Evaluation of two street canyon air quality models using data from European cities

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Abstract

This paper presents a sensitivity analysis of the Operational Street Pollution Model (OSPM) and an evaluation of OSPM and the Assessing the Environment Of Locations In Urban Streets (AEOLIUS) model. Both models calculate airborne concentrations of exhaust gases emitted by motor vehicles within street canyons. They perform best when the street canyon aspect ratio is 1.0. OSPM and AEOLIUS have been evaluated using data collected over a two-year period (1994-95) in Jagtvej, Copenhagen, Denmark. Further evaluation of the models was carried out using data collected in Göttinger Strasse, Hannover (1994) and Schildhorn Strasse, Berlin (1995), both in Germany. In all cases, model runs were carried out for carbon monoxide (CO). In the case of OSPM, two sets of newly proposed emission factors were used for the street canyons in Germany. In the calculation of these factors, the urban driving patterns and variations in the composition of the vehicle fleet according to the engine capacity were assumed as the most appropriate for the cases considered. Furthermore, parameters such as engine operating temperature and the use of catalytic converter were taken into account. Scatter plots of modelled against measured CO concentration yielded an average regression coefficient of 0.90 for the street canyons considered. With the newly proposed emission factors for Germany a lower regression coefficient was obtained. From similar scatter plots, the AEOLIUS model gave a regression coefficient of 0.86 for Jagtvej in 1994 and 0.78 for 1995. For Göttinger and Schildhorn Strasse, the regression coefficient obtained was 0.81.

1 Introduction

Urban areas cannot be considered homogenous and the highest pollution occurs in street canyons where the dilution of car exhaust gases is limited by the confined environment. Several street canyon air quality models exist, such as STREET by Johnson *et al.* [1] and the Canyon Plume Box Model (CPBM) by Yamartino and Wiegand [2]. The Operational Street Pollution Model (OSPM) is a dispersion model developed on the same lines as the CPBM. The former was evaluated using data from Vesterbrogade in Copenhagen and St. Olavs Street in Oslo as described in Berkowicz and Hertel [3]. The present version of OSPM can be used with several street-canyon configurations and various meteorological conditions.

The Assessing of the Environment Of Locations In Urban Streets (AEOLIUS) model developed by Buckland and Middleton [4] is based on the same theories used in OSPM. It is constructed on improved nomograms to calculate hourly pollutant concentrations at a receptor, as a function of wind direction, namely cross-canyon and along-canyon directions. AEOLIUS is generally used as a screening tool for air quality in a street canyon. It has been evaluated using data from Cromwell Street in London and Stratford Street in Birmingham (Buckland [5]).

2 Sensitivity analysis

Runs of OSPM were carried out in order to identify those input parameters that would require accurate measurement. The dependence of CO concentration, emission and traffic-induced turbulence within the canyon, on the various input parameters was established.

It is worth noting that as the re-circulating vortex has an important role in the distribution of pollution within a street canyon, the sensitivity analysis was carried out for two receptors, one on each side of the canyon.

From the sensitivity analysis, it was found that the following input parameters affect considerably the modelled CO concentration (output):

- width of street canyon,
- aspect ratio (affecting mostly the concentration on the leeward side of the street canyon),
- short vehicle velocity up to 40 km h^{-1},
- number of passenger cars and
- percentage of passenger cars fitted with a catalytic converter.

The height of the street canyon, long vehicle velocity, percentage of vehicles whose engines are running cold, wind speed greater than 4 m s^{-1} and exception width (equivalent to angles giving the position of an irregular structure in the street canyon with respect to the North, taken as a reference direction) have a much lesser effect on the modelled concentrations.

According to Berkowicz *et al.* [6], in windless conditions, traffic-induced turbulence is crucial in determining the highest pollution levels in the street canyon, since it becomes the only dispersion mechanism. The sensitivity analysis carried out here indicated that traffic-induced turbulence is affected considerably by the width of the canyon, average number of passenger cars and the short vehicle velocity, for an increasing number of passenger cars.

Analysis of the emission module has shown that emission is affected greatly by the average number of passenger cars, percentage of passenger cars without a catalytic converter for a large number of vehicles and short vehicle velocity in the range 0–30 km h^{-1} of passenger cars without a catalytic converter.

3 Evaluation of OSPM

Comprehensive sets of hourly-average data were available so that it was possible to evaluate the performance of OSPM under various meteorological conditions and traffic situations.

The traffic data gathered included the hourly-average counts of short and long vehicles. The percentage of passenger cars with and without a fitted catalytic converter, vans, trucks and buses were estimated from relevant data collected on site and national statistics. Other general information on the three street canyons and the monitoring campaigns is available on the TRAPOS network website: www.dmu.dk/atmosphericenvironment/Trapos/datadoc.htm.

From Table 1, one concludes that OSPM performs well for Jagtvej (1994 and 1995). This observation can be confirmed from the time series plotted in Figure 1, for Jagtvej 1995. For Göttinger 1994 and Schildhorn 1995, there is more data scatter and the model overpredicts significantly. One possible reason for this behaviour might be the under estimation of the percentage of passenger cars having a catalytic converter in 1994 and 1995 for the streets in question. Similar results were obtained for two model runs at different rooftop wind speed. There is more data scatter for low as compared to high wind speed. This indicates that the model is not adequately simulating the physical processes occurring within the canyon, for relatively calm wind conditions.

Table 1: Results of scatter plots of modelled against measured hourly-average CO concentration.

R^2 (Slope)	JAGTVEJ 1994	JAGTVEJ 1995	GÖTTINGER 1994	SCHILDHORN 1995
Whole data set	0.9190 (1.05)	0.9234 (0.96)	0.8877 (1.37)	0.9101 (1.43)
$U_{roof} \leq 2.0$ m s^{-1}	0.9115 (1.00)	0.8828 (1.01)	0.8804 (1.52)	0.8632 (1.56)
$U_{roof} > 2.0$ m s^{-1}	0.9347 (0.84)	0.9328 (0.95)	0.8994 (1.30)	0.8864 (1.47)

In Figures 2 and 3, the regions between the vertical dotted lines indicate the wind sector for which the receptor happens to be on the leeward side, when the wind blows right across the street canyon rooftop. Data measured from 8:00 till 20:00

eliminates uncertainty in emissions associated with night time hours, when the traffic volume is low. From these graphs it can be confirmed what was discussed by Berkowicz *et al.* [6], namely that at low wind speed there is hardly any distinction in pollutant concentration between the leeward and windward sides of the street canyon due to the absence of a vortex. Due to the lack of advection of pollution at low wind speed concentration is higher on average. At high wind speed, OSPM simulates very well the situation since vortex re-circulation of pollution is adequately modelled, where the leeward side concentration is consistently higher than that on the windward side.

In the evaluation discussed above, any information relating to the emission module was based on data collected and experiments performed in Denmark (Fenhann and Kilde [7] and Solvgang [8]). Table 2 shows the basic emission factors assumed for the different vehicle classes, as required by OSPM, at a speed of 50 km h^{-1}. It also shows a new set of basic emission factors based on the Road Transport Emission Inventory (RTEI) Guidebook (version 3) by Samaras *et al.* [9]. Equations according to vehicle class and different speeds were used to generate these factors. A second set of emission factors that were worked out using the Hand Book Emission FActors for Road Transport (HBEFA, version 1.2) by Keller *et al.* [10] are also given in Table 2. This handbook was developed to work out emission factors specifically for Germany and Switzerland.

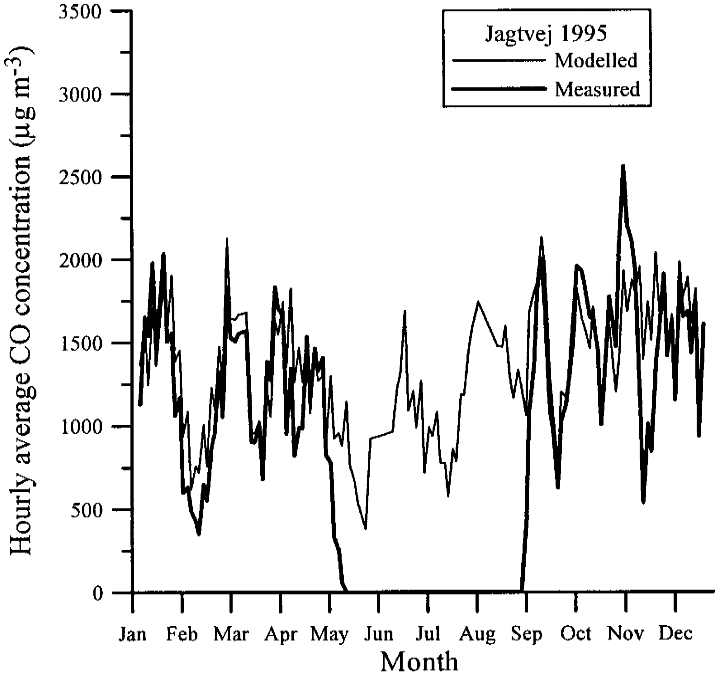

Figure 1: Time series of hourly-average measured and modelled CO concentration for Jagtvej 1995.

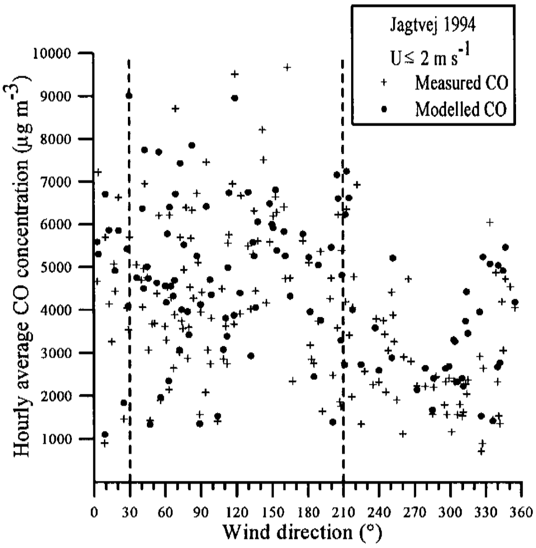

Figure 2: Dependence of hourly-average modelled and measured CO concentration on wind direction for roof-top wind speed U ≤ 2 m s^{-1}, from 8:00 to 20:00 for Jagtvej in 1994.

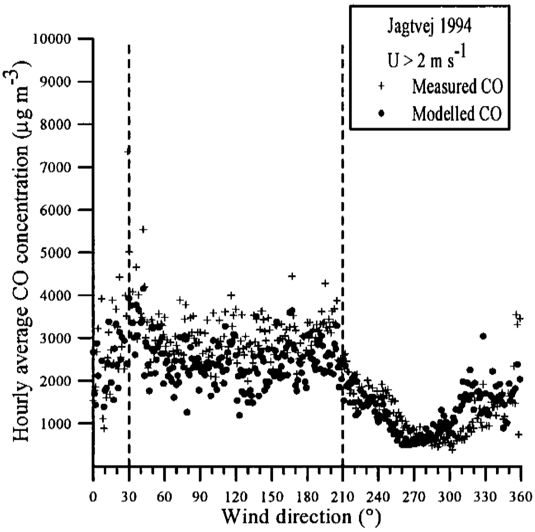

Figure 3: Dependence of hourly-average modelled and measured CO concentration on wind direction for roof-top wind speed U > 2 m s^{-1}, from 8:00 to 20:00 for Jagtvej in 1994.

Table 2: CO emission factors from data and information for Denmark and modified CO emission factors using the RTEI Guidebook and the HBEFA for Road Transport.

Basic Emission Factors for CO (g km^{-1})					
	Passenger Cars with catalytic converter	**Passenger Cars without catalytic converter**	**Vans**	**Trucks**	**Buses**
Using data for **Denmark** (reference year 1993)	3.5	35.0	18.5	28.0	28.0
Using **RTEI Guidebook**	0.70	7.42	9.73	2.46	3.20
Using **HBEFA** (reference year 1994)	1.54	7.87	2.74	2.07	4.91

An important assumption made in both evaluations, was that the percentage of gasoline-powered passenger cars with a catalytic converter was 65% in 1994 and 70% in 1995, in Germany. The CO emission file contains yearly traffic correction factors to allow for changes in traffic patterns that affect emissions from year to year. The original yearly emission correction factors available for Denmark were retained for Germany, as no information was available for the latter. Apart from driving modes, a parameter affecting emissions is cold starts. This was not accounted for.

Table 3 shows the regression coefficients and slopes obtained from scatter plots of hourly-average modelled against measured CO concentrations for the two proposed schemes of emission factors. The two proposed schemes resulted in more scatter and underprediction.

Table 3: Results of scatter plots of modelled against measured hourly-average CO concentration, using the newly-proposed emission factors.

Regression Coefficient, R^2 (Slope)	**GÖTTINGER 1994**	**SCHILDHORN 1995**
Original emission data for Denmark	0.8837 (1.02)	0.9123 (1.02)
Emission data using RTEI Guidebook	0.8349 (0.44)	0.8876 (0.38)
Emission data using HBEFA for Road Transport	0.8161 (0.40)	0.8539 (0.29)

4 Evaluation of AEOLIUS

The full version of AEOLIUS, called AEOLIUSF, available from www.metoffice.gov.uk/environment/aeolius1.html, the UK Meteorological Office website, was evaluated using the three datasets used with OSPM.

AEOLIUSF requires traffic data for short and long vehicles. Passenger cars and vans were considered as short vehicles while trucks and buses as long vehicles. Hourly-average traffic counts were assumed to be the same for working days, Saturdays and Sundays. The hourly-average vehicle speed variation of short and long vehicles was assumed to be the same as that used in OSPM.

Table 4: Adaptation of basic emission factors from OSPM to AEOLIUSF according to vehicle classification.

Vehicle classification used in OSPM					
Percentage (%) of vehicle type in:	**PC – Without a catalytic converter**	**PC – With a catalytic converter**	**Vans**	**Trucks**	**Buses**
Jagtvej 1994	57.0	25.0	11.0	3.5	3.5
Jagtvej 1995	52.0	30.0	11.0	3.5	3.5
Göttinger 1994	19.0	65.0	9.4	4.4	2.2
Schildhorn 1995	19.0	70.0	8.0	1.5	1.5
Dataset	Weighted emission factors for CO used in **AEOLIUSF** for **Small vehicles**		Weighted emission factors for CO used in **AEOLIUSF** for **Large vehicles**		
Jagtvej 1994	24.50		28.00		
Jagtvej 1995	22.89		28.00		
Göttinger 1994	11.42		28.00		
Schildhorn 1995	10.91		28.00		

The radial plot in Figure 4 shows the CO modelled concentration dependence on wind direction for different rooftop wind speeds, U_{roof}. The difference between the leeward and windward CO concentrations is as expected, with higher concentrations on the leeward side. However, along the street axis, the change in concentration between the leeward and windward side is not smooth. Similar plots were obtained for the other street canyons considered. This effect is because unlike OSPM, AEOLIUSF does not perform wind averaging. This is corroborated by another comparison between the same two models made by Buckland [5] using a different data set than the one used here.

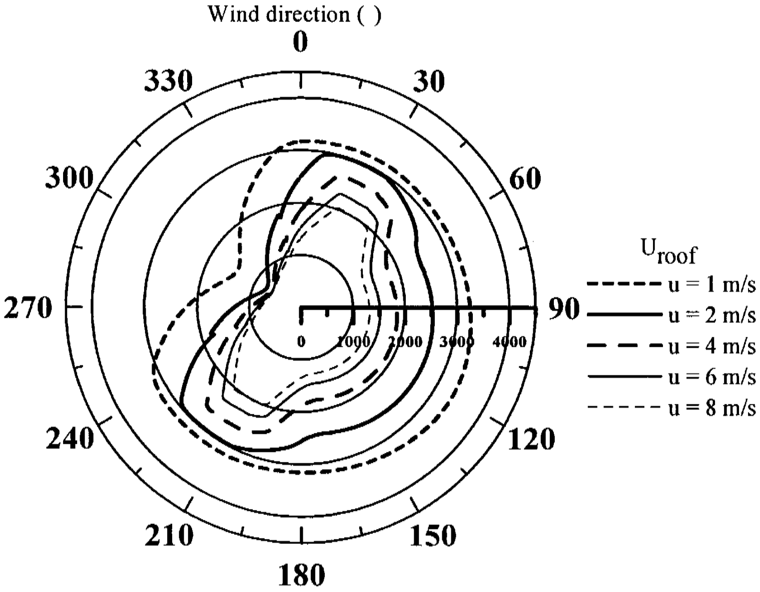

Figure 4: Sensitivity analysis of AEOLIUSF using street properties for Jagtvej.

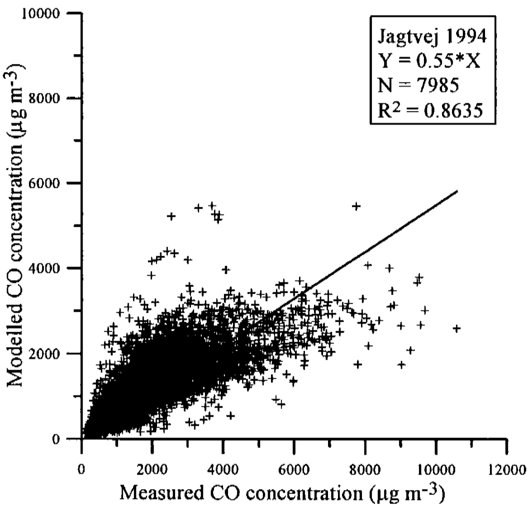

Figure 5: Scatter plot of modelled against measured CO concentration on hourly basis for Jagtvej 1994.

Figure 5 shows a scatter plot of modelled against measured CO concentration, for Jagtvej 1994. The same was done for Jagtvej in 1995. In the latter case a regression coefficient of 0.78 was obtained. For Göttinger and Schildhorn the regression coefficient was 0.81. AEOLIUSF underpredicts especially at high concentrations. Reasons for this could be that all passenger cars, vans and small lorries were assumed as short vehicles, making the emission factor used highly approximate.

5 Conclusions

From the sensitivity analysis of OSPM, vehicle classification and velocity variation are crucial in calculating CO emissions, concentration and traffic-induced turbulence. Furthermore, knowledge of the number of passenger cars with a catalytic converter greatly affects the calculated emissions and concentrations. A more detailed vehicle classification can help to solve the problem.

In OSPM, measured and modelled CO concentrations did not correlate very well when using newly-proposed emission factors for the street canyons in Germany. It is evident that the uncertainty of estimation of emission factors increases for small spatial scales such as those of a street canyon. The assumed traffic patterns are not necessarily the ones found in practice. The vehicle classification in Germany is very elaborate and OSPM is not capable of distinguishing between engine capacities. This implies that the emission module of OSPM has to take into consideration road gradient, signalized intersections and how the latter affect the vehicle velocity, which in turn affects emissions.

The AEOLIUSF model is by far easier to operate than OSPM as it requires less detailed information. Despite the fact that the model does not distinguish between several vehicle classes it gives surprisingly good results.

Considering the performance of both models, OSPM simulates different situations more accurately. Although the models remain easy to operate, they need refinements in certain modules in order to be able to simulate better different conditions. As an example, neither OSPM nor AEOLIUSF account for road gradient, road curvature, signalised intersections, fuel consumption and engine capacity as done in the Street Level Air Quality (SLAQ) model developed by Micallef and Colls [11].

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