14.3 ANALYSIS OF THE AIR QUALITY WITHIN THE RANGE OF AN URBAN GREEN AREA

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1. INTRODUCTION

The urban air quality shows a spatially and temporally diversified pattern, which is mainly influenced by the different types of land-use and emission structures. Urban road traffic is still one of the major emission sources, whose relative fractions of the total emissions of nitrogen oxide NO and carbon monoxide CO remains on a constant high level (NO_X: 51 %, CO: 53 %; Umweltbundesamt, engl.: Federal Environmental Agency (2001)). Within the structure of urban land-use distribution, green areas hold important thermal and air-hygienic recreational functions for city dwellers (Givoni, 1991). These functions are based on several facts: a.) Within green areas nearly no additional emissions take place (except biogenic emissions), b.) trace gases, which had been transported into the green area will be removed as a result of adsorption and absorption by the vegetation, and c.) surface- and air-temperatures are distinctly lower than within the surrounding built-up structure as a result of bowen-ratios >1. In addition, thermally induced air-circulations („park breeze“) between the green area and the built-up structure can be generated during suitable clear and calm weather conditions (Hupfer, Kuttler, 1998). Whereas a huge number of publications exists concerning the thermal structure of green areas (e.g. Spronken-Smith et al. 1998; Upmanis et al., 1998), only a few studies have been given to the spatial and temporal characteristics of the air quality situation within urban green areas (e. g. Kuttler et al., 1999; Straßburger et al., 1998; Straßburger, 2004; Upmanis et al., 2001).

One aim of this study was the determination of the atmospheric trace gas transport from a high traffic road into a green area by continuous measurements. The results should help to answer the question to what extend the air quality within an urban green area is influenced by adjacent high traffic roads.

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2. MEASUREMENT SITE / METHODS

The green area examined has an area of 140 hectares and is located south of downtown Düsseldorf (51°12'N / 6°48'E; 570.000 inhabitants; Germany). This urban park serves as an effective air exchange area which supports the fresh air supply to the city centre. To determine the traffic-induced air pollution input into the green area, measurements of selected atmospheric trace gases (NO, NO_2, O_3, CO) were carried out from January to December 2001 continuously and simultaneously both at the south border of the green area at a high traffic road (four-lane, 50.000 vehicles per day) and 200 m away from this location within the green area. In addition to the standard point analyzers several remote sensing systems (OP-FTIR and UV-DOAS) had been used, which offer some advantages especially concerning the analysis and characterization of fugitive emissions. The performance and the validity of the remote sensing systems had been proved and demonstrated in several previous studies (e.g. Ropertz et al., 1999; Kuttler et al., 2002, Weber et al. 2003). Two meteorological measurement towers had been used for the detection of the atmospheric exchange conditions near ground.

3. RESULTS

The trace gas concentrations of the air pollutants NO, NO_2, CO and O_3 presents a clear variation at both locations in dependence of the season, the day of the week, the time of the day, the emission situation and the atmospheric stability. The annual variation shows clearly higher concentrations for NO, NO_2 and CO at both locations during winter months, whereas the maximum ozone concentrations were found in summer. Table 1 contains the comparison of the corresponding mean values.

First of all, the annual variation of the primary emitted trace gases NO and CO can be attributed to the main emission times and the atmospheric stability at that times, respectively. During the winter months the emissions of rush-hour traffic take place mainly before sunrise and after sunset. These hours of the day are typically characterized by stable boundary layer conditions, that suppress an effective diffusion and dilution of the emitted air pollutants. In the course of summer months the rush-hour traffic takes place to a higher extend during the daytime which is characterized by

Tab. 1 Yearly means, minimum and maximum monthly means for the trace gases NO, NO_2, CO and O_3 at the different measurement sites near the street and within the green area (data: 1/2h-mean, January to December 2001).

	unit	street	green area
NO			
yearly mean	µg/m³	32	19
min. monthly mean	µg/m³	14	6
max. monthly mean	µg/m³	63	42
ratio (max./min.)	1	4,5	7,0
NO_2			
yearly mean	µg/m³	47	23
min. monthly mean	µg/m³	31	19
max. monthly mean	µg/m³	63	30
ratio (max./min.)	1	2,0	1,6
CO			
yearly mean	mg/m³	0,64	0,53
min. monthly mean	mg/m³	0,49	0,32
max. monthly mean	mg/m³	0,88	0,79
ratio (max./min.)	1	1,8	2,5
O_3			
yearly mean	µg/m³	31	37
min. monthly mean	µg/m³	13	11
max. monthly mean	µg/m³	52	64
ratio (max./min.)	1	4,0	5,8

more unstable atmospheric conditions as a result of solar radiation and higher heat flux densities in the boundary layer near ground.

Apart from the monthly mean values, the annual variation can also be found at the diurnal courses of the corresponding data. Figure 1 shows as an example mean diurnal variations of the primary emitted NO and the sensible heat flux density Q_H for the summer and winter months in combination with the mean course of the daily traffic. The sensible heat flux density has been determined within the green area (lawn) at a height of 10 m using a 3D-ultrasonic anemometer.

A secondary maximum of the concentrations emerges in the course of the afternoon hours aside to the primary maximum in the morning hours on a higher level in absolute values during the winter months which does not exist during the summer months.

These different trace gas concentrations during the main rush-hour in the morning and afternoon hours cannot be explained by different emission situations, because the maximum traffic density reaches the same values in the afternoon like in the morning rush-hour. Even the afternoon values of the traffic density are slightly higher than in the morning rush-hour. However, this effect can be explained by chemical conversions and turbulent diffusion as well as the spatial situation at the measurement site: The two traffic lanes with the direction out of the town (afternoon rush-hour) are located at a greater distance of about 20-25 m to the street measurement site than the traffic lanes into the town (morning rush-hour). This could be a first reason for the lower intensity of the secondary maximum during the afternoon hours. However, the deciding factor for these characteristic in the diurnal and annual variation are the variations of air exchange conditions or rather the stability of the atmosphere near ground and the solar radiation as one of the driving forces for chemical conversions.

The sensible heat flux density Q_H can be described as a measure of direction and intensity of the energy transformation in the atmosphere near ground and is here defined positive if an energy flux is directed from the ground into the atmosphere. Consequently, negative values of the sensible heat flux density usually occur at night without solar radiation in combination with a negative net radiation balance. These nighttime conditions are often coupled with a stable boundary layer.

In figure 1 it can also be seen, that the time period, in which a positive sensible heat flux can contribute to a more unstable boundary layer, was strongly shortened in the winter months compared to the summer months. At the same time the heat flux densities in absolute values were decreased for about 4 times in contrast to the summer period, so that in the direct vicinity of the emissions no appreciable turbulent diffusion of the emitted air pollutants could take place.

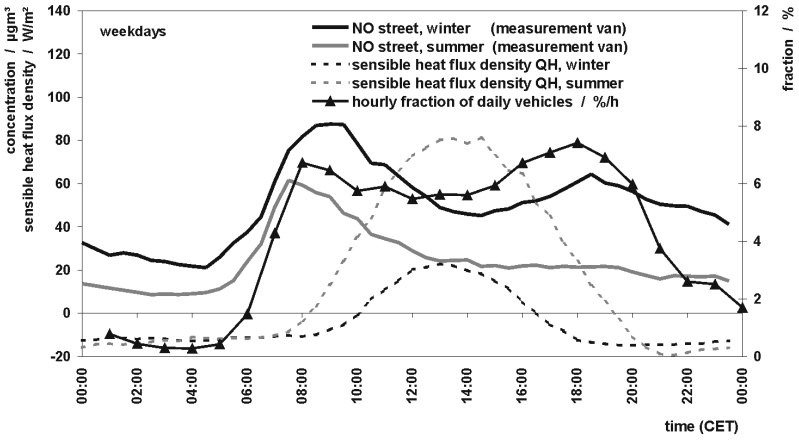

Fig.1 Mean diurnal courses of the primary pollutant nitrogen oxide NO near the street and the sensible heat flux density Q_H for the winter (October-March) and summer (April-September) months and weekdays, and the diurnal course of the traffic (data: 1/2h-mean, January to December 2001).

In addition, as a result of the correlation between the sensible heat flux density and the increased solar radiation during summer months, the photochemical conversions are more effective in summer with strongly higher radiation flux densities compared to the winter months. In this context, dry deposition of NO can be neglected because of the chemical properties of nitrogen oxide NO and the short spatial and temporal distances (Wesely et al., 2000).

An exact division of the observed trace gas reduction into the mechanisms of photochemical conversion and the turbulent diffusion in quantity is difficult, but the present data allow an assignment in quality. For this purpose the corresponding data of more reactive (e.g. NO) and chemically more inert components (e.g. CO) had been compared. In a first step, figure 2 shows such an intercomparison for diurnal variations of carbon monoxide CO and nitrogen oxide NO, divided again into summer and winter months and for wind directions, from which an air pollution input into the green area results and for weekdays (wind directions: ESE-SW).

On this limited spatial and temporal scales the more inert trace gas CO shows two distinct maxima in the diurnal course during winter months. Even the second maximum in the afternoon is slightly higher than the first one in the morning hours and is therefore in a good agreement to the diurnal variation of traffic density which is shown in figure 1. The more reactive nitrogen oxide NO reaches only a weak maximum during the afternoon hours in winter although it is influenced by the same turbulent diffusion like the carbon monoxide CO. This difference could be explained by the more effective chemical conversions of NO. During the summer months the diurnal variation of CO also differs in relation to the diurnal course of the traffic density with a clearly reduced second maximum in the afternoon. The increased vertical mixing of the boundary layer near ground remains at these afternoon hours (approx. 6 pm) and is responsible for the reduced second maximum in summer.

Concerning the concentration of nitrogen oxide NO, the sum of turbulent diffusion and additional photochemical processes leads to a diurnal course, in which a second concentration maximum during the afternoon rush-hour could not be found.

Aside from the air-hygienic characterization of this urban measurement site in principle, the determination of the traffic-induced air pollution input into the green area and the reduction within the urban park was one of the aims of this measurement campaign. In this context, figure 3 contains mean diurnal variations of nitrogen oxide NO near the street and within the green area for wind directions, from which an air pollution input into the green area results (wind directions: ESE-SW, N ≈ 130 days). As well the sensible heat flux density Q_H related to this set of data is shown again. According to the determination of traffic-induced air pollution input only weekdays are considered.

Like in the diurnal variations shown before, a positive correlation between the diurnal course of the NO concentration and the diurnal variation of the traffic density (figure 1) exists including both the primary as well as the secondary maximum. A clear reduction of the nitrogen oxide NO results during daytime on the 200 m distance from the street into the green area. This reduction during the day is a result of solar radiation with increased photochemical conversions combined with an unstable boundary layer near ground.

The relative reduction reaches its maximum of approx. 40 % in the early afternoon hours shortly after the maximum of solar radiation during maximum unstable conditions. This unstable period of the day is connected with a positive sensible heat flux density Q_H, which is directed upwards. In contrast to that effect a concentration balance was redressed during the nighttime hours as a result of stable boundary layer condi-

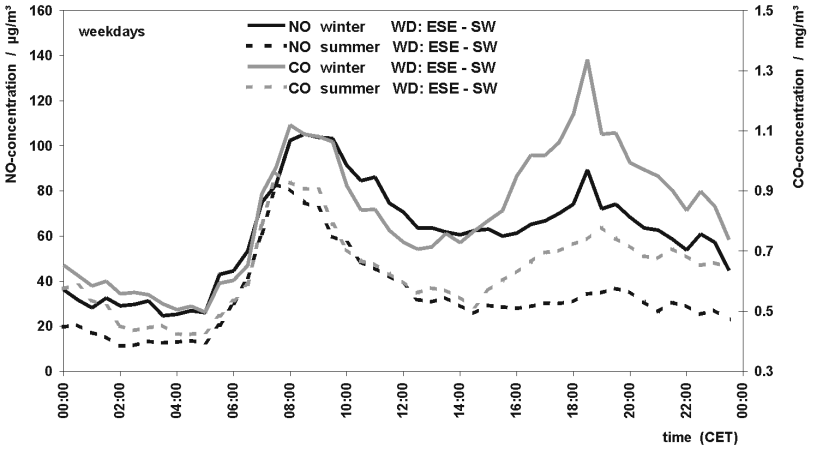

Fig.2 Mean diurnal courses of the primary pollutants nitrogen oxide NO and carbon monoxide CO for weekdays, wind directions between ESE and SW, and winter (October-March) and summer (April-September) months (data: 1/2h-mean, January to December 2001).

tions without solar radiation and strongly decreased emissions. This lead to an adjustment of the concentrations at both measurement sites on the same low level.

The marking of the stable and unstable periods of time in the diurnal courses of figure 3 is chosen depending on the change of sign of the sensible heat flux density Q_H. However, this classification was only qualitative because of the selection of the data set according to wind directions without consideration of different seasons. This classification of the stable and unstable periods should only serve as an illustration.

To get the balance of air pollution transport from the street into the green area the corresponding mass flow densities (unit: g/(m²s)) and the mass flow density doses (unit: g/m²) of the different air pollutants have to be determined in addition to the concentration values at the different measurement sites. The mass flow density dose represents a suitable parameter to asses the air pollution flow into the green area throughout a defined time period.

In a first step, the mass concentration of the relevant air pollutant has to be multiplied by the wind velocity at the same time for this purpose. In this context, the measurement height of the wind velocity has a clear influence on the determined mass flow density as a result of the vertical wind profile. To calculate the resultant air pollutant dose the mass flow density has to be integrated over the relevant time period in a second step. The result can be understood physically as a mean mass flow of an air pollutant across an assumed reference plane of one square meter, related to the chosen time period. In this study, the mass flow density has been calculated using the wind velocity measured at a height of 10 m within the green area. The combination of wind measurements at a height of 10 m with air pollution measurements at a height of 3.5 m within this study could lead to an slightly overestimation of mass flow densities related to a reference height of 3.5 m.

The mass flows also show the clear annual variation of the air pollution loads with higher values during winter months as well. This effect has still been strengthened by slightly higher wind velocities in winter. At the same time, a strong dependence on wind directions has been seen in the data which can be attributed to the long term frequency distribution of wind directions at the measurement site. A strongly emphasized sector of wind directions between ESE and SW was responsible for the bulk air pollution input into the green area. Exactly this directions are correlated with the site of the high traffic road south of the green area (50,000 vehicles per day).

Table 2 presents the mass flow density doses for the air pollutants NO, NO_2, CO and O_3 at both measurement sites near the street and within the green area, related to the measurement period of one year. In addition, the mass flows are distinguished between the relevant sectors of wind directions ESE-SW (south) and WSW-E (north). During this study, the southerly wind directions occurred in 56 % and the northerly wind directions in 44 % of the yearly hours. The relative fraction of these sectors of wind directions on the total mass flow density dose and the reduction into the green area is of special interest apart from the absolute values of the mass flow density doses. For the primary emitted nitrogen oxide NO results 74 % of the mass flow density dose near the street and 70 % within the green area, related to 56 % of the yearly hours. At the same time, the mass flow density dose of NO was already reduced on 49 % on the relatively short distance of 200 m into the green area. For the secondary formed nitrogen dioxide NO_2 a reduction of the mass flow density dose into the green area of up to 50 % was observed. The relative fraction of the southerly wind directions (ESE-SW) were slightly lower in values of 62 % near the street and 60 % within the green area as expected. The relative inert carbon monoxide CO was reduced only by 35 % combined with a decreased influence of wind directions as a result of its chemical properties. The results for CO

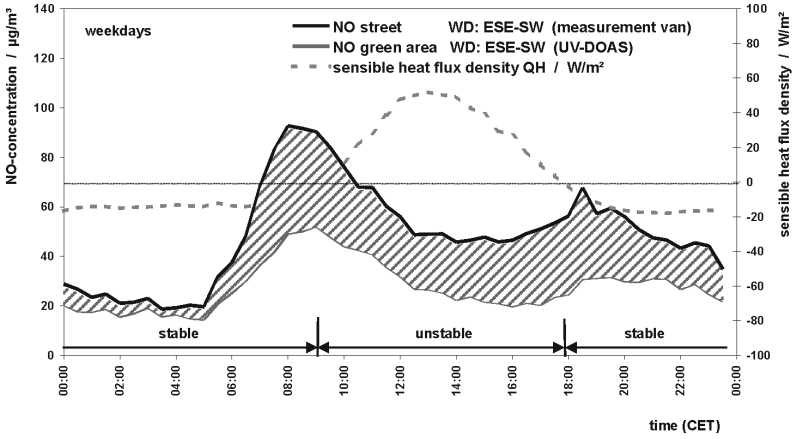

Fig.3 Mean diurnal courses of the primary pollutant nitrous oxide NO near the street and within the green area and the sensible heat flux density Q_H for wind directions between ESE and SW and weekdays (data: 1/2h-mean, January to December 2001).

Tab. 2 Mass flow density dose for the trace gases NO, NO_2, CO and O_3 related to the one year measurement period at the street and within the green area (data: 1/2h-mean, January to December 2001).

mass flow density dose / g/m²				
nitrogen oxide	street (measurement van)		green area (UV-DOAS)	
NO	g/m²	%	g/m²	%
all wind directions	1579	100	768	49
ESE-SW (south, 56%)	1174	74	539	70
WSW-E (north, 44%)	405	26	229	30
nitrogen dioxide	street (measurement van)		green area (UV-DOAS)	
NO_2	g/m²	%	g/m²	%
all wind directions	2613	100	1307	50
ESE-SW (south, 56%)	1628	62	789	60
WSW-E (north, 44%)	985	38	518	40
carbon monoxide	street (measurement van)		green area (OP-FTIR)	
CO	g/m²	%	g/m²	%
all wind directions	33160	100	21708	65
ESE-SW (south, 56%)	20592	62	12165	56
WSW-E (north, 44%)	12568	38	9543	44
ozone	street (measurement van)		green area (UV-DOAS)	
O_3	g/m²	%	g/m²	%
all wind directions	2087	100	2524	121
ESE-SW (south, 56%)	988	47	1212	48
WSW-E (north, 44%)	1099	53	1312	52

showed an increased influence of the urban background concentration. In comparison, the relative fraction of the additional air pollution input as a result of the traffic emissions is greater for the nitrogen oxide NO than for the carbon monoxide CO. In contrast to the aforementioned trace gases, the results for ozone O_3 showed up to 21 % higher mass flow density doses within the green area than near the street. This inverted effect has to be attributed to the lower NO and the potentially higher concentrations of biogenic hydrocarbons within the vegetation area. Within the scope of this study, ozone was therefore the only analyzed atmospheric trace gas, which has been contributed to a deterioration of the air quality within the urban green area. Higher ozone concentrations appeared in this case especially during clear and calm weather conditions in summer, while the other atmospheric trace gases remain at lower concentration levels.

An assessment of air quality within the region of the urban green area and especially inside the park has to be distinguished regarding several aspects. Concerning primary emitted air pollutants like nitrogen oxide NO and carbon monoxide CO the measurement site at the border of the green area near the street represents a highly traffic-influenced characteristic. The typical annual and diurnal variations are controlled by the temporal courses of the traffic-emissions and the atmospheric exchange conditions near ground. However, a clear reduction of the primary trace gases is possible on a relatively short distance of approx. 200 m within the green area without additional emissions. The absolute amount of the reduction is mainly dependent on the meteorological conditions of the atmosphere near ground and solar radiation flux densities. In relation to its overall extension of approximately 140 hectares the green area has the potential to reduce a large part of the southerly air pollution input. Fresh air can be supplied to the city centre of Düsseldorf downwind of the green area in northerly directions as a result. Because of the structure of vegetation within the green area with partly extensive lawn areas, the effect of fresh air supply can be supported by a partly reduced surface roughness.

Concerning the photochemical pollutant ozone O_3 it can be stated that higher concentrations appeared within the urban green area as a result of decreased concentrations of nitrogen oxide NO and increased biogenic emissions. Similar effects were found downwind of cities and conurbations in several previous studies (e.g. Straßburger, 2004).

In summary, the green area examined can be characterized as a favored area in the urban structure from an air-hygienic point of view. Clearly reduced trace gas concentrations were found within the green area for NO, NO_2 and CO, whereas increased O_3 concentrations only occur, when those of the other trace gases are rather small. In conclusion the reduction of the trace gas concentrations within the green area depends strongly on the meteorological conditions.

4. CONCLUSION

In order to determine qualitatively and quantitatively, to which extent an inner urban green area is affected air-hygienically by the emissions of directly adjacent roads, an extended measurement campaign was performed within the range of a large urban green area. A special feature concerning the methodology was the combination of standard analyzers, remote sensing systems like OP-FTIR and UV-DOAS and meteorological systems. The air pollution input into the green area and the concentration gradient within the park area respectively show a clear variation at both measurement sites dependent on the season, the day of the week, the time of day, the emission situation, the atmospheric stability, the wind direction and solar radiation flux densities. These dependences underline once more the requirement of extended meteorological measurements within the scope of air-hygienic studies. The knowledge of the atmospheric exchange conditions near ground is a crucial parameter to get a

valid interpretation of the temporal and spatial air-hygienic characteristic within urban areas.

The urban green area examined shows a clear potential to reduce primary emitted trace gases like nitrogen oxide NO and carbon monoxide CO. Here, the intensity of reduction is influenced mainly by the atmospheric exchange conditions and chemical conversions. Increased concentrations of the photochemical trace gas ozone O_3 within the green area occur during clear and calm weather conditions in summer, when those of the other trace gases are rather small. In conclusion, this green area fulfills an important function regarding the air-exchange and fresh-air supply to the city centre of Düsseldorf, not least because of its favorable location within the urban structure related to the long term frequency distribution of wind directions,

The mainly positive effects on urban air quality is complemented by the thermal effectiveness in the vicinity of the green area, which counteracts the urban heat island phenomena.

5. ACKNOWLEDGEMENT

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