PREDICTING EMISSION AND MEAN AIR QUALITY IN UNDERGROUND GARAGES

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ABSTRACT
Air quality measurements in vehicle garages indicate that high pollutant concentrations caused by car-induced emissions may occur. An examination in an underground garage of an administration office with 240 parking places results in maximal half-hour mean values of 50, 290, 180, 180 and 40 µg/m³ for soot (as elementary carbon), benzene, dust, NO_2 and CO. Theoretical assessments indicate that exposure of exhaust air on people living in the surroundings may be significant.

In order to predict emissions from a particular garage and its air quality, a numerical model is required. With the garage volume, parking capacity , air exchange and temporal distribution of incoming and outgoing cars as input, the model should be able to calculate the temporal variation of the emission and mean concentration of CO, NO, NO_2, HC, benzene and soot in the garage. Such a model is presented here. In order to evaluate the method, measurements in 2 different garages were carried out. The predicted emission factors for CO, HC and benzene agree with the results gained from the measurements. A part of the evaporation of HC and benzene was underestimated by the theoretical assessment. For soot and NO_x, the emission factor gained from the measurements exceeded the theoretical values by a factor of 2 to 3. In respect to soot, this corresponds to the results of other authors. The examination demonstrates that by combining the emission and mixture models, it is possible to predict air-quality in garages and their emissions.

Key words: Underground garage, air-quality prediction, car-induced emissions, emission factors, soot emission

1. INITIAL SUBMISSION

Introduction

Air quality regulations for parking garages do exist. In Germany, CO concentration in parking areas must be maintained at a lower value than 100 ppm over an average of a half hour. CO is seen as the main pollutant and air exchange is adjusted in order to observe the limit. This means that by adjusting the CO concentration limit of 100 ppm, other vehicle-induced pollutants should stay within an non-critical range. A simple assessment demonstrates that high benzene, soot and NOx concentrations may occur, even if the CO limit is maintained (Zenger, 1998). In this connection, it must be considered that the CO limit is valid for short-time loads, while benzene and soot limits, due to carcinogenic effects, must be considered over a longer period. With respect to users, who generally stay only a few minutes in the parking area, even high concentrations of benzene and soot are of little relevance. For people working in this zone and especially for all who are exposed to waste air, such as people who live nearby, high benzene, soot and NOx concentration may be quite relevant. Therefore it is necessary to optimise air exchange and exhaust air release. To do this, a first step is the development of a numerical model which predicts the release and indoor concentration of CO, benzene, soot and NOx. As input, the number of parked vehicles, the traffic cycle of in- and outgoing cars, the air exchange rate and the garage characteristics should be sufficient.

Traffic induced emissions

Many different pollutants are emitted by vehicles. Apart from the well-known pollutants CO, NO_x, and SO_2 , the carcinogenic compounds benzene and soot are of central importance. The following air quality standards correspond to German guidelines (VDI 2310, §40.2 BImSchG with 23 BImSchV). For CO, the maximum concentration allowed in order to protect human health is 50 mg/m³ over a period of half an hour. In parking areas the CO concentration (half hour mean) must be lower than 100 ppm, corresponding to 125 mg/m³. For NO_2 the maximum concentration (half hour mean) is 0,2 mg/m³. In traffic areas a value of 0,16 mg/m³ for NO_2 may not be exceeded for more than 2% of the ½-hour mean values of one year. As a goal the annual mean of benzene should be lower then 2,5 µg/m³ (LAI, 1993). In hardly any urban areas is this aim achieved. Traffic control measures should be explored if an annual mean benzene concentration of 10 µg/m³ or an annual mean soot concentration of 8 µg/m³ is exceeded.

Pollutant release by vehicles is expressed in emission factors. Depending on the condition of the engine, „warm“ and „cold“ factors [(both g/(m·car)] are distinguished. Even while parked vehicles emit hydrocarbon compounds (HC) and therefore benzene by evaporation. This emission is differentiated into evaporation due to engine heat [(g/(stop·car)] and that due to tank air exchange [g/(day·car)].

Prediction of vehicle emissions

In order to predict traffic-induced emissions in garages, the model T-emi was developed (Zenger et al., 1998a). The data base consists of emission factors of different types of vehicles which were measured on test stands and emission factors which were coordinated by the automobile industry together with the German environmental protection agency (TREMOD, Knörr et al. 1998). Sensitivity analyses demonstrate the dependence of emissions on user vehicle type composition and the driving pattern in the garage. It is also seen that the emission factors in the engine warm-up period strongly depend on the distance travelled inside the garage. This is of central importance for pollutant release.

Calculation model for mean air quality inside the garage

Mean air quality and pollutant concentration can be calculated using the emission factor of the layer group, the number of incoming, parked and outgoing cars, the mean travel distance, the air exchange and the volume of the garage. The model used is based on a numerical integration of the continuity equation and is described in Zenger (1997, 1998a). The change of pollutant concentration in the garage ΔC_i in a time step Δt results in:

$$\Delta C_i / \Delta t \cdot V = \sum Q_i + \Delta V/\Delta t \cdot C_z - \Delta V/\Delta t \cdot C_i - S$$

C_i the concentration in the garage in g/m³
V the volume in m³
Q_i the emission flux due to traffic movement and evaporation in g/s
dV/dt the air exchange in m³/s
t time in s
C_z pollutant concentrations in the incoming air in g/m³
S a possible sink or conversion of the pollutant in g/s

Application

To verify the model and the predicted emission factors, measurements in two different garages were carried out. The first underground garage, with 240 parking places on two levels, is in an administration building in Munich. It has a central air supply and exhaust air release (both by ventilator) and there is only a small diffuse air exchange. Vehicles enter and leave at various times of day in brief intervals. The mean travel distance for entering and leaving the garage is 185 m. The second garage examined has 310 parking places and is in a hospital in Munich. It has a central exhaust air release (by ventilator). Fresh air enters the building by several windows, all on the same side of the garage. Both mechanical and natural air exchange may occur. Visitor and employee vehicles enter and leave all day long. The mean travel distance was estimated to be 110 m.

In order to analyse the air exchange rate, SF_6-tracer gas was induced into both garages over a period of 2 hours. The air exchange was determined from the fade out of the SF_6 -concentration. The fundamental characteristics and the flow of traffic are presented in table 1 and figure 1 respectively.

Table 1: Characteristics of both underground garages

	Administration office	Hospital
Parking places	240	310
Volume	13000	19000
Air exchange rate	1,95	3,8
Mean travel distance	185	110

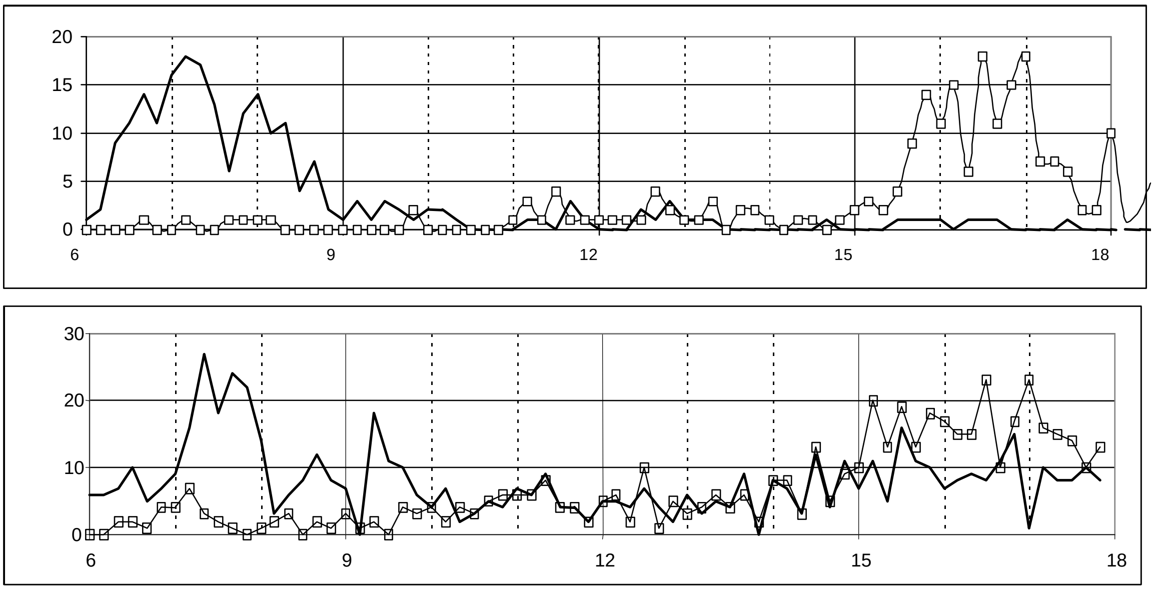

Fig1. : Time series of incoming and leaving vehicles. Upper part: Administration office, lower part: hospital

Results

The emission factors of the vehicles can be determined by the mixture model, using the pollutant concentration in the incoming and waste air, the air exchange rate, the garage volume and the flow of traffic. To do this, the emission factors were modified until the optimal adjustment between the predicted and measured concentration time series was achieved. As a result, the predicted rates of CO- and benzene concentration (with adjusted emission factors) is presented in figure 2 together with those actually measured. An emission factor for CO of 6,5 10-2 g/(m·car) was used for outgoing vehicles (cold engine condition) and of 7,0 10-3 g/(m·car) for incoming vehicles. For benzene, the corresponding factors are 4 10-4 g/(m·car) and 4,5 10-5 g/(m·car). For parked vehicles with a warm engine, 0,04 g/ (car· 2h) was used and with a cold engine 0,16 g/ (car day). The car type composition in the garage was known.

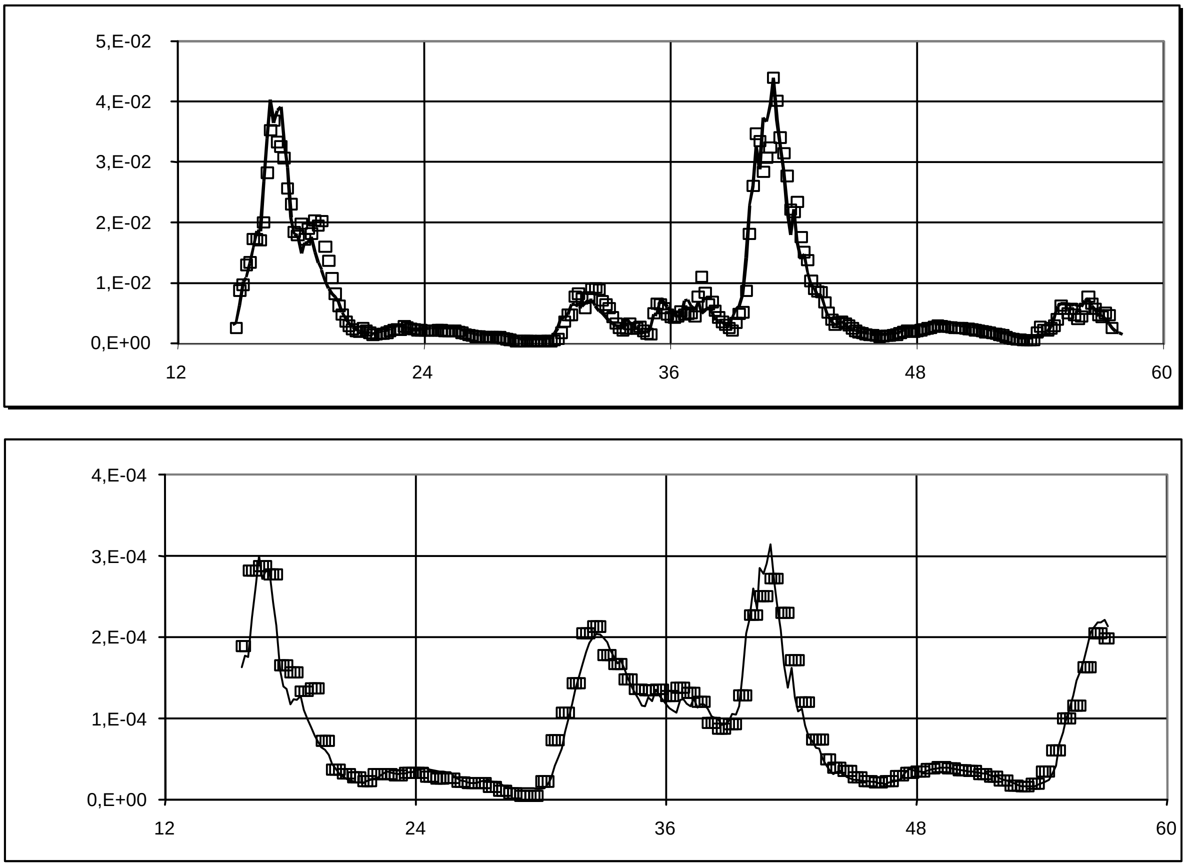

Figure. 4: Time series of CO (upper part) and benzene (lower part) concentration in the administration building garage. The line represents the prediction and the symbols the measurements.

The correlation factor R^2, is 0,95 for CO and 0,93 for benzene and confirms the great extent to which model prediction and measurement agree. Similarly HC, NOx, and soot emission factors were determined in both garages (Zenger et al., 1998a). In table 2, the factors are listed together with the T-emi model prediction for outgoing cars (cold engine conditions). The error stated is due to uncertainties in the following factors: volume, air exchange, travel distance, measurements and the process of optimising the agreement between measurement and prediction.

Table 2 : Emission factors (cold start condition) for a travel distance of 185 m and 260 m and the vehicle type composition observed in the administration building garage, together with the results of the measurements. The predicted soot emission was obtained by multiplying the dust factor by 0.4.

		Administration office (185 m)			Hospital (110 m)		
		Prediction	Measurement Admin. bldg.	Measurement / prediction	Prediction	Measurement hospital	Measurement/ prediction
Benzene	[mg/m]	0,32	0,4 ±• 0,08	1,2	0,423	0,45 ± 0,09	1
CO	[mg/m]	63	65 ± 13	1	82,3	85 ±• 1,7	1
HC	[mg/m]	6,1	6,2 ± 1,2	1	8,25	7 ± 1,4	0,85
NOx	[mg/m]	0,68	1,55 ± 0,3	2,3	0,92	2,5 ± 0,5	2,7
Soot	[mg/m]	0,025	0,09 ± 0,03	3,6	0,025	0,07 ±• 0,02	2,8

As can be seen from table 2, the emission factors for benzene, CO and HC obtained from the measurements for both of the different garages largely agree with the predictions of the model. The derived factors for NOx and soot exceed the predicted values by a factor of 2- 3. This is in agreement with results from Israel et al. (1996) for soot. The listing of warm factors is found in Zenger et al. (1998a).

Emission by evaporation

Table 3 compares the predicted and measured evaporation emission factors for HC and benzene due to a warm engine (as a mean emission over a 2-h period).

Table 3 : Predicted HC- and benzene warm engine evaporation factors from a parked vehicle (type composition as observed in the administration building garage) and results from the measurements

		Prediction	Measurement in the hospital garage	Measurement in the administration garage
	Dim.			
Benzene	[g/Stop]	0,015	0,03 • 0,01	0,04 • 0,01
HC	[g/Stop]	1	0,75 • 0,25	1,1 • 0,3

As can be seen from table 3, the HC-emission factor derived from the measurements agrees with the prediction. For benzene the results observed are twice as high as predicted. This can be explained if the amount of benzene in petrol is 2,5 to 3% (by weight) instead of 1,5% as usual in Germany. Some indications confirm this assumption for southern parts of Germany.

For evaporation (cold engine), emission factors of 8 10-2 g/(day*vehicle) for benzene and 2 g/(day·vehicle) for HC were derived. This is much more than predicted. Other sources for HC and benzene in the examined garage can be excluded. It is possible that some of the parked vehicles had a higher emission due to leaks in the petrol system . It should be noted that no petrol had leaked onto the floor, because emissions disappeared immediately after the vehicles left in the late afternoon.

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