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Calculations of personal exposure to particulate matter in urban areas

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Abstract

One of today's most important environmental concerns of today is the negative impact of pollution on human health. Environmental changes affect human health through multiple pathways such as air, water and food. These changes influence human health in direct or indirect ways and the resulting health impact may not simply be the sum of the individual effects through various pathways of exposure.

Exposure to particulate matter in air is one pathway of concern. The health effects of particulate matter (PM) are thought to be strongly associated with particle size, composition, and concentration. Long-term exposure to the current urban levels of especially fine particles ($PM_{2.5}$) is associated with increased mortality (Pope et al., 2002). People are exposed to PM from many sources as they go about their daily activities, spending time in their homes, at work, in recreation, and when travelling. Some individuals or groups of the population are more susceptible than others to PM exposures, due to factors such as respiratory habits, pre-existing diseases, or genetics (Davidson et al., 2005).

The aim of the EU funded project "Integrated exposure management tool characterizing air pollution-relevant human exposure in urban environment" (Urban Exposure 2002-2005) was to study human exposure to air-pollution compounds through two important pathways of exposure, namely inhalation and dermal absorption, and further to quantify exposure specifically for particulate matter and chloroform in European urban areas (Coulson et al., 2005). For this purpose a comprehensive computer tool for calculation of personal exposure to particulate matter in indoor and outdoor environments as well as water disinfection by-products from tap water and swimming pools, has been developed.

This paper describes the Urban Exposure Management tool, with emphasis on the calculation of exposure to particulate matter, and presents a case study from Oslo to illustrate the utilisation of the tool.

1 Description of the tool

The Urban Exposure management tool has been implemented within the air quality management system AirQUIS (AirQUIS, 2005).

Particle concentrations of PM_{10}, $PM_{2.5}$ and PM_1, in both outdoor and indoor environments and resulting deposition in the respiratory system are calculated using a dispersion model, a specific indoor concentration model and a respiratory deposition model (Fløisand, 2006). The calculations are performed for individuals moving along predefined daily routes using daily activity patterns. Selected indoor sources can be activated over certain periods of the day in the various microenvironments.

Three environmental models have been integrated as part of the new tool: an indoor model for calculation of indoor concentrations (Holländer et al., 2004), an inhalation model for calculation of respiratory deposition (Fløisand, 2006) and a dermal absorption model for calculation of uptake through the skin (Psychogios et al. 2004).

The Urban Exposure user interface is shown in Figure 1. A scenario is defined for a specified time period in terms of the subject's gender and age, daily route and time spent in the various microenvironments: *Home*, *Work* or *School/Kindergarten*, *Travel to* and *Travel from* and *Leisure*. In addition the subject's activity level is defined in order to calculate the resulting respiratory deposition of particles. The interface has three sub forms. In the first one the user defines the subject's microenvironments and daily routines for each hour throughout the day shown in Figure 1. The second one is for definition and activation of indoor sources in the indoor environments shown in Figure 3. The third one is for defining the input parameters for calculation of multi pathway gas uptake (not shown).

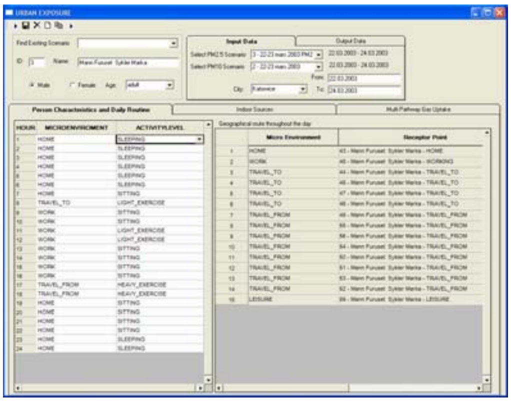


Figure 1: The Urban Exposure management tool user interface, featuring the form for defining Person characteristics and daily routine. The microenvironment and activity level is selected from a drop down list. The main functionalities of the tool are accessed through the toolbar at the top of the interface.

The ambient concentrations determine the outdoor exposure and contribute to the indoor exposure. The dispersion model EPISODE (Laupsa and Slørdal, 2003, Slørdal et al., 2003, Laupsa et al., 2005) in AirQUIS calculates the outdoor concentrations of both PM_{10} and $PM_{2.5}$ for the various microenvironments. The particle concentrations are divided into 48 size bins, logarithmically equidistant from 10 nm to 100 µm. Particle size distributions are based on lognormal density distributions of PM_{10} and $PM_{2.5}$ using actual ambient concentrations of PM_{10} and $PM_{2.5}$.

A list of the defined receptor points and the corresponding microenvironments are presented in the form showing the geographical route throughout the day, see Figure 1. Figure 2 shows how to define the geographical position for the various microenvironments using the GIS.

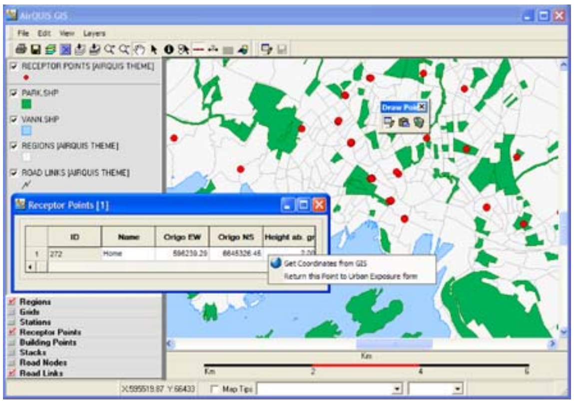


Figure 2: Defining the coordinates for the various microenvironments, using the GIS functionality.

The required input for calculating the respiratory deposition of particulate matter is the activity levels. The different activity level options are *Sleeping*, *Sitting*, *Light exercise* and *Heavy exercise*, and are selectable from a drop down list menu.

The indoor module is activated for the calculation hours the subject spends indoors. Various indoor sources can be selected and thereby contribute to the indoor concentrations for specified hours (Figure 3). The indoor module calculates discrete one-hour source contributions using the indoor concentration model (Fløisand, 2006).

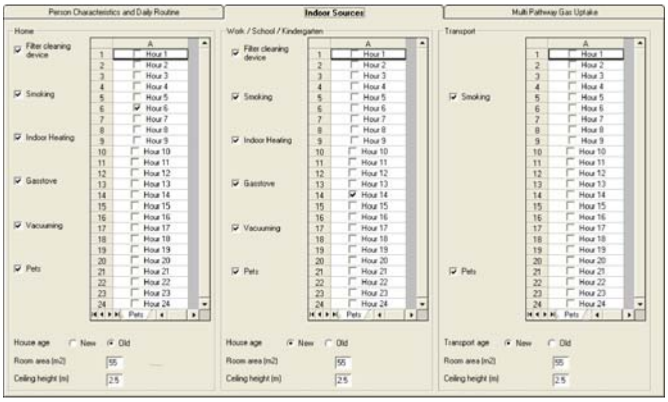


Figure 3: The Urban Exposure tool, Indoor sources – selecting indoor sources and time variability. The various sources are activated by using the check boxes on the left hand side. In addition the user can select the specific hours the sources should be active throughout the day.

The indoor microenvironments are *Home* and *Work/School/Kindergarten*. In addition, *Travel to* and *Travel from* are assumed to be indoor environments if the activity levels are *sleeping* or *sitting*. In these cases one assumes travelling by public transport or car. If the activity level is either *light or heavy exercise* then the system assumes that the person is outdoors, for example moving by bike or foot. For each of the indoor environments there is a list of various sources to be added (see Table 1). For *Home* and *Work/School/Kindergarten*, it is possible to select *Filter cleaning*, *Smoking*, *Gas stove*, *Vacuuming* and *Pets*. For *Travel to* and *Travel from* the only options are *Smoking* and *Pets*. The microenvironment *Leisure* is always an outdoor environment.

Table 1: Defined indoor sources and source characteristics.

Smoking	Fine fraction, passive smoking
Gas stove	Mostly fine fraction
Indoor heating	Defined as coal fire heating in the current data set (based on measurements from Katowice)
Vacuuming	Coarse fraction
Pets	Mostly coarse fraction
Filter cleaning	A sink for particles indoors

The user defines the size of the room and whether the house is old or new (Figure 3). The latter affects the penetration rate of outdoor air.

The respiratory deposition for various particle sizes is calculated on the basis of the microenvironmental concentrations, activity level, gender and age. The aggregated daily dose is calculated from the hourly values (Fløisand, 2006).

2 Example application: Effects on exposure of traffic velocity reduction on an urban highway

To illustrate the possible application of the Urban Exposure Management tool, calculations for an abatement scenario for Oslo have been carried out. Oslo is the capital of Norway and the main emission sources for particulate matter there are traffic and resuspension of particulate matter as well as wood burning in small stoves for domestic heating.

In many Norwegian cities PM_{10} exceeds the European limit value for daily average several times a year, especially during early springtime. One of the main reasons for this is traffic induced resuspension of road dust due to the extended use of studded tyres, contributing mainly to the coarse fraction of PM_{10}. In order to investigate this further, the Oslo department of the Norwegian Public Roads Administration carried out a field experiment over a two-year winter-spring period in Oslo. The aim was to identify the effect of a reduced speed limit on the PM levels. Measurements were carried out along one of the main roads entering Oslo (RV4). During the first measurement period the speed limit was 80 km/h. The following year the speed limit was reduced to 60 km/h. Analysis of the measurements showed a reduction of the PM_{10} level of approximately

35% due to the reduced speed limit, and a reduction of the coarse fraction of approximately 40 % (Hagen et al., 2005).

A case study was carried out, calculating the effect of the abatement measures on the personal exposure for a given exposure scenario. The activities of two individuals were simulated. The first one is a male adult living close to the main road working in downtown Oslo and travelling along the main road to work (see Figure 4). In the evening he plays sport on a football pitch near his home. The second person simulated is his five-year-old child, who spends his day in kindergarten near their home. There he is indoors during the morning hours and outdoors in the afternoon. The time activity patterns and activity level are described in Table 2 and the geographical routes are shown in Figure 4. Calculations have been performed for 22 March 2003. The effect of the speed reduction on their exposure has been evaluated according to their time activity patterns and activity levels.

The estimated PM_{10} concentration for speed limits of 60 and 80 km/h are presented in Figure 5 and compared to measurements at an urban background station in Oslo. The result shows that there is a significant reduction in the outdoor concentration of PM_{10} from the road when reducing the speed limit. Due to the proximity of the house to the road (only about 15 m) the PM_{10} concentration is reduced considerable at their home address. For the kindergarten situated approximately 350 m from the road however, the ambient concentration is much less reduced. The levels at the kindergarten are similar to the measured levels at the closest urban background station Skøyen (Figure 5). This station is located approximately 10 km from their home in the southwest direction.

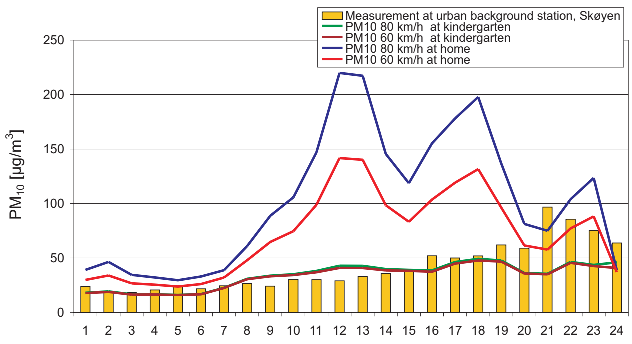
The coarse particles are removed efficiently when the outdoor air passes the building shell. The difference between the indoor concentrations for the two speed limits are therefore smaller than the difference between the outdoor concentrations for each speed limits (Figures 5 and 6). Staying in an indoor environment the reduction of exposure is relatively small compared to the reduction of the outdoor concentrations. The exposure is therefore strongly dependent on the amount of time spent outdoors vs. indoors. In the case where indoor sources are active, e.g. smoking, this would dominate the resulting indoor concentration.

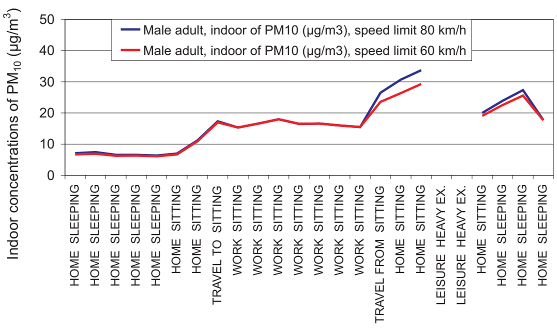
Figure 4: Map of Oslo showing home, work and kindergarten as well as travel routes for male adult and five year old child.

Table 2: Time activity pattern and activity level for male adult and five-year-old child living in Grorud. Blue indicates indoor environments and green is time spent outside.

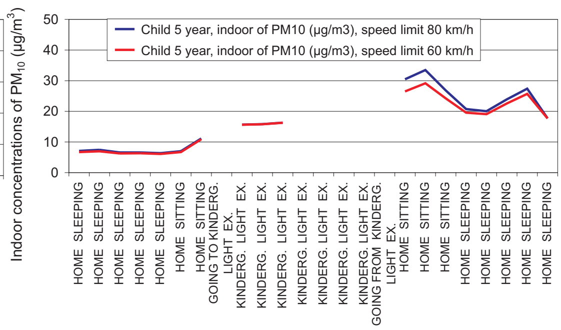
Hour of the day	Male adult	Five year old child
1	home sleeping	home sleeping
2	home sleeping	home sleeping
3	home sleeping	home sleeping
4	home sleeping	home sleeping
5	home sleeping	home sleeping
6	home sitting	home sitting
7	home sitting	home sitting
8	travel to work sitting	going to kindergarten light exercise
9	work sitting	kindergarten light exercise
10	work sitting	kindergarten light exercise
11	work sitting	kindergarten light exercise
12	work sitting	kindergarten light exercise
13	work sitting	kindergarten light exercise
14	work sitting	kindergarten light exercise
15	work sitting	kindergarten light exercise
16	travel from work sitting	going from kindergarten light exercise
17	home sitting	home sitting
18	home sitting	home sitting
19	leisure heavy exercise	home sitting
20	leisure heavy exercise	home sleeping
21	home sitting	home sleeping
22	home sleeping	home sleeping
23	home sleeping	home sleeping
24	home sleeping	home sleeping

Figure 5: Estimated PM_{10} at Home and Kindergarten for speed limits of 80 km/h and 60km/h compared to measurement of PM_{10} at an urban background station on 22 March 2003.





a)



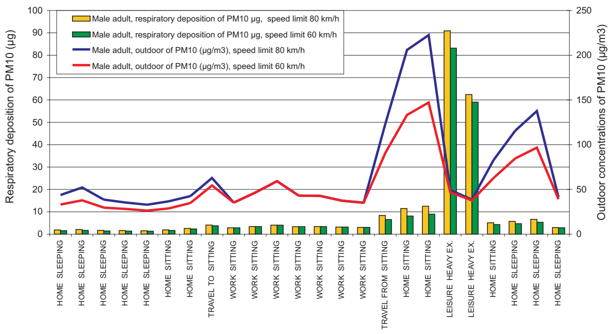
b)

Figure 6: Calculated indoor concentration for a) adult male and b) 5-year old child for the two speed limits.

Figures 7 and 8 show the calculated outdoor PM_{10} concentrations and resulting respiratory deposition for the adult and five year old, respectively. The respiratory deposition is based on either indoor or outdoor concentrations depending on the hour of the day (see Table 2).

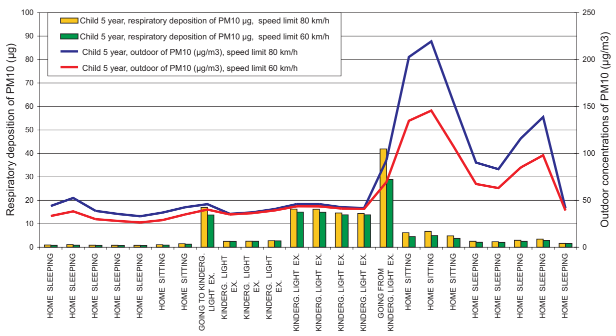
For the male adult, the largest impact of the reduced speed and resulting concentration reduction is calculated for the afternoon hours when the outdoor concentrations are highest. The two hours he spends in leisure (25 m from the main road), doing heavy excise in the evening contribute a lot to his total respiratory dose, but is not much affected by the reduced speed limit because the leisure site is upwind of the main road during the leisure hours.

Figure 7: Estimated PM_{10} concentrations and corresponding respiratory deposition for adult male during his daily route calculated for speed limits of 80 km/h and 60 km/h.



For the five-year-old child the hour spent along the main road going back from kindergarten has an important impact on the overall exposure level and the effect of reduced speed limit is significant. Overall the child receives the highest dose while walking back and forth to the kindergarten and playing outside in the afternoon.

Figure 8: Estimated PM_{10} concentrations and corresponding respiratory deposition for the five year old child during his daily route for speed limits of 80 km/h and 60 km/h.



3 Conclusions

A numerical tool for calculations of personal exposure to particulate matter has been developed and integrated into an existing Air Quality Management System, AirQUIS. Based on defined daily routes, the hourly concentration of particulate matter is calculated for various microenvironments. The outdoor concentrations are calculated using an Eulerian dispersion model. The indoor concentrations are calculated on the basis of both outdoor concentrations and contributions from selected indoor sources. Based on the concentrations, activity level, gender and age, the respiratory deposition for various particle sizes is calculated as hourly values.

Calculations have been made for an abatement scenario where the speed limit was reduced along one of the main roads into Oslo. The case studies show how this affect the exposure and resulting respiratory deposition of particulate matter for two individuals with certain defined time-activity patterns. For the male adult, the largest relatively exposure reduction is calculated during the afternoon hours when the outdoor concentrations are highest. The two hours he spends in leisure doing heavy exercise contribute a lot to his total respiratory dose. Overall the child receives the highest dose while walking back and forth to the kindergarten and playing outside in the afternoon.

Acknowledgements
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