EVALUATION OF THE OPERATIONAL STREET POLLUTION MODEL USING DATA FROM EUROPEAN CITIES

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Abstract. This paper presents a sensitivity analysis and an evaluation of the semi-empirical model known as Operational Street Pollution Model (OSPM). The model is capable of calculating airborne concentrations of exhaust gases emitted by vehicles, within a street canyon. OSPM has been extensively evaluated using data collected over a two year period (1994–1995), during a monitoring campaign carried out in Jagtvej, Denmark. Further evaluation of the model 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. Two sets of emission factors were used for the two street canyons in Germany; namely that available within OSPM and another separate set of emission factors derived from data collected in Germany. In the calculation of the latter set, the urban driving patterns and variations in the vehicle fleet composition according to the engine capacity were assumed accordingly. A correlation coefficient of 0.90 between the modelled and measured concentrations was obtained for all the cases considered when using the emission factors of OSPM. A correlation coefficient of about 0.85 was obtained with the newly proposed emission factors when applied to Göttinger and Schildhorn Strasse.

Keywords: air quality, emission factors, model evaluation, street canyon

1. Introduction

Urban areas cannot be considered as homogenous entities and the highest pollution levels occur in street canyons where the dilution of car exhaust gases is limited by the buildings on each side of the street canyon. Here, as the dispersion phenomena occur in the immediate vicinity of the cars, the modelling has to account for micro-scale processes.

There exist several traffic-related urban street-level air pollution models such as STREET by Johnson *et al*. (1973) and the Canyon Plume Box (CPB) model by Yamartino and Wiegand (1986). The Operational Street Pollution Model (OSPM) is a semi-empirical, dispersion model developed at the National Environmental Research Institute of Denmark, on the same lines as the CPB model.

Refinements of the parameterisations within OSPM, improved the performance of the model with regards to different street canyon configurations and various meteorological conditions. However one has to keep in mind that no model is capable of handling all different street configurations and simulate all real-life conditions.

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In spite of all its simplifications OSPM seems to perform well when compared to CPB (Berkowicz, 1997).

The following is an evaluation of OSPM using comprehensive datasets available from three European cities. The exercise incorporates a sensitivity analysis of the model and model runs using two newly proposed sets of emission factors applicable to the different street canyons considered.

2. Model Overview

The general modular structure of OSPM is shown in Figure 1, which demonstrates the input data required and the separate modules making up the emission-dispersion model. The modules are qualitatively described in the following section.

OSPM can calculate concentrations of the exhaust gases carbon monoxide (CO), nitrogen oxides (NO_x), nitrogen dioxide (NO_2) and benzene at two receptors, one on each side of the street canyon.

2.1. Emissions

Emission estimation depends on the application. For an urban street canyon, the emissions from motor vehicles can be calculated as the sum of three specific terms: hot emissions, emissions when the engine is running cold and evaporative emissions (Corvalán *et al.*, 2002). Hot emissions correspond to the exhaust gases from the tailpipe under normal operational conditions. Cold engine emissions represent additional emissions due to the engine operating below the optimum temperature. Evaporative emissions occur due to fuel evaporation during travel.

The OSPM emission module makes use of emission factors based on hot emissions. Hot vehicle emissions depend on several parameters, namely (Corvalán *et al.*, 2002):

- traffic conditions (e.g. congestion);
- vehicle operating conditions (e.g. average speed, load trip length, driving mode, mileage);
- vehicle technological parameters (e.g. model and year, state of maintenance, engine type, control emission system);
- fuel characteristics (e.g. type, chemical composition) and
- topography.

Hot emissions are normally calculated by multiplying an average basic emission factor with the hourly traffic volume of each vehicle category (Fu *et al.*, 2000). In OSPM, emission factors are speed-dependent, consequently, basic emission factors are multiplied with a speed-dependent factor, for every vehicle category. OSPM does not take into consideration the effect on emission rates as a result of modal behaviour of vehicles' motion caused by signalized intersections or at street junctions. Vehicle technological parameters, fuel characteristics and topography such as road gradient are not accounted for within the emission module.

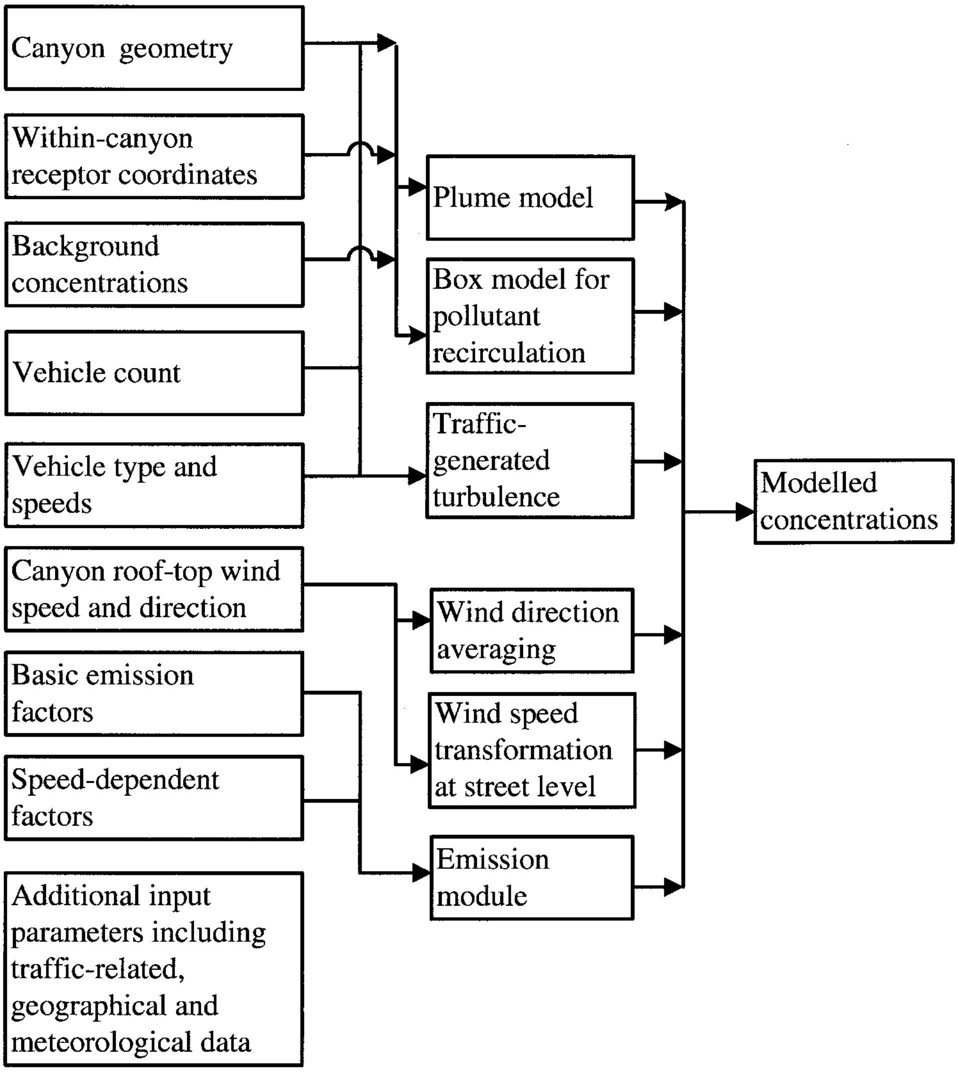

Figure 1. Schematic representation of the principal modules of OSPM.

2.2. Dispersion

OSPM calculates the concentration of exhaust gases from vehicles in a street canyon similarly to the Canyon Plume Box model. In OSPM, the Plume model is used to calculate the direct contribution of emissions from the vehicles in the street (see Figure 2), (Berkowicz *et al.*, 1997). These emissions are assumed to come from a number of infinitesimal line sources that are aligned perpendicularly to the wind direction at street level. The pollution is then advected to the (sheltered) leeward side of the street by a wind vortex created as an effect of the wind blowing at rooftop level, across the canyon. The Box model calculates the concentrations that

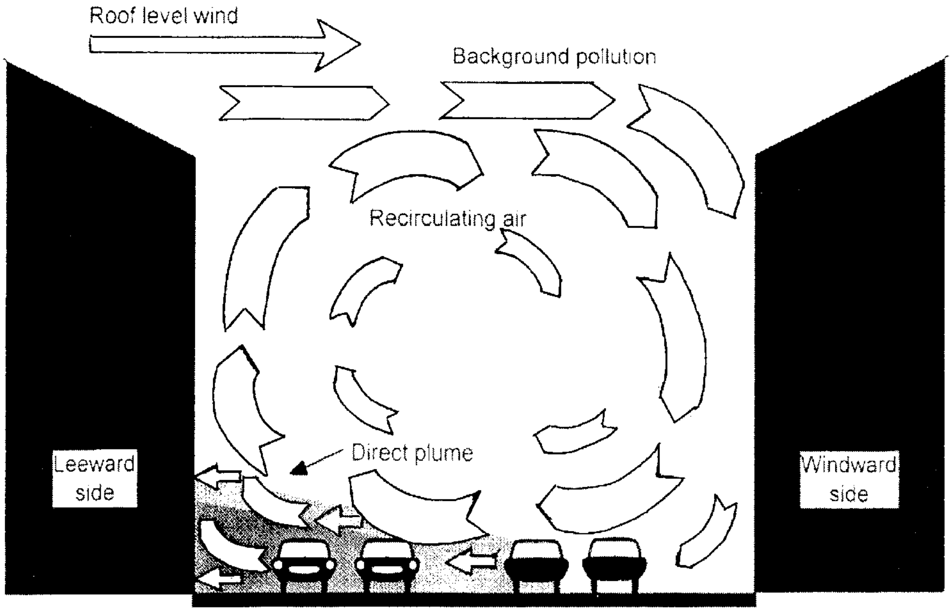

Figure 2. Schematic illustration of flow and dispersion in a street canyon. (Berkowicz *et al.* (1997)).

are not coming directly from the vehicles but as a result of the recirculation of the polluted air and any other emissions from outside the recirculation zone, that are injected in the canyon on the windward side (see Figure 2). Parameters related to the canyon geometry (e.g. building height on each side and canyon width), shape of the roofs and rooftop wind speed can influence how much the recirculation zone extends inside the canyon. The pollution within the recirculation zone is based on a mass balance of well mixed pollutants, where the inflow rate of the pollutants into this zone is equal to the outflow rate as described in Berkowicz and Hertel (1989a).

2.3. External influences

The most important external influence is the background concentration, which is required as input by the model. Background concentration accounts for the contribution to the within-canyon receptor concentration from all sources other than the vehicles within the canyon. It is important that the measurement of this parameter is not done upwind at rooftop level. According to Micallef and Colls (1999) if the measurement is done at rooftop level, any contributions from vehicles on side streets are not accounted for. One way of dealing with this problem is to measure background concentration at monitoring stations situated in the vicinity of the canyon.

2.4. Meteorological pre-processors

Several parameterizations are used within OSPM, which process the basic meteorological data to give parameters that are not generally available, but required by OSPM in its calculations. The following discussion describes some of the more important parameterisations.

The most severe pollution episodes are usually associated with calm or very low wind speed conditions. Vignati *et al*. (1995) have shown that differences in prevailing wind speed conditions seem to explain much of the differences in urban pollution concentrations.

Street canyon pollution models typically require wind speed data at roof level. Such data are sometimes not available. Transformation of wind measurements collected at some location in the city or even outside the city is then necessary. Rotach (1995) argues that the determination of the wind speed at roof level requires knowledge of the turbulence structure above. Local modification of wind flow and turbulence might also be due to some pronounced building formations near the measuring site. Based on wind tunnel modelling, Kennedy and Kent (1977) have demonstrated that high buildings influence the wind flow and thus the dispersion conditions at the measuring site. Therefore, in OSPM the wind speed at street level is calculated assuming a logarithmic reduction of the wind speed at roof top towards the bottom of the street.

In urban areas, the wind direction is rarely constant over short periods of an hour or less. This is particularly true for low wind speeds, less than 1 m s^{-1}. The dependence of concentration on fluctuations, when averaged over a period of an hour, is smoothed significantly. In order to account for this effect an averaging interval with respect to the wind direction is introduced in the model (Berkowicz and Hertel, 1989b).

2.5. Mechanical turbulence

At very low wind speeds, the wind vortex in the canyon vanishes and turbulence created by the traffic flow will become significant in determining the highest pollution levels in a street canyon. In a street canyon, the flow of vehicles is generally dense and thus the turbulence field cannot be considered as a simple superposition of non-interacting vehicle wakes. For this reason, the vehicles in a canyon are considered as moving roughness elements. In Berkowicz *et al*. (1997), it is shown that traffic-induced turbulence increases with the square root of the traffic flow and decreases with increasing canyon width. Apart from these parameters, knowledge of the number of vehicles passing the street per unit time and the average driving speeds of cars and heavy vehicles are needed.

The flow regime within a street canyon is primarily determined by its geometry (e.g. height-to-width, (H/W), and length-to-height, (L/H) ratios). For wind flow across the street axis, Oke (1988) distinguishes between ‘skimming flow’ with a characteristic vortex occurring for a relatively large H/W, ‘wake intermediate flow’ for intermediate H/W, and 'isolated roughness flow' for smaller H/W. As OSPM is a model designed for street canyons of aspect ratio close to 1.0 the model assumes an isolated roughness flow regime. As already explained, the Gaussian plume from local traffic within a street canyon of an aspect ratio of 1.0 is directly advected to the leeward side while on the windward side the impact is only from the air that has recirculated in the street for wind speeds greater than 2 m s^{-1}.

2.6. Stability correction

In OSPM, the influence of atmospheric stability is considered as negligible. This assumption seems reasonable since turbulence in a street canyon is mainly mechanically-generated. Thermally-generated turbulence can be neglected because it is known that convective turbulence is usually small at the surface and becomes significant at higher levels, well above street canyon heights.

A more critical effect, mentioned in Berkowicz and Hertel (1989c) is the attenuation of the mechanical turbulence due to a surface temperature inversion. This can occur at low wind speed with a clear night sky or else during daytime in winter. It seems that in extreme stable conditions, enhanced concentrations will be measured due to an attenuation of the traffic-induced turbulence. It is assumed that attenuation takes place only at the top of the street canyon.

3. Sensitivity Analysis

3.1. General considerations

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

For the purpose of carrying out the sensitivity analysis, the chosen weekday was Monday, the percentage of gasoline powered passenger cars, having a cold start, and the velocities of short and long vehicles were all assumed to be the most representative for an urban street canyon. It should be noted that short vehicles refer to vehicles that weigh up to 3 tonnes. Vehicles weighing more than 3 tonnes are classified as long. The input data to the model associated with street geometry were those for Göttinger Straße. The meteorological inputs were all average values for the whole year.

As the recirculating 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 road, referred to as receptors 1 and 2. Which of the two receptors will be on the leeward and the windward sides depends on the wind direction.

No changes were performed in the emission factors used by OSPM, which were originally developed by the Danish Road Directorate (Solvgang, 1997). This analysis tries to identify the parameters affecting considerably the emissions in order to develop further the emission module.

The traffic-induced turbulence is crucial in determining the highest pollution levels in the street canyon, as in windless conditions, the ambient turbulence disappears and the only dispersion mechanism is due to turbulence created by traffic (Berkowicz *et al.*, 1997).

3.2. Results of the sensitivity analysis

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

- 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 (see Figure 3).

The following factors have a much lesser effect:

- height of street canyon;
- long vehicle velocity;
- percentage of vehicles whose engines are running cold (i.e. below normal operating temperature;
- windspeed greater than 4 m s^{-1} and
- width of an opening or a high building within 40 m distance on either side of the receptor.

The input parameters, which affect considerably the traffic-induced turbulence, are the following:

- average number of passenger cars;
- short vehicle velocity for an increasing number of passenger cars and
- width of street canyon.

The total emission is affected by the following input parameters:

- average number of passenger cars;
- number of passenger cars, especially those without a catalytic converter;
- percentage of passenger cars fitted with a catalytic converter for a large number of vehicles (see Figure 3) and
- short vehicle velocity of those passenger cars without a catalytic converter, in the range 0–30 km h^{-1}.

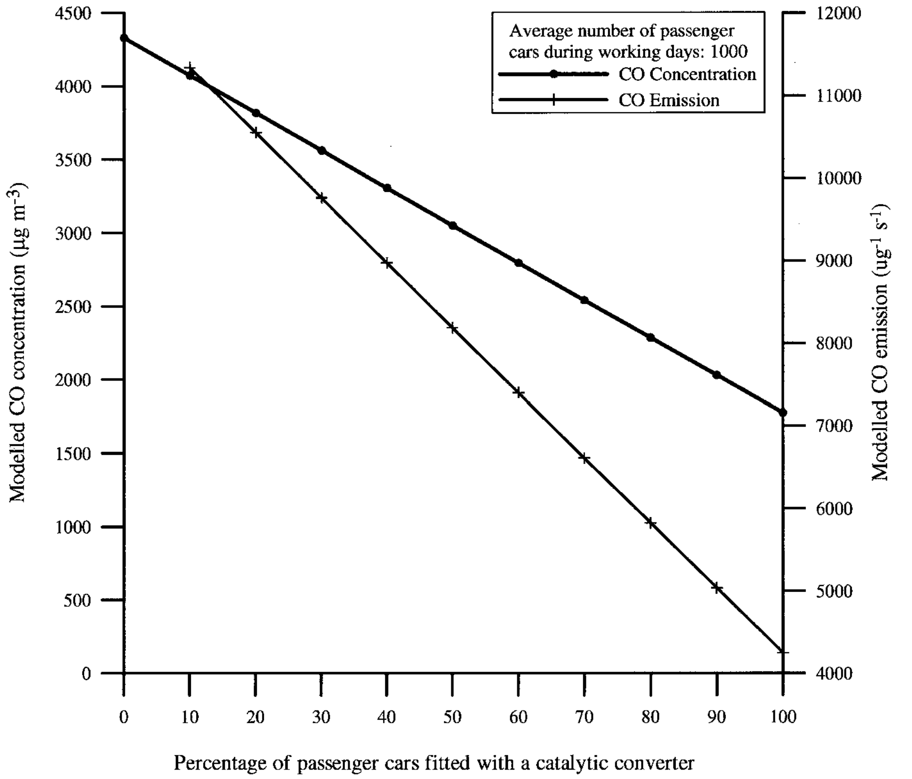

Figure 3. The effect of the percentage of passenger cars, fitted with a catalytic converter on the modelled CO concentration and emission during working days.

4. Operation of OSPM

4.1. Preparation for Model Runs

For the running of OSPM, an initialisation file is needed in order to access all the necessary input data files. OSPM reads in sequence hourly-measured data of wind speed, wind direction, air temperature, global solar irradiance and carbon monoxide concentration. A street geometry data file is required where the general features of the street canyon are gathered. The user has to choose whether or not wind direction averaging is to be performed. The receptor on either side of the street has to be chosen. Another option file allows the user to choose whether or not to work percentiles and whether calculations are to be performed in μg m^{-3}or ppb.

The required traffic input data are hourly averages. The traffic profile is subdivided into three categories, namely that associated with weekdays, Saturdays and Sundays separately. The vehicle classification required considers as insignificant the motorcycles and heavy vehicles greater than 7 tonnes, as noted by Solvgang

(1997). Short vehicles are assumed to consist of passenger cars, small vans and lorries. Long vehicles are the trucks and buses. In this work, the diurnal variation of average velocity for short and long vehicles is assumed to be the same for the three streets. The same assumption is applied for the percentage of passenger cars running on a cold engine.

The emission module utilises a set of basic emission factors for each vehicle class specified, including passenger cars with a three-way catalytic converter. These factors were developed by the Danish Road Directorate in 1993 for a speed of 50 km h^{-1} (Solvgang, 1997). The basic factors are used in conjunction with a set of scaling factors to work out the emission factors at different vehicle average speeds in multiples of 10 km h^{-1}. The yearly emission factors are used to account for changes in emissions from year to year (Fenhann and Kilde, 1994).

5. Model Evaluation

OSPM was rigorously evaluated using data available from the following website: http://www.dmu.dk/AtmosphericEnvironment/trapos/datadoc.htm

The street canyons considered in the evaluation are:

- Jagtvej, Copenhagen, Denmark
- Göttinger Straße, Hannover, Germany and
- Schildhorn Straße, Berlin, Germany.

5.1. Description of sites and data collection

Table I lists the basic data associated with the three street canyons considered and gathers the information available on all the monitoring stations used for data collection. The meteorological station in the three street canyons was located on a 10 m mast, on the roof of a building in the vicinity of the street. The background monitoring stations were placed on the roof of a building far away from the street. As regards traffic data collection in Jagtvej, automatic counters were used to distinguish between short and long vehicles, during several months between 1994 and 1995. For a more detailed traffic inventory, manual traffic counts were carried out. For Göttinger the traffic classification was done by automatic traffic counters for the four separate lanes. The vehicles were classified on an hourly basis as either short or long vehicles. For Schildhorn, no actual information was available on how hourly traffic counts were obtained.

5.2. Comparison of measured and modelled concentrations

Several runs of OSPM were performed using the same emission files for the three streets. Diurnal variations in the short and long vehicle velocities, together with the change in percentage cold starts were also assumed to be the same for the three

TABLE I

Summary of the street information required by OSPM and the general information available on the three monitoring campaigns

Information	Jagtvej	Göttinger	Schildhorn
Canyon width	25 m	25 m	26 m
Canyon height	18 m	20 m	19 m-NE, 22 m-SW
Aspect ratio	0.72	0.80	0.79
Orientation of street with respect to North	30°	163°	120°
Number of lanes	4 with 2 in each opposite direction of traffic	4 with 2 in each opposite direction of traffic	4 with parking lanes on both sides
Average number of vehicles per day	22,000	30,000	45,000
Location of CO Monitor (Height of monitor from ground level)	On the East side of the street (3.5 m)	Close to a 32 m building on the South-West side of the street (1.5 m)	On the South-West side of the street (2.5 m)
Wind sector for which monitor is on the leeward side	30° – 210°	163° – 343°	120° – 300°
Pollutants (measurement of hourly-average concentration)	NO_X, NO_2, O_3, CO, SO_2, C_6H_6, Toluene, Xylene, $PM_{2.5}$, PM_{10}.	NO_X, NO_2, CO, Soot, C_6H_6, Toluene, Xylene.	NO_X, NO_2, CO, Soot, C_6H_6, Toluene.

streets. The data were used to generate modelled concentrations, which were then compared with the corresponding measured values.

Table II summarizes the results of several scatter plots of modelled against measured CO concentration on an hourly basis for every dataset. For every scatter plot, the regression coefficient and the slope (in brackets) are presented. Model runs were also done for rooftop windspeed less than 2 m s^{-1}, and greater than 2 m s^{-1} separately.

A look at the whole dataset shows that OSPM performs well for Jagtvej (1994 and 1995). For Göttinger 1994 and Schildhorn 1995, there is more data scatter and the model overpredicts. A reason for this could be that the assumed percentages of passenger cars with a three-way catalytic converter were less than the actual (see Figure 3). Age-wise distribution of vehicles, effect of ambient temperature vis-à-vis the operating condition of the engines and use of air-conditions could

TABLE II

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)

also play role. High emitting vehicles present in the fleet and the type of inspection program undertaken in the region are also important factors that may explain the above-mentioned discrepancies.

Similar results were obtained for the other two model runs, at different rooftop windspeed. One important feature is that there is more data scatter for low as compared with high windspeed. This indicates that the model is not adequately simulating the physical processes occurring within the canyon, for relatively calm wind conditions.

From the time series in Figure 4 it is clear that for Jagtvej (1995) the measured and modelled concentrations follow a similar trend. However further analysis has shown that for the two streets in Germany, OSPM overpredicts significantly. One possible reason might be an underestimation of the percentage of passenger cars having a catalytic converter.

Figure 5 shows that for Göttinger and concentrations up to 3000 μg m^{-3}, OSPM underpredicts the measured concentration but overpredicts by roughly 5% at higher concentrations. One of the reasons for this behaviour might be that the assumed percentage of passenger cars with a catalytic converter was low for 1994. Further analysis has shown that for Jagtvej, at very low concentrations and up to 1000 μg m^{-3}, OSPM underpredicts while overpredicts for higher concentrations.

In Figures 6 and 7, 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. These graphs show the wind direction dependence of the measured and modelled CO concentrations for low wind speeds (< 2 m s^{-1}) and for high wind speeds (> 2 m s^{-1}), for data collected during daytime hours i.e. 8:00 to 20:00.

From the graphs in Figures 6 and 7, it can be confirmed what was discussed by Berkowicz *et al*. (1997), namely that at low wind speed there is hardly any

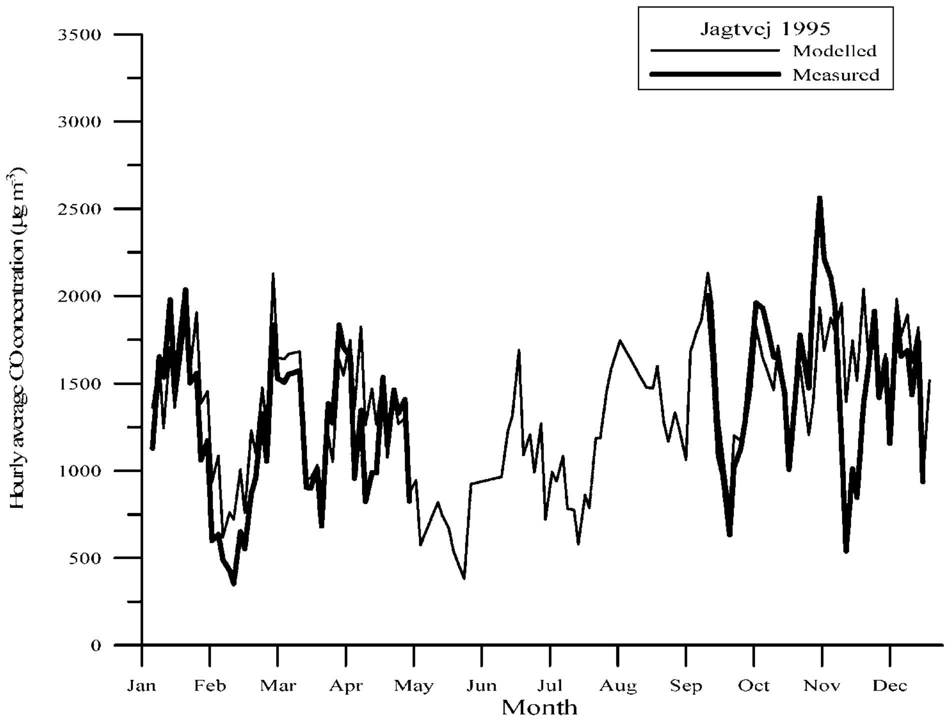

Figure 4. Time series of hourly average measured and modelled CO concentration for Jagtvej 1995.

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 recirculation of pollution is adequately modelled. In this case the leeward side concentration is consistently higher than that on the windward side.

For Jagtvej in 1994, Figures 6 and 7 show that for high wind speeds during the daytime hours, OSPM simulates very well the measured CO concentration. However, at low wind speeds the wind dependence relationship between measured and modelled concentrations is less obvious. A similar pattern was observed for Jagtvej 1995.

For Göttinger and Schildhorn Straße, the percentage of passenger cars with a catalytic converter was changed to a more appropriate nevertheless assumed value applicable to Germany for 1994 and 1995. The new assumed values gave better model performance, especially for high wind speeds, but for low wind speeds the model needs better parameterizations. In fact graphs very similar to Figures 6 and 7 were obtained. Data measured from 8:00 till 20:00 eliminates uncertainty in emissions associated with night-time hours, when the traffic volume is less.

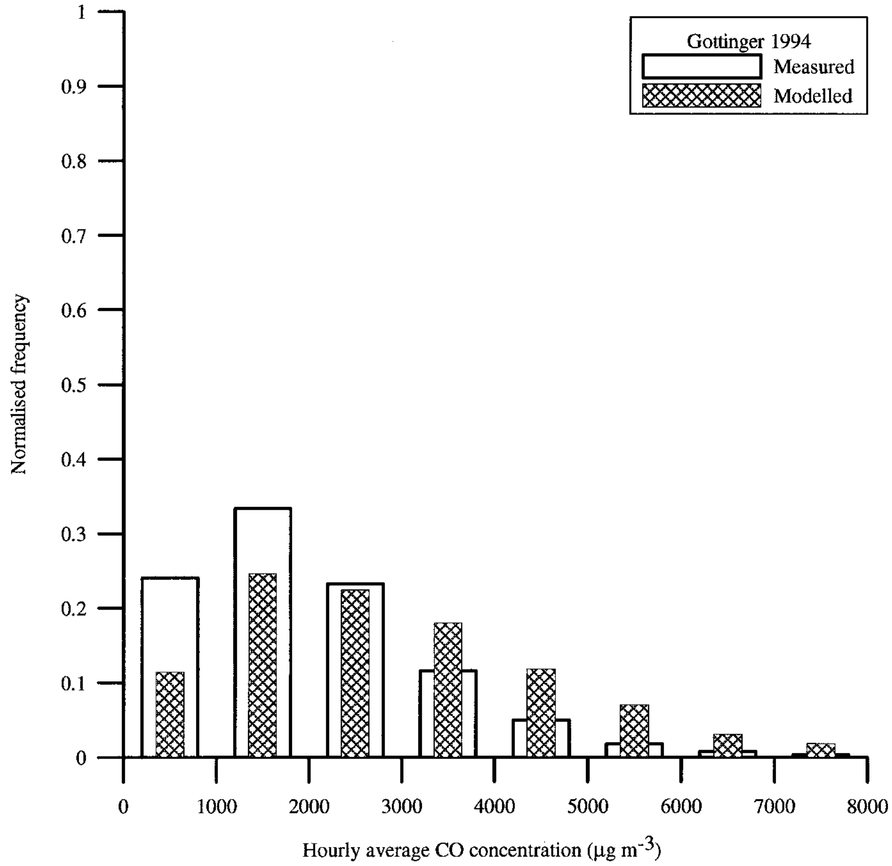

Figure 5. Normalised frequency distribution of hourly average measured and modelled CO concentration for Göttinger Straße 1994. It was assumed that 25% of passenger cars were fitted with a catalytic converter.

Using the original emission factors for Denmark, the hourly average modelled CO emission for the three streets are compared in Figure 8. The pattern of the plots identify the time periods, from 7:00 to 18:00 and 16:00 to 18:00, as higher in emissions corresponding to the morning and afternoon rush hour periods. Emissions for the two German streets are significantly higher when compared to that of Jagtvej. The two German streets carry a larger volume of traffic as indicated in Table I.

Figure 9 shows the traffic-induced turbulence plotted separately for working days, Saturdays and Sundays, and for all the week in Schildhorn Straße. Generally speaking turbulence follows the traffic pattern. One common feature observed in the three graphs is that in the early morning hours from 1:00 to 4:00 and from 16:00 to 19:00, traffic-induced turbulence during working days is less than on Saturdays and Sundays. It can be noticed that during weekends, at the early hours of the day there is less traffic that is moving at higher speeds on returning from the weekend

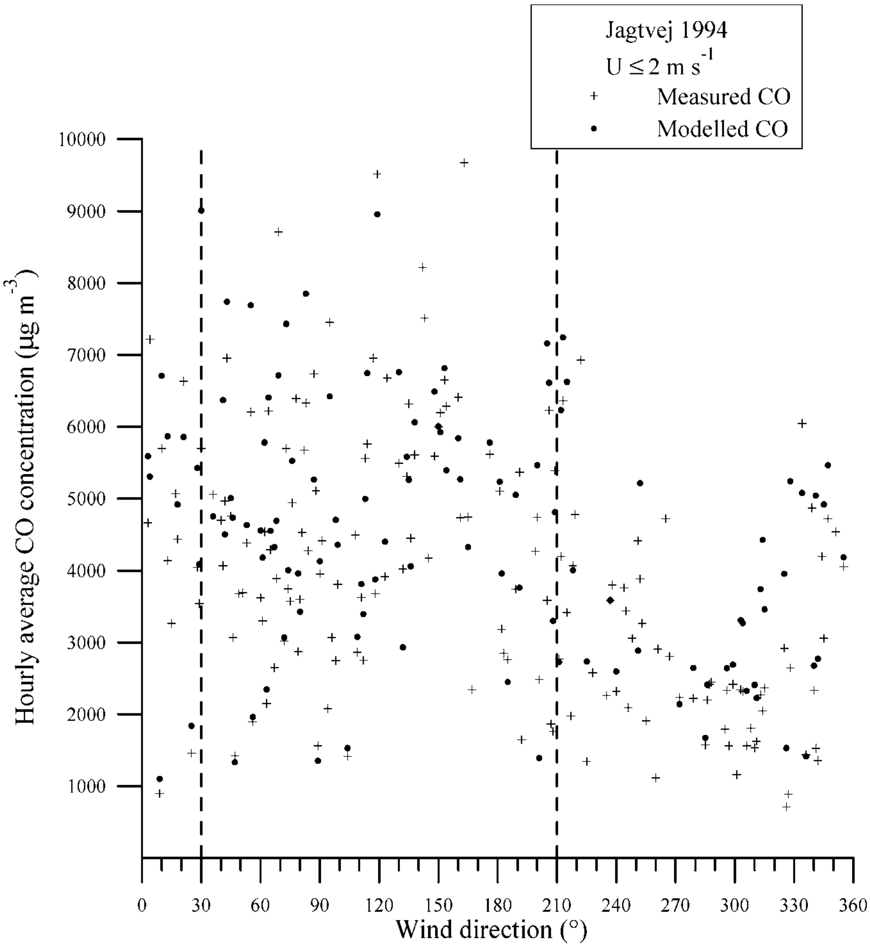

Figure 6. Dependence of hourly average modelled and measured CO concentration on wind direction for roof-top wind speed $U \leq 2$ m s^{-1}, from 8:00 to 20:00 for Jagtvej in 1994.

nightlife. For the time period 16:00 to 19:00, during working days in a heavy traffic pattern, the vehicles are moving at a lower average speed so less turbulence occurs. Figure 9 was reproduced for the other street canyons.

5.3. Newly proposed emission factors for Germany

In the model evaluation discussed in section 5.2, all the emission factors and any information related to the emission module were based on data collected and experiments performed in Denmark (Fenhann and Kilde, 1994) and Solvgang (1997). Table V shows the basic emission factors assumed for the different vehicle classes at a speed of 50 km h^{-1}.

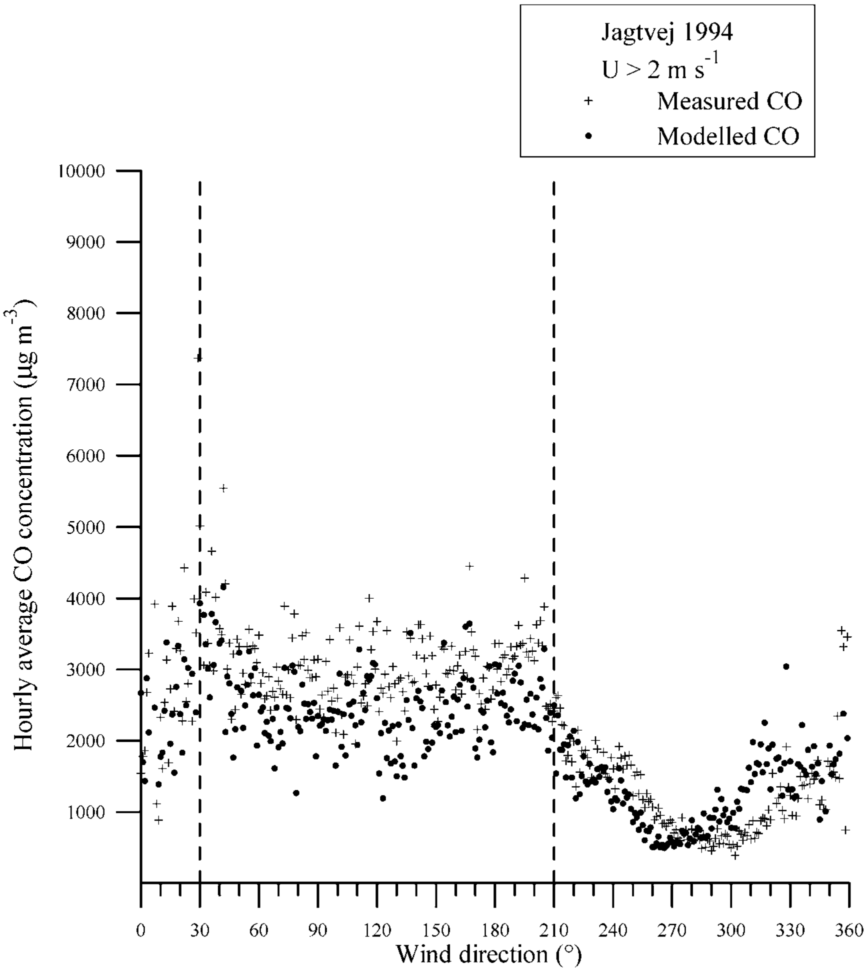

Figure 7. Dependence of hourly average modelled and measured CO concentration on wind direction for roof-top wind speed U > 2 m s^{-1}, from 8:00 to 20:00 for Jagtvej in 1994.

In this section emission factors are proposed for Germany, using two different methodologies, namely that from the

- Road Transport Emission Inventory (RTEI) Guidebook (version 3) by Samaras *et al.* (1999) and
- the Hand Book Emission Factors for Road Transport (version 1.2) (HBEFA) by Keller *et al.* (1999).

Table III shows the vehicle classification identified to be the most suitable for use with OSPM, out of the extensive information on a wide variety of vehicle classes found in Germany.

The main principles of the RTEI Guidebook are drawn from two European activities, namely:

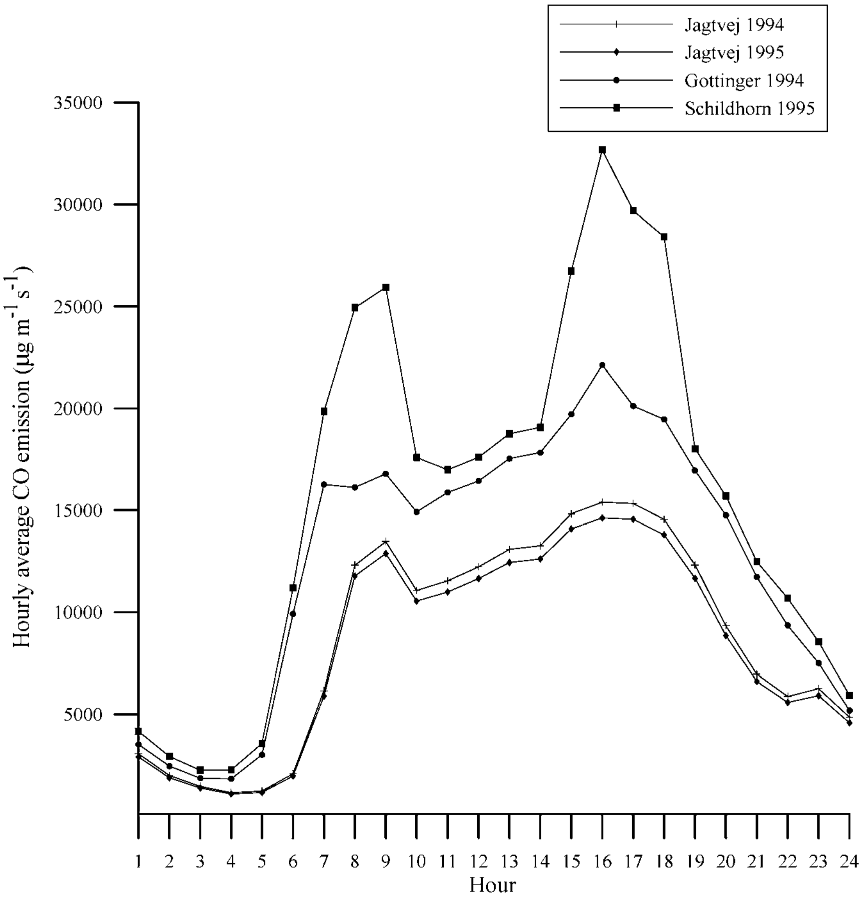

Figure 8. Diurnal variation of hourly average modelled CO emission for all street canyons, and all years.

- Co-operation in the field of Scientific and Technical Research (COST 319) on the estimation of emission factors and
- Methodologies to Estimate Emissions from Transport (MEET), a European Commission sponsored project in the area of transport.

The equations in the Guidebook are used to work out the new emission factors. These equations are applicable to European countries and are aimed at harmonizing emission factors and national methodologies developed recent years.

Table III shows the equations used in developing a new set of basic emission factors for each vehicle class, for an engine running at normal operating temperature and for an urban speed of 50 km h^{-1}. Equations used for the generation of speed-dependent factors are also given in Table III. Table V shows the modified basic emission factors generated using the above-mentioned equations.

TABLE III

Speed-dependent CO emission factors for all vehicle classes used in OSPM obtained from the Road Transport Emission Inventory (RTEI) Guidebook

Vehicle Class (Legislation)	Speed Range ($km\ h^{-1}$)	CO Emission Factor ($g\ km^{-1} veh^{-1}$)
Passenger cars with catalytic converter (1.4–2.0 l) (91/441/EEC)	10–130	$5.0786 - 0.1562V + 0.001375V^2$
Passenger cars without catalytic converter (1.4–2.0 l) (ECE 15–04)	10–60 60–130	$260.788\ V^{-0.910}$ $14.653 - 0.220V + 0.001163V^2$
LDVs (2.0–3.5 tonnes) e.g. small vans and lorries (Conventional)	10–130	$57.789 - 1.5132V + 0.01104V^2$
Trucks (> 3.5 tonnes) (Conventional)	5–100	$37.280\ V^{-0.6945}$
Buses (Conventional)	5–50	$59.003\ V^{-0.7447}$

TABLE IV

Vehicle classification from the Hand Book of Emission Factors (HBEFA) for Road Transport

Vehicle category	Weight	Engine capacity	Legislation
Passenger Cars (no catalytic converter)	0–2.5 tonnes	1.4–2.0 l	ECE 15–04
Passenger Cars (with catalytic converter)	0–2.5 tonnes	1.4–2.0 l	Open loop 88/76/EEC
			Closed loop 91/441/EEC
Light Duty Vehicles (Small vans, lorries)	2.5–3.0 tonnes	All capacities (diesel)	LDV/XXIII/EEA 1 (conventional)
Trucks	All weight categories (50% load)	All capacities (diesel)	HDV/1980ies
Urban Coaches/Buses	All weight categories (50% load)	All capacities	Urban bus/1980ies

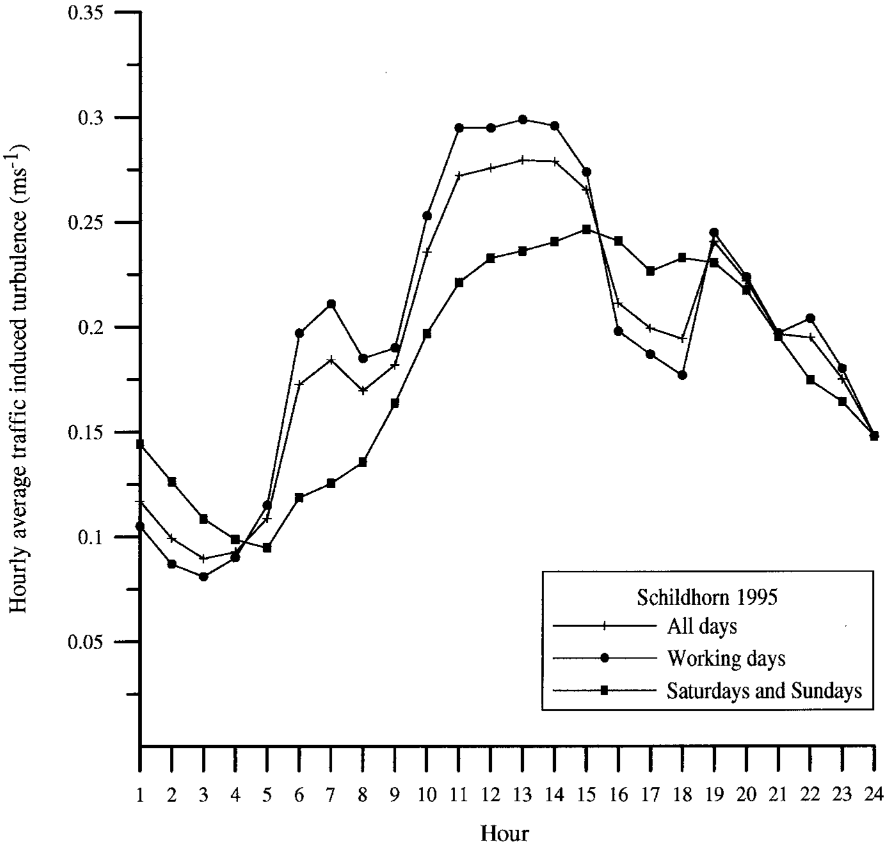

Figure 9. Diurnal variation of hourly average modelled traffic-induced turbulence in Schildhorn Straße in 1995.

The second evaluation was carried out using the HBEFA (version 1.2) developed as a joint effort between the Federal Environmental Agency (Umweltbundesamt, UBA) in Berlin and a Consulting Group for Policy Analysis and Implementation called INFRAS in Bern. The handbook was developed to work out emission factors for Germany and Switzerland. Table IV shows the most appropriate vehicle classification for the evaluation of OSPM using HBEFA. Some problems were encountered as regards trucks and urban coaches. It was assumed that the most conventional class of trucks and urban coaches corresponding to the years 1994 and 1995 were the ones known as HDV/80ies and Ubus/80ies respectively in HBEFA. HDV are heavy duty vehicles, while Ubus refers to urban coaches. Other vehicles of the same classes manufactured during the 1980s are referred to as 80ies. Table V shows the modified basic emission factors generated using HBEFA and are based on different traffic situations present in an urban street canyon.

An important assumption made in both evaluations, was that the percentage of gasoline-powered passenger cars with a three-way catalytic converter was 65% in

TABLE V

CO emission factors from data and information for Denmark and modified CO emission factors using Road Transport Emission Inventory (RTEI) Guidebook and the Hand Book of Emission Factors (HBEFA) for Road Transport

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

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.

Driving modes influence tailpipe CO emissions. However, another parameter affecting emissions is the effect of cold starts. OSPM is able to calculate emissions for an engine working at normal operating temperature, so that the effect of cold start emissions is not accounted for. The effect of the catalytic converter on emissions is only for hot engines.

Originally, the short and long vehicle speeds were different from each other in the same hour throughout the day. In this evaluation, as all types of vehicles pass from the same lanes, it is assumed that short and long vehicles should have the same speed although the speed changes on an hourly basis throughout the day.

Table VI shows the regression coefficients and slopes obtained from scatter plots of hourly average modelled against measured CO concentrations for the two proposed schemes.

From the set of results gathered in Table VI one concludes that the performance of OSPM did not improve. The two proposed schemes resulted in more scatter and

TABLE VI

Results of scatter plots of modelled against measured hourly average CO concentration, using the Road Transport Emission Inventory (RTEI) Guidebook and the Hand Book of Emission Factors (HBEFA) for Road Transport

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

underpredicting. One possible reason for this underprediction is the chosen vehicle classification schemes shown in Tables III and IV.

6. Conclusions

This paper gives an evaluation of the operational, semi-empirical street pollution model OSPM using measurements of CO from three European street canyons. The model yields good results for wind speeds higher than 2 m s^{-1}.

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

Measured and modelled CO data 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 that of a street canyon.

This implies that the emission module of OSPM has to take into consideration the road gradient, the effect of evaporative emissions, signalized intersections and how the latter affect the vehicle velocity, which in turn affects emissions.

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