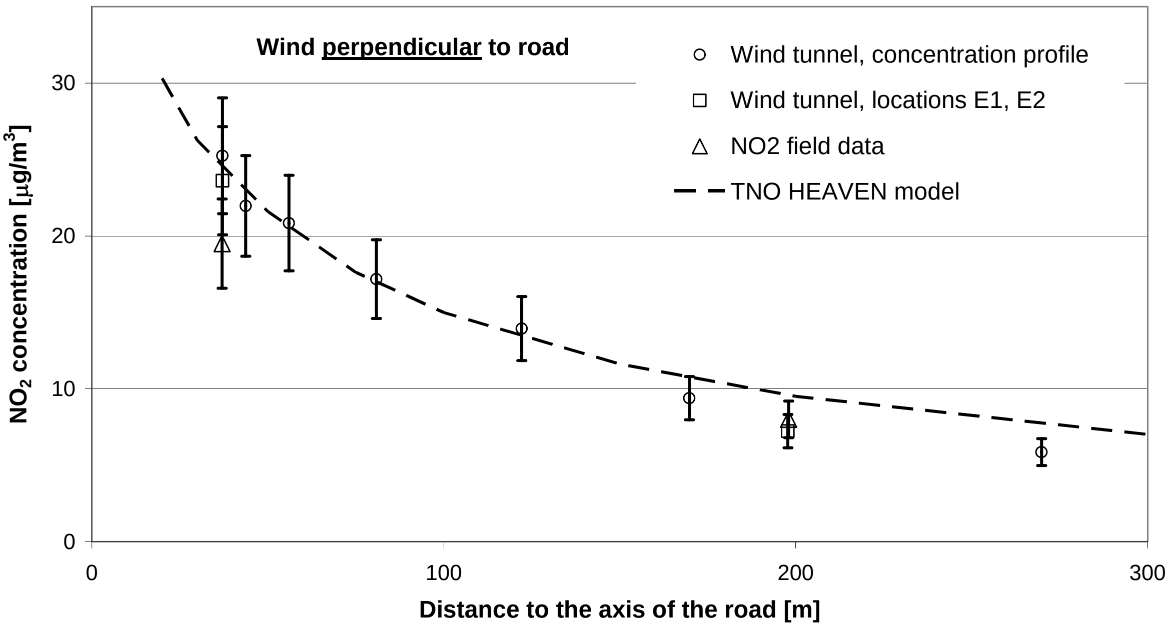

Figure 1. Measured and calculated NO_2 concentration contributions in Rotterdam.

NOx/NO2 CONVERSION

The treatment of the NO_x, O_3 and NO_2 chemistry in the HEAVEN model is according to a simple empirical method proposed by TNO (Hout, 1988). This relation is also used to convert NOx data measured in the wind tunnel into NO_2 concentrations. In the semi-empirical relationship the NO_2 concentration is related to the NO_x transported to the receptor point and the ambient NO_2 and O_3 concentrations as follows:

$$[NO_2] = f \cdot [NO_x] + \beta \, [O_3]_{background} \, \frac{[NO_x]}{[NO_x] + K}$$

where f is the fraction of NO_x emitted as NO_2 and β and K are empirical parameters.

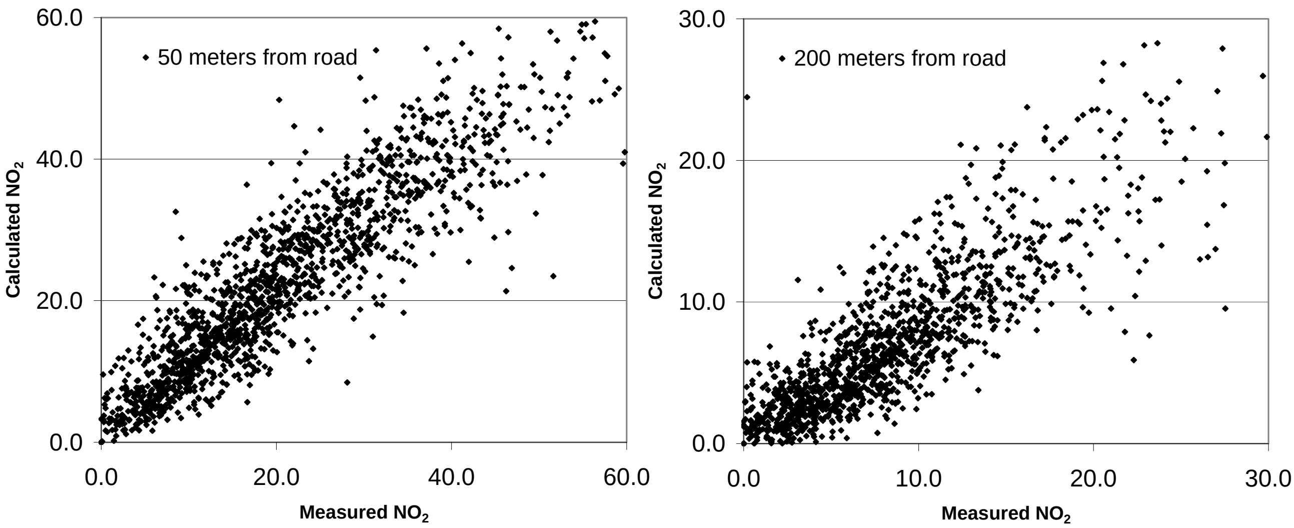

Figure 2. Correlation between NO_2 concentrations (units are μg/m^3*) calculated using the TNO conversion scheme and experimental values.*

In recent studies (Dosio, 2002 and Haspel, 2004) the empirical TNO method was compared to a number of other models, including the Canyon Plume Box Model (Yamartino, 1986), the

Discrete Parcel Method (Benson, 1989) and the Operational Street Pollution Model (Hertel, 1989). The TNO method is found to be both very robust as well as comparable in accuracy to the more complex models. As a test field data for NOx were used as input to the TNO conversion scheme. The calculated NO_2 concentrations were subsequently compared to the experimental values. In this comparison the quality of the basic NOx dispersion model is not relevant and only the performance of the NOx/ NO_2 conversion scheme is important. On analytical grounds it can be shown that the empirical constant K in the formula must be different for hourly and yearly averaged calcualtions. During the tests it was indeed observed that such an adjustment of the conversion scheme improved the description of the field data. The results are presented above in Figure 2. The agreement between calculated and measured NO_2 concentrations is very good. At a short distance from the road the average ratio between calculated and measured NO_2 concentrations is 1.04 (R^2=0.94) and at larger distance the ratio is 0.81 (R^2=0.78).

CONCLUSIONS

After previous satisfactory tests of the HEAVEN Gaussian dispersion model in an open field situation the present work shows an equally good result in an urban environment. The empirical NOx/NO2 conversion scheme used by TNO has also been tested and found to perform quite well.

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