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Calculation of personal exposure

The Urban Exposure Management Tool

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Preface

This report describes the Management tool for calculation of personal exposure to air pollution in urban environment, which has been developed as part of the project "Integrated exposure management tool characterizing air pollution-relevant human exposure in urban environment" (Urban Exposure).

The project has been funded by the European Commission under contract EVK4-CT-2002-00090 through the thematic programme Energy, Environment and Sustainable Development.

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Summary

The Urban Exposure Management Tool calculates personal exposure to air pollution in the form of particulate matter in indoor and outdoor environments as well as water disinfection by-products from tap water and swimming pools. The module for calculation of personal exposure has been implemented as part of an already existing Air Quality Management System, AirQUIS. Models for calculating indoor concentration, respiratory deposition and dermal absorption have been integrated as part of the module. The user accesses the tool through a user friendly graphical interface.

Estimates of personal exposure to particulate matter in an urban environment are based on defined daily routes, where 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, such as smoking, indoor heating, pets etc. Based on the microenvironmental concentrations, activity level, gender and age, the respiratory deposition for various particle sizes is calculated as hourly values. The aggregated dose for the various microenvironments for a given period can be calculated from the hourly values.

Individual uptake of chloroform through inhalation and dermal absorption is calculated on the basis of exposure time, concentration in air and water and the subject's physiological characteristics such as age and body weight. The difference in water to air transfer efficiency in showers and baths also affects the relative contribution from inhalation and dermal absorption to the total dose received.

The functionalities of the tool and the integration of the various models have been tested and validated.

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1 Introduction

1.1 The Urban Exposure project

The project “Integrated exposure management tool characterizing air pollution-relevant human exposure in urban environment” (Urban Exposure) is funded by the European Commission’s fifth Framework Programme under the thematic program "Energy, Environment and Sustainable Development (EESD)". The project started in October 2002 and lasted until September 2005.

The aim of the Urban Exposure project was to study human exposure from air-pollution compounds that accounted for 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. The environmental and policy-relevant product of the project was the development of scientific methods in conjunction with a robust multiphase modelling environmental management system. This is to facilitate more appropriate public health strategies for mitigation of the effects of air pollutants and drinking water to European citizens.

The objectives of the project were to:

- Study human exposure to air-pollution compounds in some European urban areas through
    - inhalation of particulate matter
    - dermal absorption and inhalation of chloroform
- Develop science-based methods for quantification of exposure
- Implement these methods into an integrated AQM system
- Facilitate development of public health strategies for mitigation of the adverse effects of air pollutants and drinking water disinfection by-products

Nine partners from seven countries have participated:

- Norwegian Institute for Air Research (NILU) (NO), coordinator
- Institute for Ecology of Industrial Areas (IETU) (PL)
- Fraunhofer Institute for Toxicology and Aerosol Research (D)
- University of Essex (UK)
    - WRc Plc (UK), subcontractor
- Academy of Sciences of the Czech Republic (CZ)
- Technion-Israel Institute of Technology (IS)
- Technical University of Crete (GR)
- National Centre for Scientific Research “Demokritos” (GR)
- Oslo Department of Public Health (NO)

A literature review of current research and data on indoor/outdoor ratios, health impacts and modelling of exposure was conducted. In addition a report on chloroform concentrations in European tap water and swimming pools has been written.

Environmental models for calculation of indoor concentrations of pollutants, respiratory deposition and dermal absorption have been developed and validated against measurements and other models. Three of the models have been integrated into the module that has been developed for calculation of personal exposure to air pollution. The module has been implemented as part of an existing Air Quality Management System.

The Urban Exposure Management tool has been applied for case studies in two selected urban areas, Oslo and Katowice. The tool and the results from the calculations have been presented to end users in six cities across Europe and the Middle East.

Information about the project and the Management tool, scientific results, publications and the case studies are available on the project web site, www.nilu.no/urban_exposure. An overview of the project is also given in Coulson et al. (2005).

1.2 Exposure calculations

One of the 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 the air we breathe, the water we drink and the food we eat. These factors all influence human health in direct or indirect ways and the resulting health impact may not be the simple sum of the various pathways of exposure to environmental toxins and pollution.

Disinfection by-products (DBP) present in tap water have been studied over the years due to their potentially harmful effects (Wallace 1996, Nieuwenhuijsen et al 2000, Reif et al 1996). These compounds are relevant for exposure through both inhalation and dermal absorption. DBPs like chloroform and bromoform have been detected in ambient air (Moore and Tokarczyk 1993; Class and Ballschmiter 1988). They have both man-made and natural sources in addition to the water disinfection process.

Epidemiological studies suggest that exposures to chloroform are associated with developmental, reproductive and pregnancy outcome effects. Nieuwenhuijsen et al. (2000) have evaluated both toxicological and epidemiological data involving chlorinated DBPs. They found that evidence was not conclusive but mounting of effects on pregnancy outcome. They further concluded that exposure assessments are usually crude, and that there is a need for large epidemiological studies with emphasis on exposure characterisation. Obtaining estimates of personal exposure involves evaluation of exposure pathways other than ingestion, such as inhalation and dermal contact. Weisel and Jo (1996) have investigated exposure through ingestion, inhalation and absorption and found similarities in uptake between the inhalation and absorption route. Lindstrom and Pleil (1996) consider inhalation and dermal exposures related to tap water and Kerger et al. (2000) have studied airborne exposures originating from tap water. It has therefore become evident that DBPs are important in relation to public health, and that there is a need to supplement exposure models with a tool to provide exposure estimates related to inhalation and absorption routes.

Exposure to particulate matter in air is another parameter 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. It complicates matters further that some individuals or groups of the population are more susceptible to PM exposures, due to factors such as respiratory habits (e.g., mouth breathing versus nose breathing), pre-existing diseases, or genetics (Davidson et. al, 2005).

Standards and guidelines are set for the outdoor concentrations of a number of organic and inorganic species as well as particulate matter. These standards are incorporated into legal and regulatory frameworks in many countries.

It has, however, been acknowledged that human exposure estimates must also take into account indoor exposure, due to the fact that people on average spend approximately 85% of their time indoors (EPA, 1996a, b). Indoor concentrations are influenced both by the outdoor concentrations, meteorological conditions, indoor sources and personal habits. In the course of a day, individuals spend a varying amount of time at home, in a working or schooling environment, partaking in leisure activities and in transit between these microenvironments.

A number of measurement studies of human exposure have been performed; most notably the EXPOLIS study (e.g. Hänninen et al., 2004), which investigated air pollution exposure in seven European cities. Data on fine particles, nitrogen dioxide, volatile organic compounds and carbon monoxide inhalation exposures were measured and exposure related questionnaire data were collected during 1996-2000.

Exposure assessment is an important part of human risk assessment and risk management. The most common approach is a static population based approach using outdoor concentrations. Recently also person-oriented methods that take into account the various indoor and outdoor concentrations encountered over a time period have been developed to predict the exposure estimates depending on microenvironments and activity patterns (Ashmore et al., 2005; Hänninen et al., 2005)

This report describes the Management tool for calculation of human exposure to particulate matter and chloroform that has been developed as part of the Urban Exposure project. Chapter 2 gives a short description of the AirQUIS model, which is used as the platform for the tool. The models for calculation of indoor concentrations, inhalation and dermal absorption are briefly described in chapter 3. The tool and its functionalities are described in chapter 4 and the results of the testing and verification are shown in chapter 5. An overview of the performed case studies and demonstration to end users is given in chapter 6.

2 The Air Quality Management System AirQUIS

This chapter gives a brief introduction to the AirQUIS system, which is used as the platform for the Urban Exposure Management Tool.

2.1 What is Air Quality Management?

The overall goal of Air Quality Management is to improve the air quality conditions. Air Quality Management is to make action plans for managing and improve the air quality. An Air Quality Management System (AQMS) is an integrated tool that includes the various elements characterising the air quality situation, such as measurements, emissions inventories, dispersion and exposure modelling. The impacts on the population and the environment are estimated from dose-response relationship. Assessment of abatements using an AQMS tool in combination with dose-response estimates and cost benefit analysis are important methods to quantify the best options for clean air.

2.2 Description of AirQUIS

AirQUIS is an AQMS developed at NILU (URL: www.airquis.com). The AirQUIS system is divided into two main parts; a measurement and a model part (Figure 1). In addition all geographically linked data, both in the measurement module and in the modelling module are visualized by a Geographical Information System (GIS). The system's measurement module consists of an Automatic Data ACquisition System (ADACS), which collects data from the instruments at monitoring sites and a measurement database where meteorological and air quality data are stored. Tools for analyses and graphical presentation of meteorological and air quality data are parts of the measurement module.

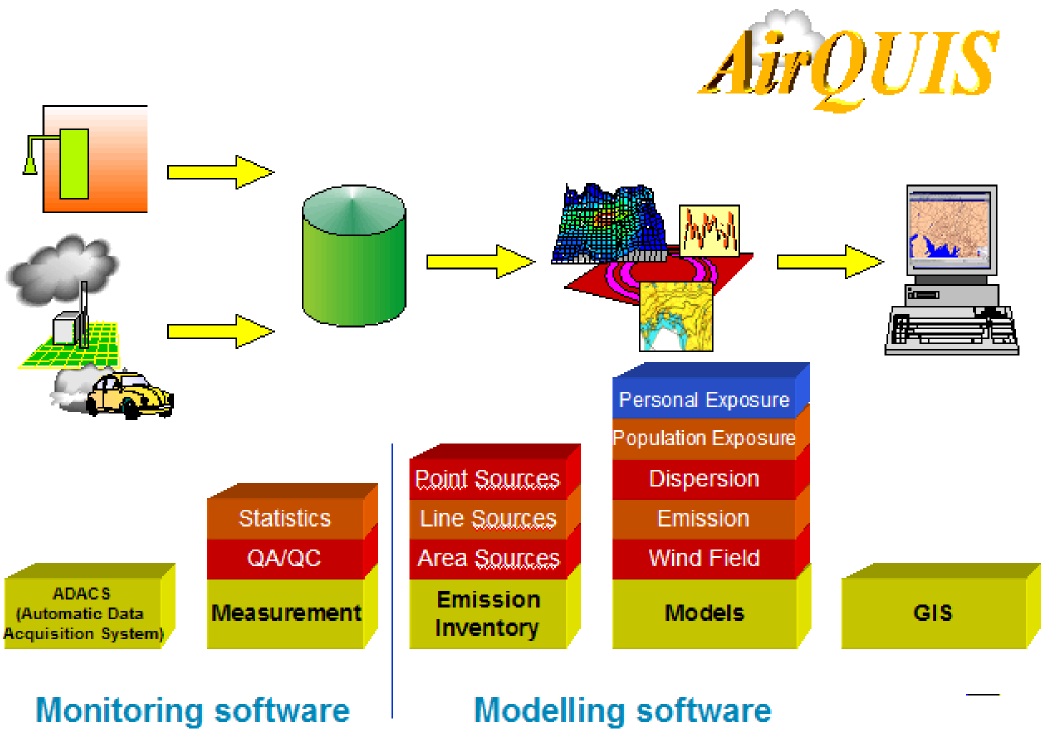


Figure 1: The Air Quality management system, AirQUIS.

The modelling software includes an emission inventory tool for storing and organizing atmospheric emission data as well as modelling tools for accessing the implemented meteorological, dispersion and exposure models.

The Emission Inventory contains the necessary functionalities for producing a complete, detailed atmospheric emissions inventory for an area. An inventory typically includes information about the emissions from major industrial sources, estimates from smaller sources and from the various types of transport. These are classified as three types of sources in the module, namely point, area and line. The point emissions are defined as being from single activities of some size, like industries, energy production etc., which are linked to single stacks. Emissions from home heating, public and private services, agricultural activities etc. are treated as area sources, while emissions from road traffic are treated as line sources in the emission database.

Air pollution dispersion models are well established and fully implemented in the system. A diagnostic model is used for calculating 3-dimensional hourly wind fields. These data are used as input for the dispersion model. In addition other wind field and meteorological data can be utilized by the AirQUIS system, like for instance the data from meteorological forecast model MM5 (Gjerstad and Ødegaard, 2005). The emission model calculates the hourly emissions from area, line and point sources defined in the emission inventory. The emissions are normally used as input for the dispersion model. The dispersion model EPISODE (Slørdal et al., 2003), which is a 3D Eulerian grid model with embedded Gaussian point and line source sub grid models. EPISODE calculates hourly concentrations both as average gridded values and as individual point values (Laupsa et al., 2005).

AirQUIS includes a model for estimating the population exposure (Figure 1) to air pollution. Air pollution impact on human health is estimated by combining the static population distribution and calculated concentrations, either in grid or in building addresses. The population exposure model estimates the number of persons exposed to air pollution above air quality guidelines, like for instance the EU directives (Laupsa and Slørdal, 2003).

The AQM system AirQUIS is applied for various purposes like for instance acquisition, presentation and analysis of monitoring data. The system is also utilized for air quality assessment, abatement and trend analysis and as a platform for scientific research. In addition, the AirQUIS system is used as an air quality forecasting system using meteorological data from weather forecast models as input to the dispersion models.

3 Models for personal exposure calculations

Calculation of personal exposure has been developed as part of the AirQUIS system (Figure 1), and three environmental models have been integrated as part of the new tool:

- Indoor model
- Inhalation model

- Dermal absorption model

All three models are also available as stand-alone versions and have been tested and verified against other models and measurements as part of the project.

The three modules are briefly described in the following sections, whereas the integrated tool and how to use it is described in chapter 4.

3.1 Indoor environment model

The indoor model calculates the indoor concentration of particles based on the outdoor air concentration and the indoor source strengths.

The flux of outdoor air entering a building is dependant on the so-called ventilation current, which is determined by the tightness of the house with closed windows (the age of the house) and the personal ventilation behaviour of the inhabitants. The former is influenced by the ambient wind speed and the latter by the ambient temperature. In addition, the calculated concentration is dependant on the volume of the room.

The current indoor model includes several indoor sources:

- Smoking
- Gas stove
- Indoor heating (coal fire)
- Vacuuming
- Pets

The particle various source strengths are based on measurements or taken from the literature.

The particles may deposit on the floor, walls and ceiling according to the deposition velocity and room area. In addition, they may be removed by a filter cleaning device.

The model is based on a mass balance approach. The input parameter distributions were assumed to be lognormal and the distributions medians and geometric standard deviations were determined experimentally or taken from the literature. The simulations use a Monte Carlo method and for this specific implementation the particle concentration is the mean of 100 random drawings.

The model has been developed by Werner Holländer at Fraunhofer, Institut Toxikologie und Experimentelle Medizin. The model was originally programmed and distributed as a Stand-Alone Indoor air Module (SAIM) executable.

3.2 Inhalation model

The inhalation model calculates the respiratory deposition of particles for several size fractions based on the air concentration, the age and gender of the subject and the level of activity.

The model is based on Weibel's generation scheme scaled to account for the subject's age. It has a mechanistic description of particle dynamics in the human respiratory tract and uses a semi-Lagrangian formulation to calculate deposition of particles as they flow along successive lung airways. The aerosol is regarded as an air parcel moving with the mean flow velocity and divided among successive airway generations of the lung.

The subject’s activity determines the breathing parameters and nose breathing is assumed. Inhalability of particles is considered.

Deposition of particles in the extra-thoracic airways is based on empirically size-resolved data. Particle deposition by the three major deposition mechanisms (diffusion, gravitational settling, inertial impaction) is considered in terms of probabilities for deposition of individual particles from a cloud of non-interacting particles. Deposition efficiencies represent up-to-date knowledge.

Experimental data suggests that carinal ridges are hot spot for deposition of both inertial and ultrafine particles. Thus, a diffusional deposition efficiency is implemented in the upper airways (generations 1 to 10) to account for this observation. Within each breath, distal generation airways are exposed to smaller respired volumes and for shorter time than proximal airways.

The model provides an option to estimate exposure via inhalation to “sticking” gaseous pollutants, which can be applied for multi pathway (inhalation + dermal) exposure.

In the Urban Exposure Management tool total respiratory deposition is presented, but values for the four separate lung compartments are stored in the system.

The model has been developed by David M. Broday at Technion - Israel Institute of Technology, Environmental, Water & Agricultural Engineering Division, Faculty of Civil & Environmental Engineering. The model is also available as a GUI-based stand-alone module.

3.3 Dermal absorption model

The dermal absorption model calculates the amount of a given chemical that is absorbed through the skin and enters the blood stream during an exposure event.

The model is based on an expanded approach for the estimation of dermal uptake by extending the Lumped Parameter Models (LPM) through the use of a distributed parameter skin compartment. The resulting Distributed Parameter Model (DPM) takes into account also reverse processes after skin exposure is terminated. The model is based on an assessment of dermal exposure to environmental pollutants through the consideration of dermal absorption principles (e.g. skin physiology) and calculates the concentration profiles throughout skin.

The dermal absorption of the active compound is calculated on the basis of the concentration and the exposure time in addition to a number of physiological parameters. In this application, these are the height and weight of the subject. The surface area of skin, body weight and corresponding blood volume are determined. In addition parameters related to the characteristics of the skin and the behaviour of the compound in contact with skin (e.g. permeability coefficients) are defined.

The module calculates the resulting dermal flux, which is the rate of the chemical entering the viable skin and the systemic flux, which is the rate of chemical entering the blood. Based on the flux and the exposure time, the corresponding dermal and systemic doses are calculated.

The module has been developed by Thanos Stubos and co-workers at the National Centre for Scientific Research "Demokritos". The model is available in a stand alone version.

4 Description of the Urban Exposure Management Tool

The management tool has been developed for calculating personal exposure to air pollution. It can be used to study human exposure from compounds that account for up to two important pathways of exposure, inhalation and dermal absorption, and to quantify exposure specifically for particulate matter and chloroform in several European urban areas. In this way, the assessment of human exposure from indoor and outdoor air to particulate matter and human exposure from house water and ambient air to drinking water disinfection by-products, has become available as a support mechanism for urban management decisions.

The various environmental models described in chapter 3 have been integrated in the developed module for calculation of human exposure in urban environments. The module is implemented as part of the Air Quality Management System, AirQUIS (Figure 1).

This chapter describes how the tool is designed, how to use it and how one can view the results.

4.1 Calculation of particulate matter

Particle concentrations of PM_{10}, $PM_{2.5}$ and PM_1, for both outdoor and indoor environments and the resulting deposition in the respiratory system is calculated. The calculations are made for a person along a predefined daily route and based on a user defined activity pattern. Selected indoor sources are activated over certain periods of the day in the various microenvironments.

For estimating the individual's exposure and respiratory deposition, the dispersion model, the indoor model and the respiratory model are applied (Figure 2). The dispersion model EPISODE in AirQUIS calculates the outdoor concentrations in the individual microenvironments. For a selected period, both PM_{10} and $PM_{2.5}$ are calculated. The geographical positions of the microenvironments (receptor points) for the scenarios must be defined before the dispersion modelling is performed because the outdoor concentrations must be calculated for each of the microenvironments. The particle concentrations are divided into 48 logarithmically equidistant size bins from 10 nm to 100 µm. The actual statistical particle size distributions are specific for the two cities studied, Katowice and Oslo, due to different emission sources.

The outdoor concentration is an input parameter for both the indoor module and the respiratory deposition module (Figure 2). If the person is indoors for a given hour, the indoor module is activated and the calculated outdoor concentration becomes a source for the indoor concentration. The calculated indoor concentration is then used as input for the inhalation module. If the person is outdoors during the specified calculation hour, the outdoor concentration is used as input for the inhalation module directly.

The calculated outdoor concentration, indoor concentration and the respiratory deposition for PM_{10}, $PM_{2.5}$ and PM_1, are stored in the database for each calculation hour.

The stored results can be graphically presented as time series for each of the scenarios as described in section 4.3.8. In addition, the aggregated respiratory dose for the calculation period for each of the microenvironments can be presented on maps by using the GIS tool (4.3.8).

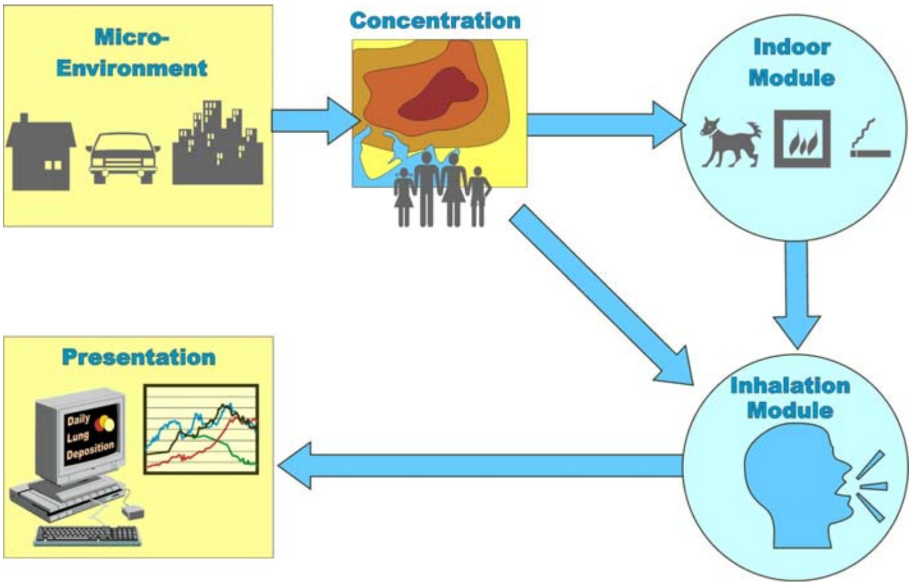


Figure 2: The schematic description of the calculations of particulate matter in Urban exposure.

4.2 Multi pathway gas uptake

Uptake of chloroform through inhalation and through skin is calculated as an example of multi pathway gas uptake. Chloroform is a by-product of chlorine disinfection of both tap water and swimming pools.

The dose of chloroform is calculated in two different parts (Figure 3). Based on the water concentration and exposure time the amount of chloroform accumulated in the blood (systemic dose) is calculated by the dermal absorption module. The respiratory gas uptake is calculated using the respiratory deposition module.

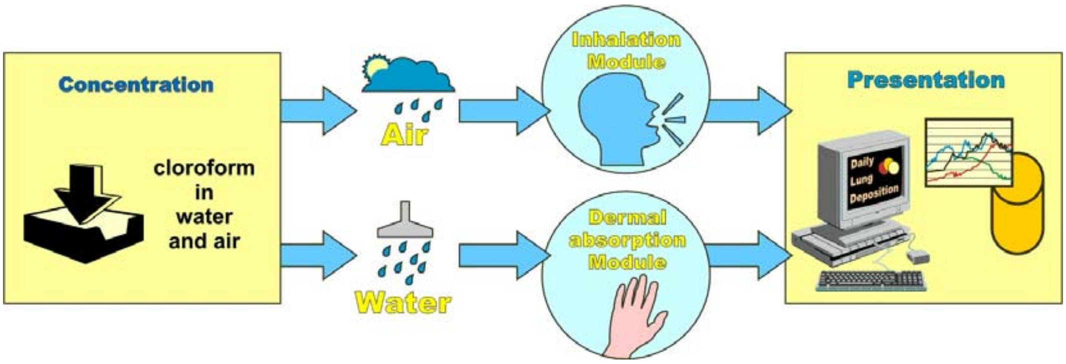


Figure 3: The schematic description of the calculations of multi pathway gas uptake in Urban exposure.

The respiratory deposition (µg) and systemic dose (µg) for the calculation hour are stored in the database and can be presented as time series in the graph presentation tool (see section 4.3.8).

4.3 The tool for calculating personal exposure

This section gives a detailed description of the user interface and how to run the module for calculation of personal exposure.

The Urban Exposure user interface is shown in Figure 4. The interface has three sub forms:

- Person characteristics and daily routine (section 4.3.2)
- Indoor sources (section 4.3.5)
- Multi pathway gas uptake (section 4.3.6)

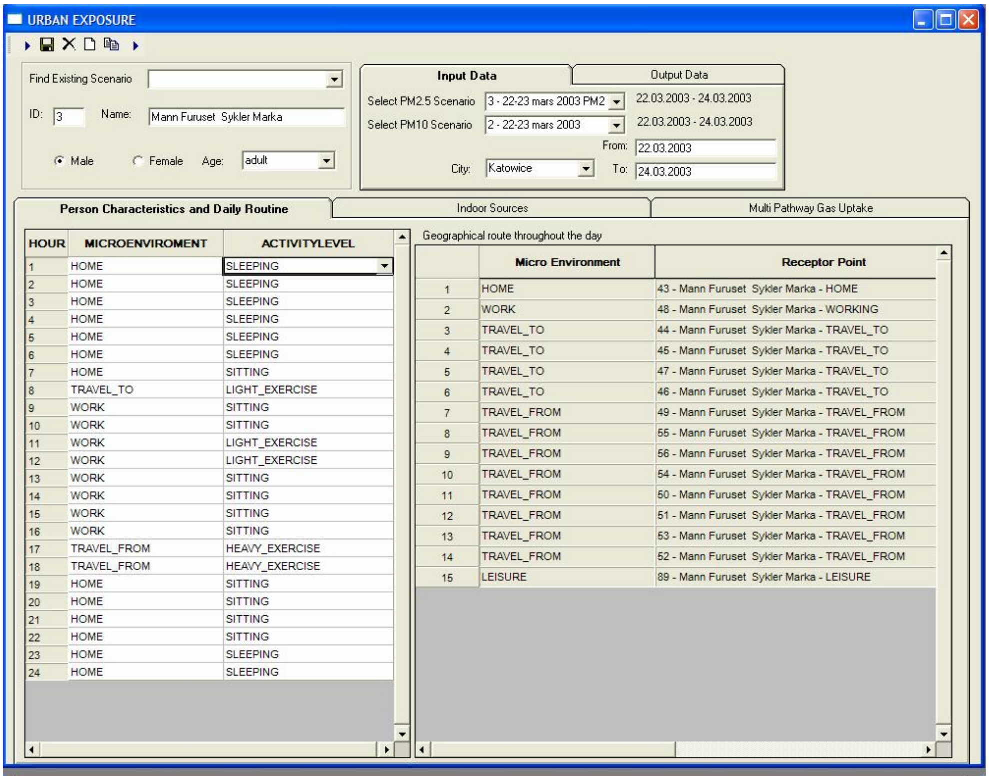


Figure 4: The Urban Exposure management tool user interface, featuring the form for defining Person characteristics and daily routine.

The main functionalities of the tool are accessed through the toolbar at the top of the interface.

Features

	Run	Start Particulate Matter and Multi Pathway Gas Uptake Calculations
	Save	Save scenario
	Cancel/delete	Delete scenario
	New	Create a new scenario
	Copy	Copy a defined scenario

4.3.1 Define a scenario

To run the Urban exposure module the user has to define a scenario that describes all the input parameters for the model calculation.

Features

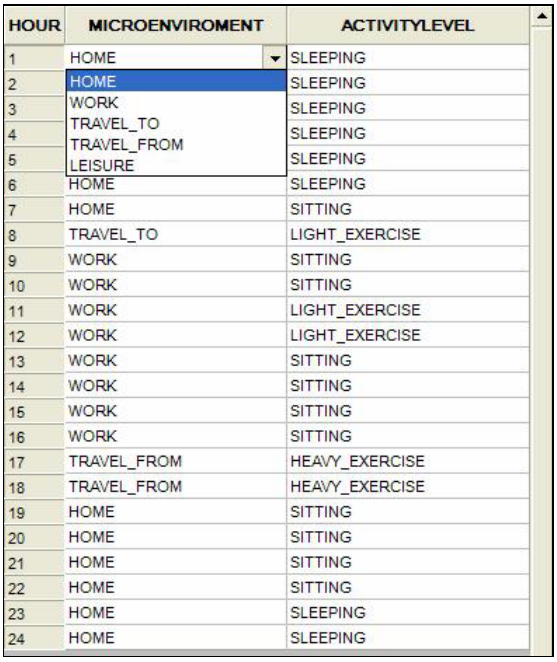
Find existing scenario	Drop down list of all Urban Exposure scenarios defined
ID	Scenario ID
Name	Scenario Name

To specify the necessary input for calculating the respiratory deposition of particulate matter and gas, information about age and gender must be defined.

Male/ Female	Gender
Age	Age classes (3 months, 1 year, 5 years, 10 years, 15 years or adult)

4.3.2 *Personal characteristics and daily routine*

As mentioned, the outdoor air concentrations determine the outdoor exposure and contribute to the indoor exposure. Therefore the outdoor concentration must be calculated for all the person's microenvironments. Before running the dispersion model for calculating the outdoor PM_{10} and $PM_{2.5}$ concentrations, the geographical positions for all the microenvironments must be defined. For each hour throughout the day, the microenvironments where the person stays are defined. The microenvironments are selected from a drop down list (Figure 5).



HOUR	MICROENVIROMENT	ACTIVITYLEVEL
1	HOME	SLEEPING
2	HOME	SLEEPING
3	WORK	SLEEPING
4	TRAVEL_TO TRAVEL_FROM	SLEEPING
5	LEISURE	SLEEPING
6	HOME	SLEEPING
7	HOME	SITTING
8	TRAVEL_TO	LIGHT_EXERCISE
9	WORK	SITTING
10	WORK	SITTING
11	WORK	LIGHT_EXERCISE
12	WORK	LIGHT_EXERCISE
13	WORK	SITTING
14	WORK	SITTING
15	WORK	SITTING
16	WORK	SITTING
17	TRAVEL_FROM	HEAVY_EXERCISE
18	TRAVEL_FROM	HEAVY_EXERCISE
19	HOME	SITTING
20	HOME	SITTING
21	HOME	SITTING
22	HOME	SITTING
23	HOME	SLEEPING
24	HOME	SLEEPING

Figure 5: The Urban Exposure management tool, Person characteristics and daily routine showing how to define microenvironments.

The options are *Home*, *Work*, *Travel to*, *Travel from* and *Leisure*. The geographical coordinates for a scenario's microenvironment are defined by double-clicking on one of the microenvironments in the "Personal characteristics and daily routine form" (Figure 5). A new form, called receptor points, appears (Figure 6). The user can either add the position by typing the coordinates in the form or selecting the position by using the GIS interface (Laupsa and Krognes, 2004). After the coordinates are defined the receptor point must be returned to the urban exposure module.

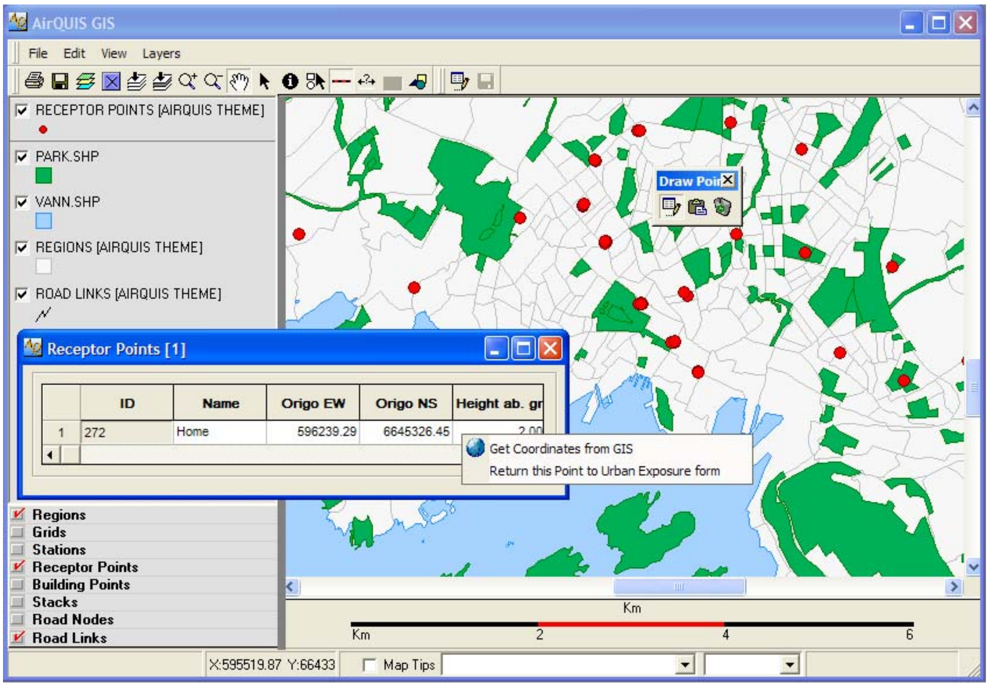
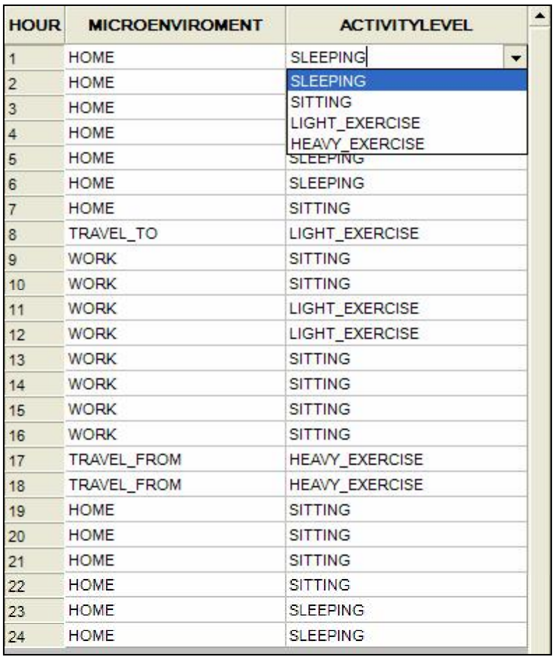


Figure 6: Defining the coordinates for the various microenvironments (exemplified by Home*), using the GIS functionality.*

A list of the defined receptor points and the corresponding microenvironments are visible in the form showing the Geographical route through out the day Figure 4.

Activity levels are required input for calculating the respiratory deposition of particulate matter. For each hour throughout the day the user must define the scenario person’s activity level (Figure 7). The different activity level options are *Sleeping*, *Sitting*, *Light exercise* and *Heavy exercise*, and are selected from a drop down list.



HOUR	MICROENVIROMENT	ACTIVITYLEVEL
1	HOME	SLEEPING
2	HOME	
3	HOME	
4	HOME	
5	HOME	SLEEPING
6	HOME	SLEEPING
7	HOME	SITTING
8	TRAVEL_TO	LIGHT_EXERCISE
9	WORK	SITTING
10	WORK	SITTING
11	WORK	LIGHT_EXERCISE
12	WORK	LIGHT_EXERCISE
13	WORK	SITTING
14	WORK	SITTING
15	WORK	SITTING
16	WORK	SITTING
17	TRAVEL_FROM	HEAVY_EXERCISE
18	TRAVEL_FROM	HEAVY_EXERCISE
19	HOME	SITTING
20	HOME	SITTING
21	HOME	SITTING
22	HOME	SITTING
23	HOME	SLEEPING
24	HOME	SLEEPING

Figure 7: The Urban Exposure management tool, Person characteristics and daily routine showing how to define Activity level.

4.3.3 Calculation of outdoor concentrations

When the user has defined all the geographical positions for the microenvironments for one or several scenarios, the outdoor concentrations in these microenvironments are calculated by using the dispersion model.

4.3.4 Input data

The user has to define the calculation period and select the pre-calculated dispersion results of PM_{10} and $PM_{2.5}$ before running the urban exposure tool for particulate matter (Figure 4). In addition, one has to select which city to perform calculations from the drop down list. This is because different statistical particle size distributions are used for estimating the PM size distribution from 10 nm to 100 µm.

Features

Select PM25 Scenario	Select a predefined PM25 dispersion run
Select PM10 Scenario	Select a predefined PM10 dispersion run

On the right hand side the result period appears after selecting a scenario.

From	Select From date for calculating the personal exposure
To	Select To date for calculating the personal exposure
City	Select City

Only if there have been changes in the microenvironment positions for a scenario it is necessary to rerun the dispersion model before running the Urban Exposure management tool.

4.3.5 Indoor sources

The indoor module is activated for the calculation hours the person spends indoors. Various indoor sources can be activated and thereby contribute to the indoor concentrations for specified hours. The indoor module uses discrete one-hour source contributions.

Features:

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
Room area [m^2]	Used for calculation of deposition and concentration
Ceiling height [m]	Used for calculation of deposition and concentration
House age	Define if the house is new or old which affects the penetration rate.

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 going by bike or foot. In these cases the microenvironment is outdoors and the system does not access the indoor module. For each of the indoor environment there is a list of various sources to be added. 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.

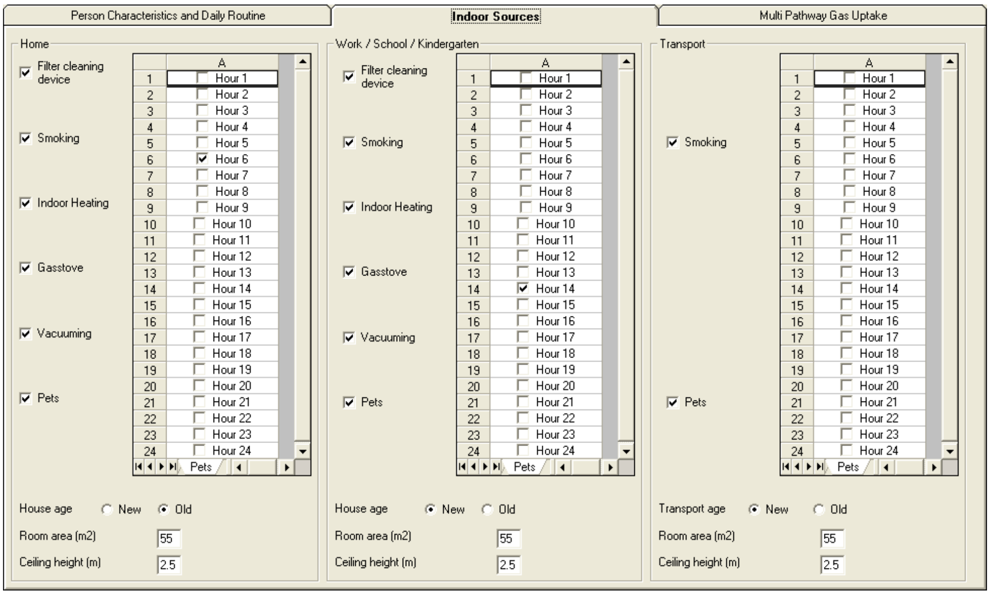


Figure 8: The Urban Exposure tool, Indoor sources – selecting indoor sources and time variability.

Using the check boxes on the left hand side activates the sources. In addition the user can select the specific hours the sources should be active throughout the day.

To calculate the indoor concentrations the room size has to be defined. In addition, the user has to define if the house is old or new in order to estimate the contribution of the outdoor concentrations. This is because the penetration rates though the building shell is dependent on the age of the house.

4.3.6 Multi pathway gas uptake

The Urban Exposure management tool includes an option for calculating the multi pathway gas uptake of chloroform through inhalation and dermal absorption.

Features:

Gas	Select gas from drop down list
Person weight	Add person weight (kg)
Person height	Add person height (cm)
Applied	Tick the hours to be calculated
Microenvironment	Environments defined in “Person characteristics and Daily routine” tab
Activity level	Activity levels defined at “Person characteristics and Daily routine” tab
Water sources	Select water source from drop down list. Options are *Shower*, *Bathtub* and *Swimming pool*
Exposure time	Define exposure time in minutes
W.C (water concentration)	Define water source concentration (µg/L)
A.C (air concentration)	Define air concentration (µg/m^3)

The user has to select the predefined component from the drop down list. Currently the only available component is chloroform ($CHCl_3$). The person’s height and weight have to be defined. The activity level and the microenvironment are define in “Person characteristics and daily routine” tab. For selected hours, select water source from the drop down list. The options are *Swimming pool*, *Bathtub* and *Shower*. Define the exposure time in minutes. “W.C” and “A.C” are the water concentration and air concentrations, respectively. These concentrations are user defined.

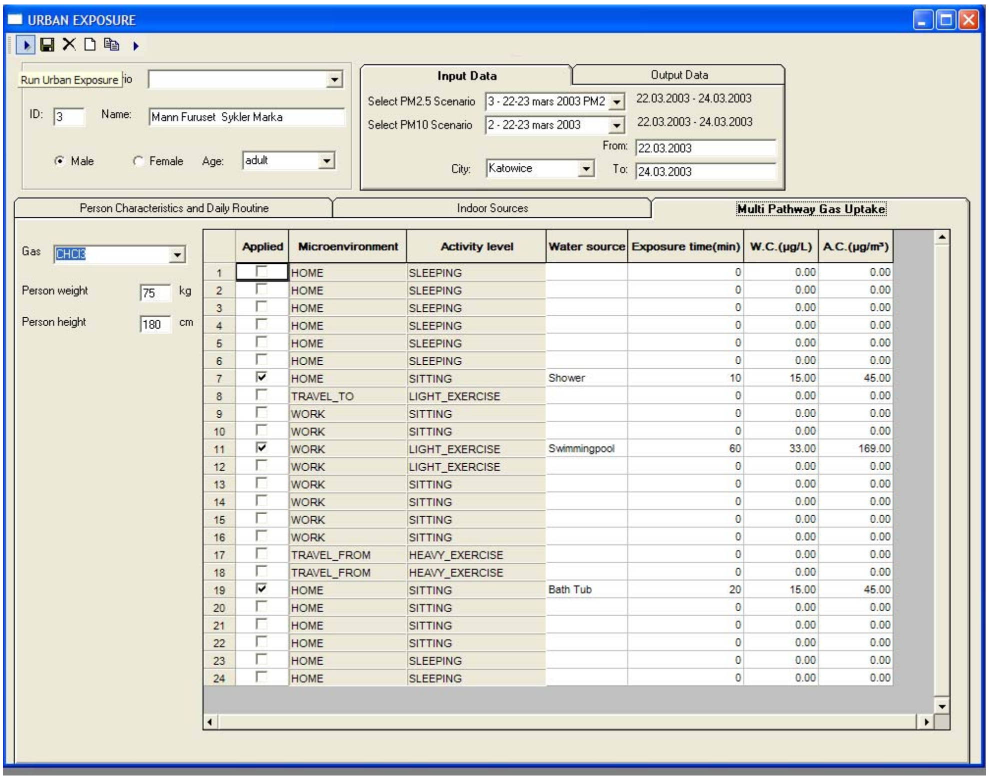


Figure 9: The Urban Exposure tool, featuring Multi Pathway Gas Uptake.

After the user has defined the input, the multi pathway gas uptake can be calculated. The results are stored as time series in the measurement module as systemic dose from the dermal exposure calculation and respiratory dose from the inhalation module (4.3.8).

4.3.7 Running the Urban exposure tool

After defining the input for the particulate matter calculation or the multi pathway gas uptake, use the run buttons to perform calculations.

4.3.8 Presentation of the results

There are two ways of presenting the calculated results from the Urban Exposure tool, either as graphs or as values on the GIS.

Calculation of particulate matter generates time series of concentrations and respiratory deposition (Figure 10). In addition the aggregated deposition in each microenvironments can be displayed on GIS (Figure 16).

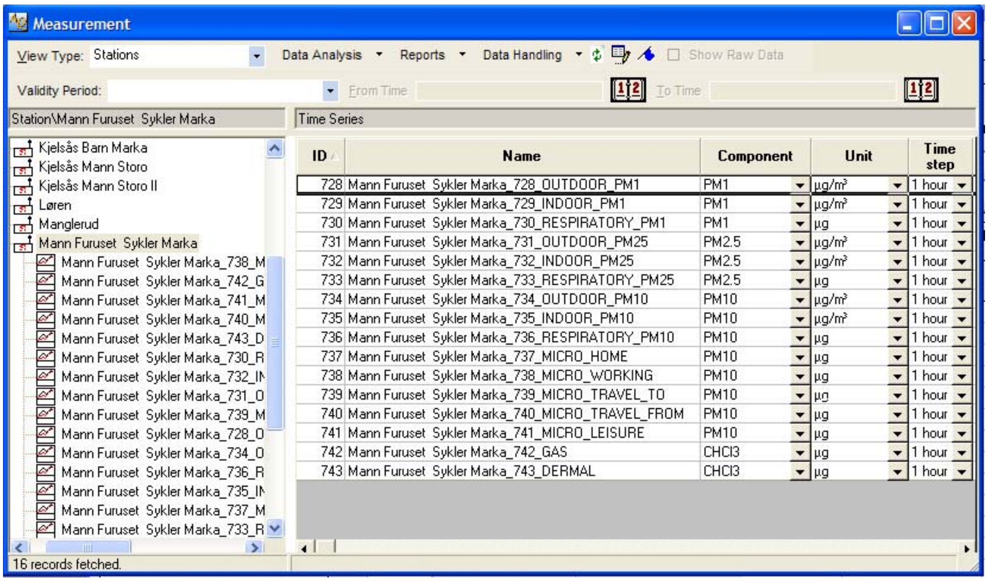


Figure 10: The time series results.

For each scenario the outdoor concentration of PM_{10}, $PM_{2.5}$ and PM_1 are stored hour by hour for the calculation period (Figure 11). In the same way the indoor concentrations are stored (Figure 12). In cases where the person is outdoors the indoor concentrations will not be calculated.

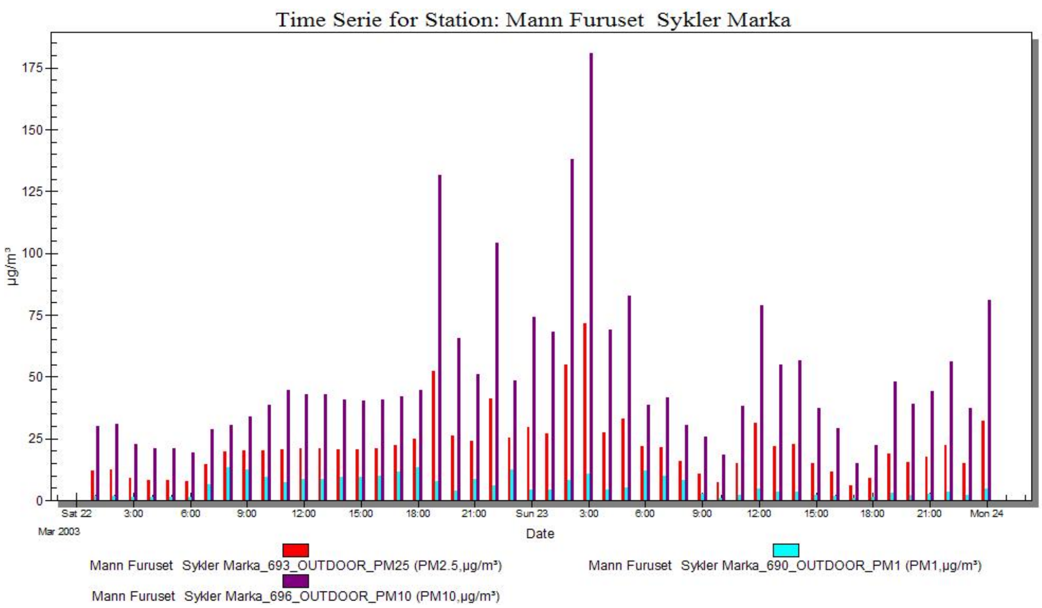


Figure 11: The estimated outdoor concentrations of PM_{10}, $PM_{2.5}$ and PM_1 ($\mu g/m^3$).

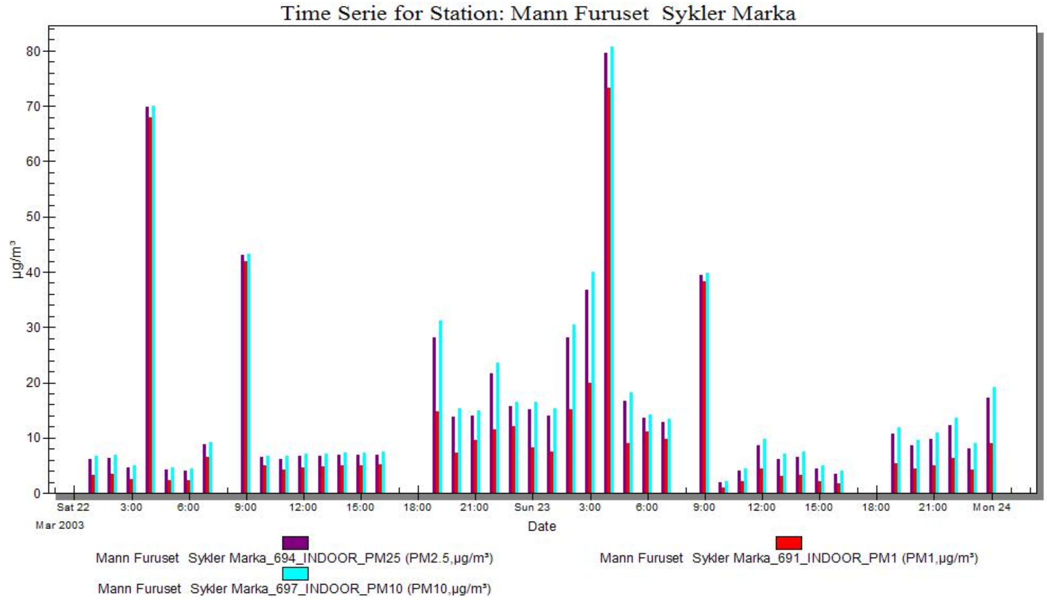


Figure 12: The indoor concentrations of PM_{10}, $PM_{2.5}$ and PM_1 (µg/m^3).

For each hour the respiratory deposition, dependent on concentration, age, gender and activity level are stored (Figure 13).

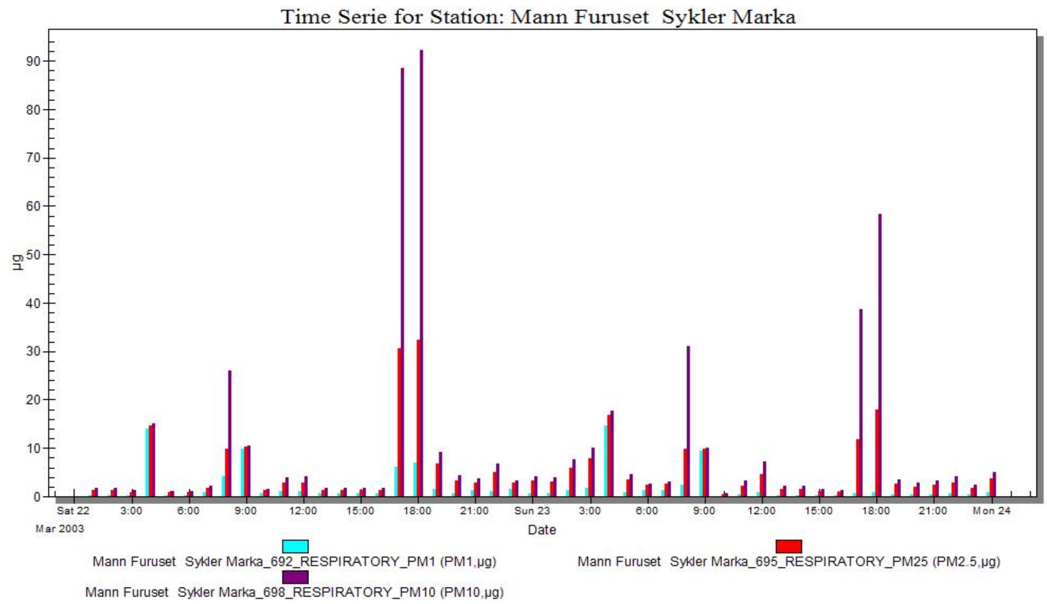


Figure 13: The respiratory deposition of PM_{10}, $PM_{2.5}$ and PM_1 (µg).

In addition the respiratory deposition hour by hour for PM_{10} can be displayed as a function of microenvironments (Figure 14). The user can then easily identify the contribution from each of the microenvironments. Another feature is to present the aggregated dose in each of the microenvironments accumulated over the hours spent there (Figure 15).

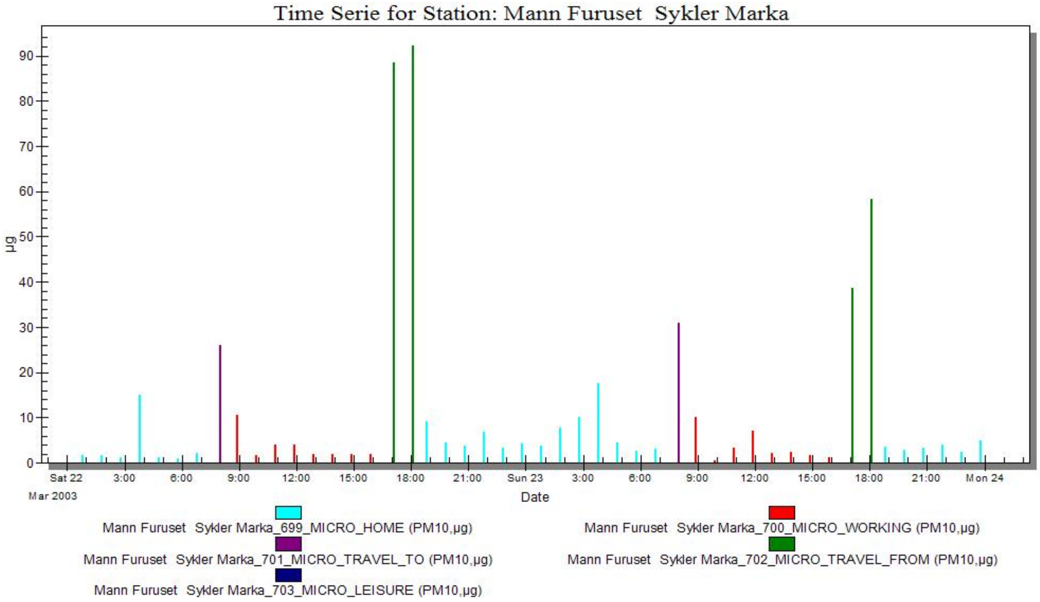


Figure 14: The respiratory deposition of PM_{10} per microenvironment (µg).

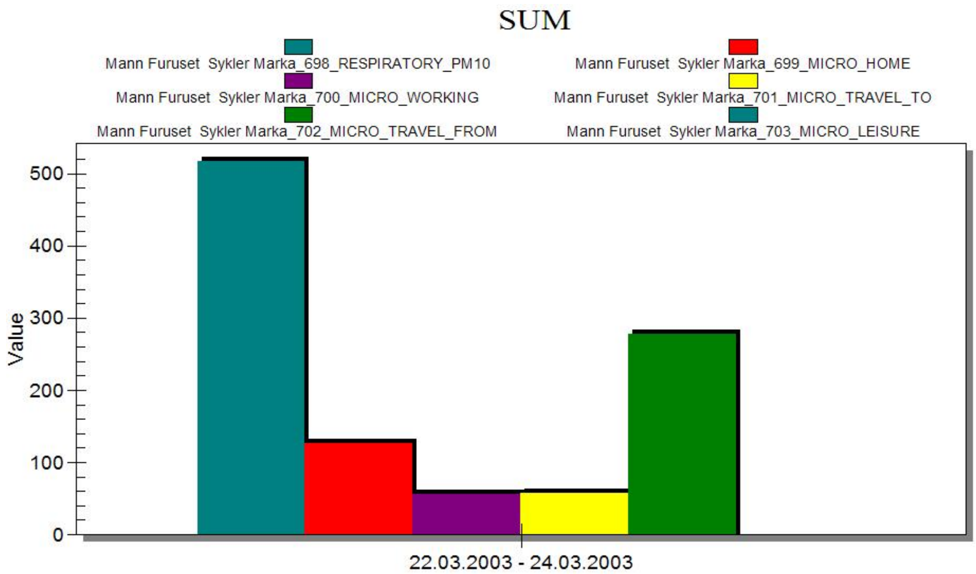


Figure 15: The sum of respiratory deposition of PM_{10} per microenvironment and in total over the calculation period (µg).

The accumulated dose of PM_{10} in each microenvironment for the calculation period can be presented on the GIS (Figure 16).

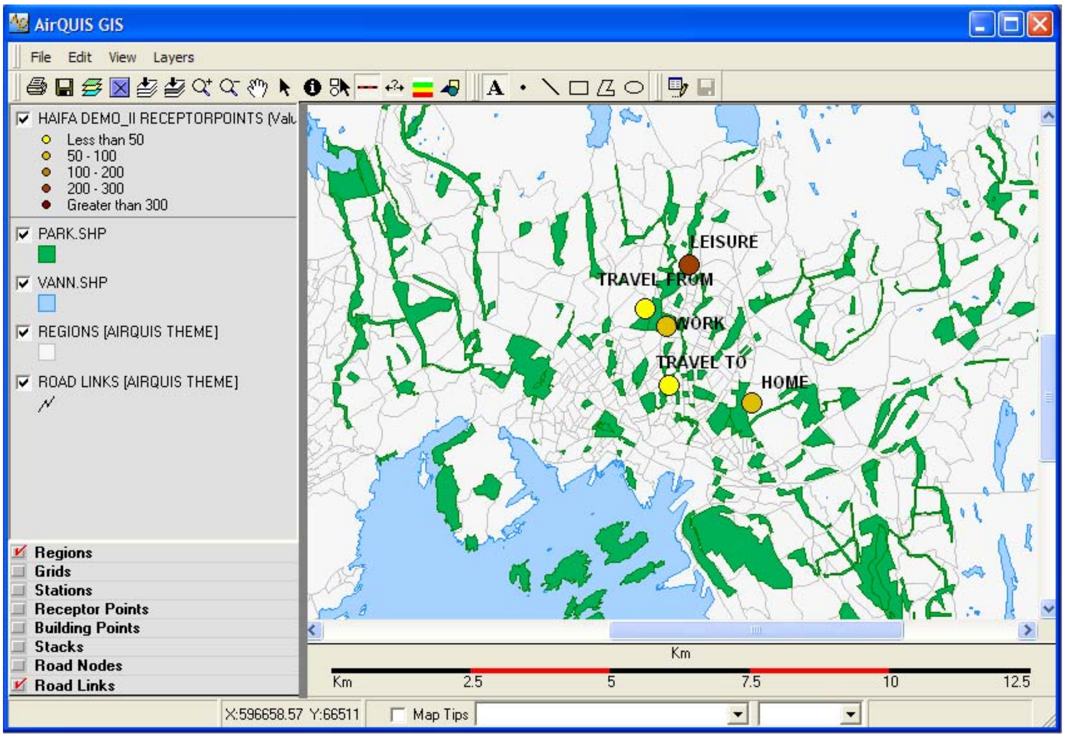


Figure 16: The sum of respiratory deposition of PM_{10} per microenvironment (µg) presented on GIS.

Results from the multi pathway gas uptake are stored as time series. For each of the exposure pathways, dermal absorption and respiratory deposition, the dose of chloroform (µg) are stored in separate time series. The results can be displayed as graphs (Figure 17).

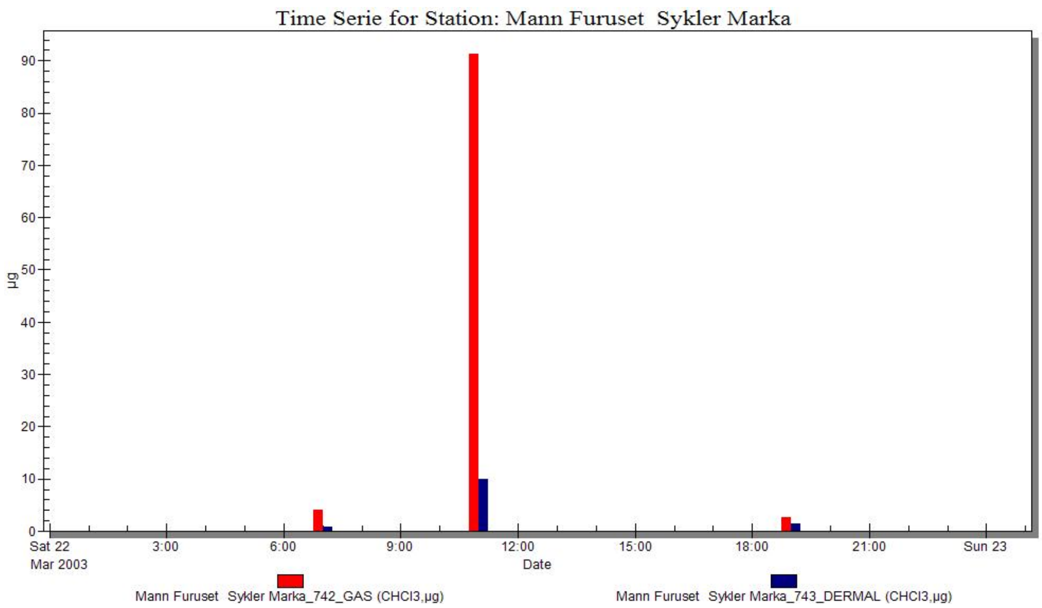


Figure 17: The dermal absorption and sum of respiratory deposition of chloroform.

5 Evaluation of the Management Tool

The Urban Exposure Management Tool has been tested in terms of functionality, dataflow and integration of the environmental modules. The environmental modules themselves; indoor, inhalation and dermal absorption, have been tested separately as part of the Urban Exposure project. Evaluation of the dispersion model has been performed in previous studies (Laupsa and Slørdal, 2003, Laupsa et al., 2005).

5.1 Calculated outdoor concentration

The outdoor concentrations calculated by the dispersion model are used as input for the Urban Exposure tool. The particle concentrations in the management tool are divided into 48 logarithmically equidistant size bins from 10 nm to 100 µm. To evaluate the effect of the statistical size distribution of PM, the concentrations from the dispersion model are compared to the aggregated concentrations of PM_{10} and $PM_{2.5}$ calculated in the Urban Exposure tool. As input from the dispersion model fixed ambient PM_{10} and $PM_{2.5}$ concentrations are used.

The ambient concentrations from the Urban Exposure tool are almost identical with the ambient concentrations calculated by the dispersion model (Table 1). The minor discrepancies are due to numerical inaccuracies in the statistical distribution.

Table 1 Estimated outdoor concentration in the Urban Exposure tool.

	PM_{10}	**$PM_{2.5}$**	**PM_1**
Dispersion model	20	10	-
Urban Exposure	20.00401	10.00397	4.380243

As an additional check, the outdoor concentration was calculated by using 0 µg/m^3 as input from the dispersion models.

The contribution of the ambient concentration to the indoor concentration due to penetration of ambient air through the building shell has been verified. The estimated indoor concentrations are calculated without any additional indoor sources. Constant outdoor concentration of 20 and 10 µg/m^3 are used for PM_{10} and $PM_{2.5}$, respectively. The resulting indoor concentration of PM_{10}, $PM_{2.5}$ and PM_1 are presented in Figure 18.

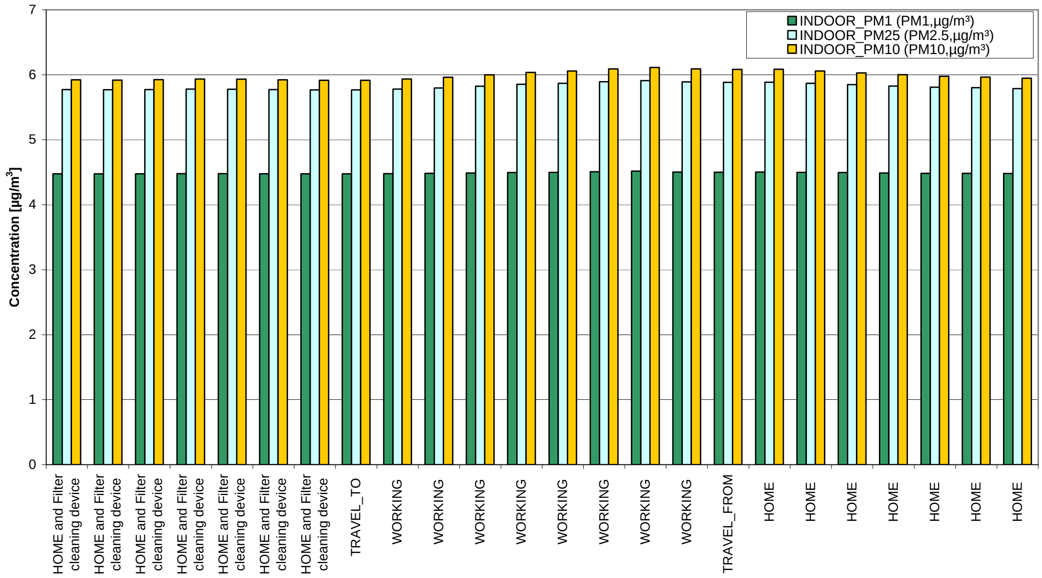


Figure 18: Contribution of ambient concentrations to indoor concentration [µg/m^3] for PM_{10}, $PM_{2.5}$ and PM_1 when outdoor concentration are 20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

The result shows that the largest reduction in concentration from ambient air to indoor air is for PM_{10}. This is reasonable since the particle size distribution is changed when the air passes the building shell. The coarse particles are removed more efficiently than the fine ones.

The reduction of the ambient air contribution to the indoor concentration for the various fractions is approximately 3-6% in a new building compared to an old one.

5.2 The indoor module

Each of the indoor sources has been tested in each of the microenvironments. The sources have been turned on one by one at home, work/school/kindergarten and transport (Figure 19). The room size (55 m^2, 2.5m) and the house age (old) are the same for all indoor environments. The dominant indoor source is *Indoor heating* and the least important source is *Vacuuming*. Some of the sources are composed of only fine particles like e.g. smoking while some are composed of the two coarser fractions like pets. The concentrations in the various microenvironments are comparable considering the statistical approach used in the indoor module (section 3.1). The hour to hour variations in indoor concentrations are due to the statistical approach of the indoor module and the meteorological conditions (wind speed and temperature). The meteorological conditions affect the indoor concentrations due to penetration and personal ventilation habits.

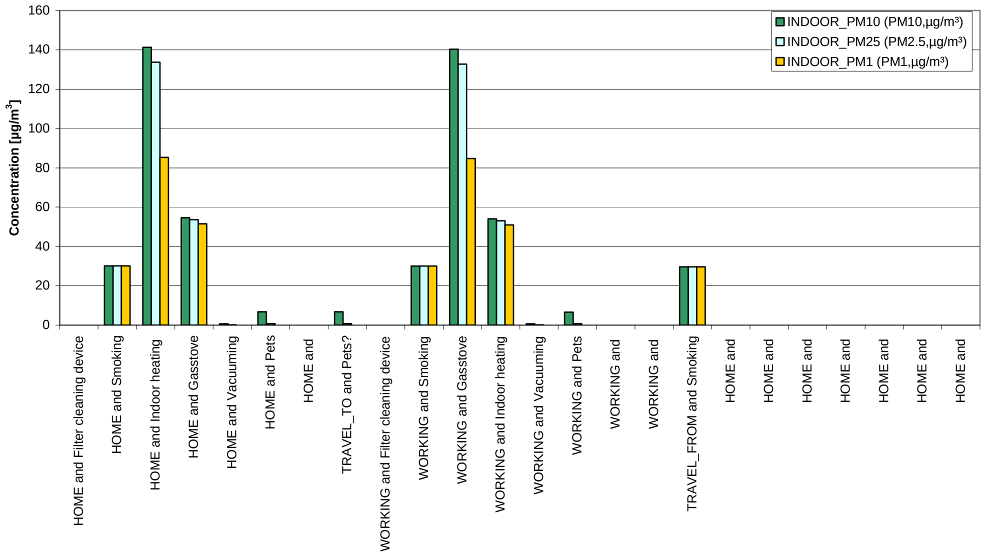


Figure 19: Calculated indoor concentrations for PM_{10}, $PM_{2.5}$ and PM_1 for the various indoor sources in an old building. The outdoor concentrations are in µg/m^3.

Additional calculations for a new building show an increase in the indoor concentration from the various sources and for the different size fractions of 15-25% compared to an old building. This is because the new building is tighter, thereby altering the ventilation conditions.

5.3 Inhalation module

Calculations of respiratory deposition for PM_{10}, $PM_{2.5}$ and PM_1 have been made for a five-year-old child (Figure 20), adult females (Figure 21) and adult males (Figure 22) for various activity levels in an outdoor environment. The ambient concentration is 20µg/m^3 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

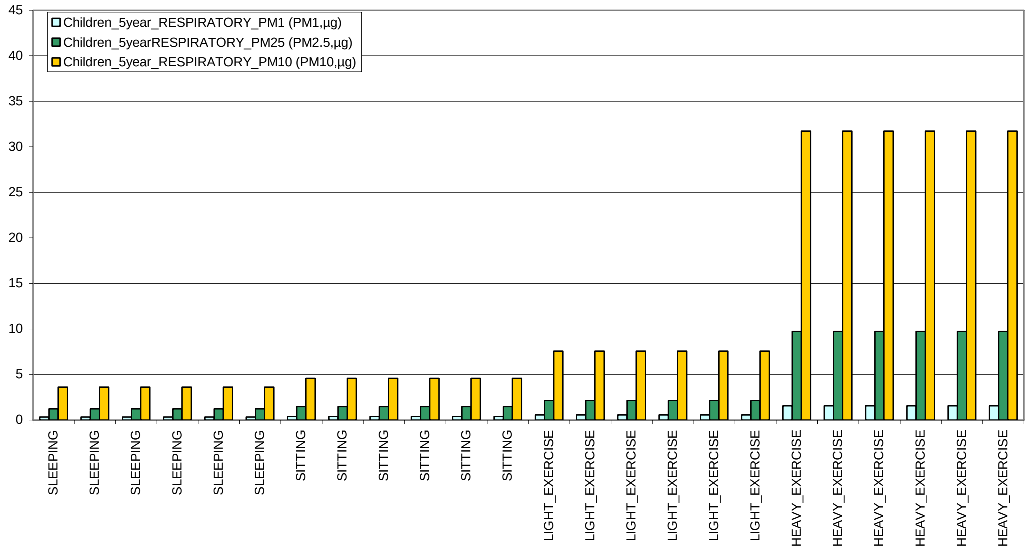


Figure 20: Respiratory deposition of PM_{10}, $PM_{2.5}$ and PM_1 for a 5 year old child when ambient outdoors concentrations are 20 µg/m^3 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

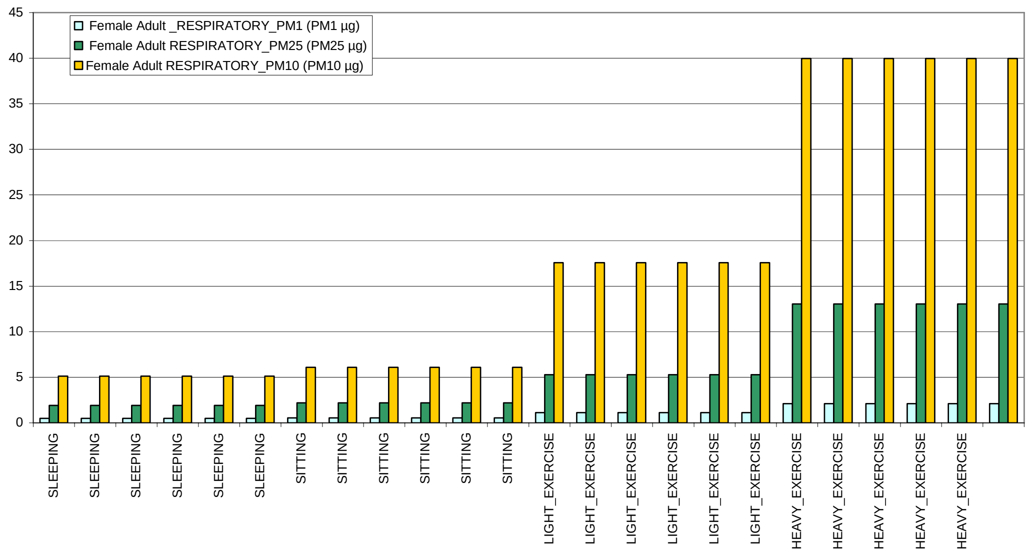


Figure 21: Respiratory deposition of PM_{10}, $PM_{2.5}$ and PM_1 for an adult female when ambient outdoors concentrations are 20 µg/m^3 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

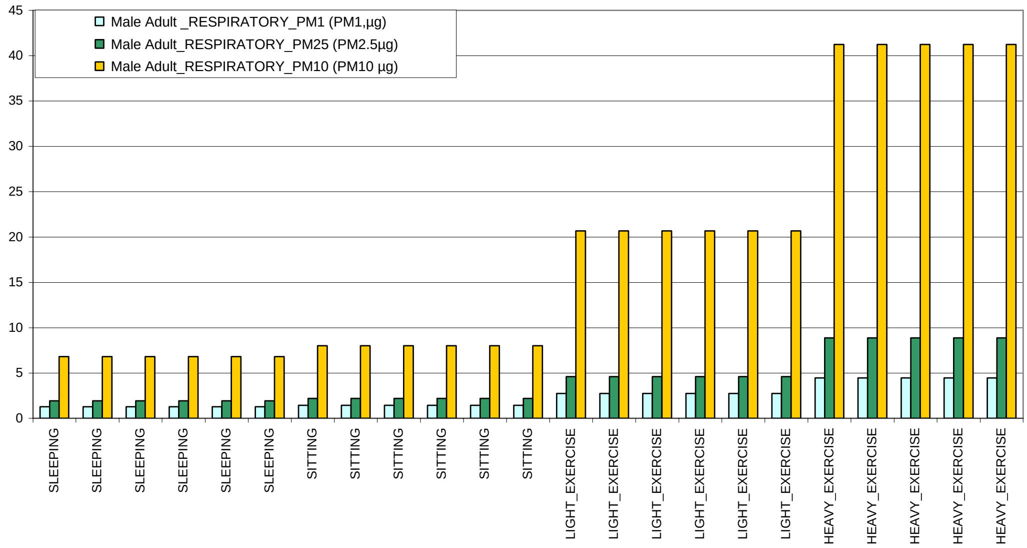


Figure 22: Respiratory deposition of PM_{10}, $PM_{2.5}$ and PM_1 for an adult male when ambient outdoors concentrations are 20 µg/m^3 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

The respiratory deposition increases with increased activity level and are highest for male and less for children, because of differences lung capacity, and the values for the various activity levels are as expected.

An additional testing of the respiratory deposition was preformed while outdoor concentrations are 0 µg/m^3 for both PM_{10} and $PM_{2.5.}$ This confirmed that for zero air concentration the respiratory deposition was also zero.

Calculations of respiratory deposition in an indoor environment were also performed in order to test the combination of the indoor module and the inhalation module. This was done without any additional indoor sources and outdoor concentrations for PM_{10} is 20 µg/m^3 and $PM_{2.5}$ is 10 µg/m^3.

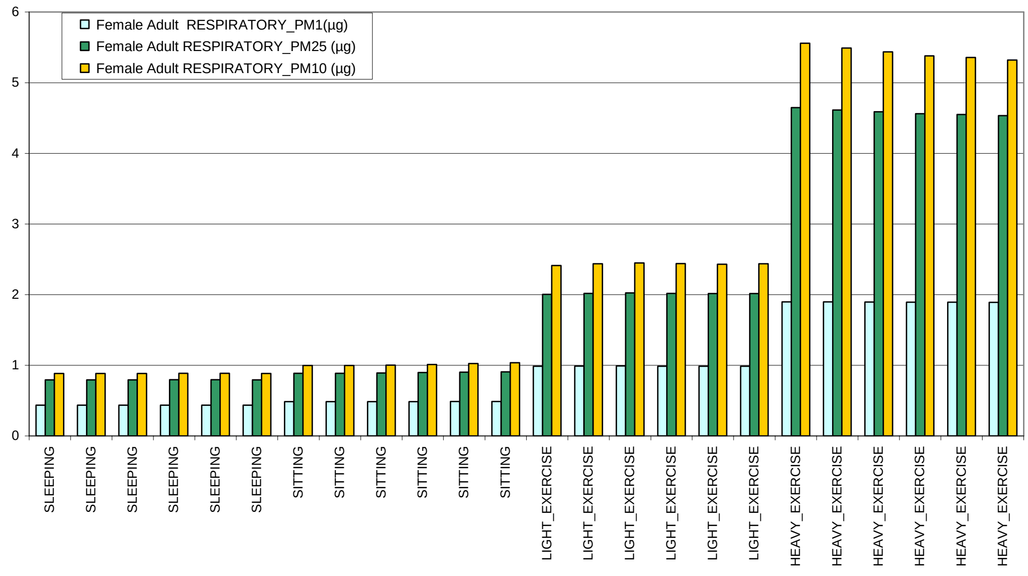


Figure 23: Respiratory deposition in an indoor environment of PM_{10}, $PM_{2.5}$ and PM_1 for various activity levels without any indoor sources for a adult female when ambient outdoors concentrations are 20µg/m^3 and 10 µg/$m^3$for PM_{10} and $PM_{2.5}$, respectively.

The respiratory depositions are lower indoors than outdoors, as expected since the indoor concentrations are lower. The difference in respiratory deposition between outdoor and indoor air is largest for PM_{10} and smallest for PM_1. This is because there is a change in the shape of the particle size distribution when the indoor module is applied. The coarse particles are removed more efficiently than the fine ones when the outdoor air passes the building shell (Figure 23).

5.4 Multi pathway gas uptake

The multi pathway gas uptake has been tested for various exposure time and air and water concentrations (Table 2) both for a male grown up (180 cm, 80 kg) and a 5-year-old child (120 cm, 20 kg).

Table 2: Input data for testing of the multi pathway gas uptake tool.

	Exposure time	**Hour**	**WC** (µg/L)	**AC** (µg/m^3)
Shower	10	07:00	15.00	45.00
Swimming pool	60	11:00	33.00	169.00
Shower	20	12:00	15.00	45.00
Bathtub	20	19:00	15.00	15.00

The results are presented in Figure 24 and Figure 25 and show the difference for different exposure time, concentrations and physiological parameters for dermal absorption and inhalation, respectively. The most important pathway for uptake chloroform is through inhalation.

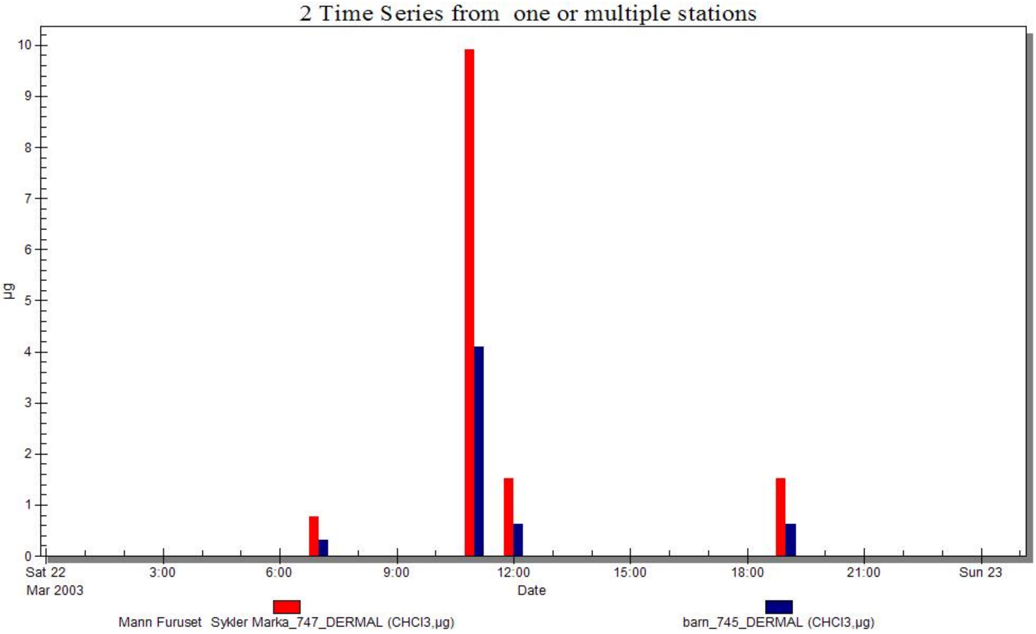


Figure 24: Calculated systemic dose for a male adult and a 5-year-old child using the values from Table 2.

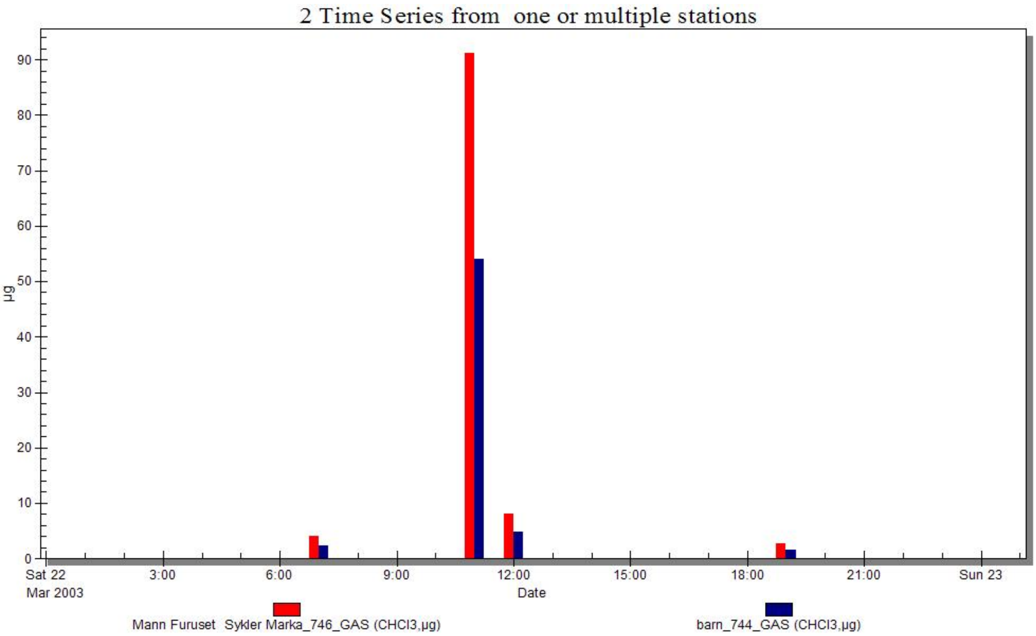


Figure 25 Calculated respiratory deposition for a for a male adult and a 5-year-old child using the values from Table 2.

The difference in physiological characteristics (skin area and lung volume) between the adult and the child is reflected in both the respiratory deposition and the uptake through skin. Further the water and air concentrations and exposure time determine the received dose from the various exposure cases defined in Table 2.

6 Application of the Management Tool

6.1 Case studies

The Urban Exposure Management Tool provides the possibility to calculate more realistic personal exposure. Important sources can better be identified and taken into account in health studies, strategies and planning.

Katowice (PL) and Oslo (NO) have been end user sites in the project, and the management tool has been applied for several scenarios for these two cities.

The two cities have a somewhat different pollution situation. For instance, the use of chlorine in treatment of drinking water is more common in Katowice than in Oslo. In terms of particulate matter, source distribution in outdoor urban air is different in the two cities. Katowice is an urban industrial area in the south of Poland with high pollution concentrations from heavy industry with coal burning for electricity production as well as the main source for domestic heating. Oslo, on the other hand, is dominated by traffic emissions and particle resuspension as well as wood burning. The Oslo case studies are presented in full in Lützenkirchen (2005).

The case study results reflect the differences in concentrations in the various microenvironments, the time spent there, the indoor sources, the activity level and the variations in respiratory capacity due to age and gender. For example, the effect of air pollution exposure differs between children and adults and reflects the children’s higher activity levels and more time spent outdoors (Fløisand et al., 2005). The results also show that the home environment makes a substantial contribution to the aggregated dose of particulate matter, mostly because a significant part of a day is spent there. Penetration of outdoor air is a major source for indoor concentrations of particulate matter, but some indoor sources can enhance the indoor concentrations and thus the exposure significantly. In addition, choices of travel route between work and home and activity level are of importance.

Additional case studies were carried out for the Haifa Bay Area by Technion and NILU. This was possible because the AirQUIS system was already implemented for this area in collaboration with the Haifa District Municipals Association for the Environment (HDMAE).

6.2 Demonstration to End Users

The Exposure Management tool and the results from the case studies have been presented for end users at demonstration workshops in:

- Oslo
- Prague
- Athens
- London
- Haifa
- Katowice

The demonstrations were an important step to exploiting the project results in order to maximise the use of the developed methodology and to stimulate its integration with air quality management systems used by management-level decision makers and city/regional planners.

The Management tool is targeted to support the urban authorities' decision-making process in the field of air pollution, as an information tool for the public and as an expert system for specialists.

Regulatory authorities have basically two main policy options to mitigate emissions and related exposure. On the one hand through changes in conditions such as traffic policy, urban planning, measures to reduce industrial emissions etc., and target changes in behaviour on the other hand. In order to set priorities for policies that identify an optimal package of measures, assessments of exposure and source contribution for each urban area must be made.

For air quality managers, the tool will provide a better understanding of the total exposure and dose related to various activities, as opposed to basing the evaluation on ambient concentrations only. This will in turn provide a better base for decisions and measures related to exposure and dose reductions.

7 Conclusions and further work

An integrated module for calculation of personal exposure to air pollution in urban environments has been developed as part of the Urban Exposure project. The tool calculates exposure to particulate matter in indoor and outdoor environments as well as chloroform from tap water and swimming pools. The Urban Exposure management tool has been implemented within the framework of the user-friendly air quality management system AirQUIS. The tool incorporates state of the science modules for calculation of indoor air concentrations, inhalation of particulate matter and gas and uptake of chemical compounds through skin. The functionalities of the tool and the integration of the various modules have been tested.

Although the management tool is a major innovation, there are still gaps in knowledge that need to be investigated and implemented. These are connected on one hand to the description of sources and concentrations of particles in terms of particle size distributions, and on the other hand, to the need to extrapolate the exposure scenarios from individuals to populations.

Both indoor and outdoor sources of particulate matter affect the overall personal exposure. In terms of ambient air pollution, population exposure assessments for cities under different emission abatement and exposure reductions scenarios would give valuable information on source apportionment.

In addition, the inclusion of the appropriate indoor sources for calculation of indoor concentrations is a prerequisite for quantifying the contribution from indoor air to personal exposure. Measurements of particle size distributions for relevant indoor sources need to be available. Another option would be to include an indoor background concentration of particles.

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ABSTRACT

The Urban Exposure management tool calculates personal exposure to air pollution in the form of particulate matter in indoor and outdoor environments as well as water disinfection by-products from tap water and swimming pools. The module for calculation of personal exposure has been implemented as part of an already existing Air Quality Management System, AirQUIS. Models for calculating indoor concentration, respiratory deposition and dermal absorption have been integrated as part of the module.

NORWEGIAN TITLE

KEYWORDS		
Personal exposure	Particulate matter	Chloroform

ABSTRACT (in Norwegian)

Et integrert verktøy for beregning av personlig eksponering til luftforurensninger er utviklet som en del av det EU-finansierte prosjekter Urban Exposure. Verktøyet er implementert som en del av luftkvalitetsforvaltningssystemet AirQUIS. Modeller for beregning av innendørskonsentrasjoner, opptak av gass og partikler i lungene samt opptak av gass gjennom hud er integrert i modulen. Verktøyet kan brukes til å beregne personlig eksponering til partikler i luft i ulike mikromiljø og opptak gjennom innånding samt opptak av kloroform fra vann gjennom innånding og hud.

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	B	*Restricted distribution*
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