Modelling the Exposure to PM10: an Italian Experience

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A computational tool has been developed to calculate PM10 exposure values for different population classes, based on the concentration field produced by a chemistry and transport model. The tool is composed by three main components: a meteorological, an air pollution and a population exposure model. Basic concept of the exposure model is that time-weighted average exposure is a sum of partial exposures, determined by the concentration and the time spent in the visited microenvironments (outdoor, work or school etc.) during a typical day. Indoor concentrations were modelled as a sum of hypothetical indoor sources and a contribution due to ambient concentrations using the infiltration approach.
The tool has been useful to compare exposure distributions of different populations groups or various scenarios, obtained under different input data conditions (infiltration factor, indoor sources values etc.) and to gain an insight into population exposure distributions and exposure determinants. The paper will describe the modelling tool and data used in the application to a test case located in the North of Italy.

1. Introduction

Over a typical day, a person spends time in many locations. For example, in cities most people spend the majority of the day in indoor environments, at home and at work; some time is spent on a vehicle; and relatively little time outdoors. The proportion of time spent in different environments varies with age, day of the week, environmental and socio-economical conditions (Monn, 2001).
The World Health Organization (WHO, 2000) recognizes modelling as one of the major methodologies for assessing air quality, population exposure and related health effects. A modelling system for exposure assessment must be able to integrate numerous and various pieces of information such as land use, emissions, meteorology, atmospheric dispersion and chemical reactions of pollutants, population mobility and time–activity patterns. The usual approach that has been undertaken till a very recent time was that of employing different models to simulate different group of processes, often without reciprocal intercommunication. During the last years, progress in computer resources and improvements in interface dataset allowed the integration of nearly all this partial simulations into more sophisticated and comprehensive modelling systems.
In the frame of a research project carried on by ARPA Lombardia (Regional Protection Agency) and supported by APAT (Italian National Environmental Protection Agency), a methodology for determination of population exposure from various emission sources using dispersion modelling and air pollution monitoring needed to be developed. In the context of this research, a complete overview of different modelling techniques has

been performed, pointing out differences in approach, in input data sources, in temporal and spatial details, in final utilization and dissemination media. For this purpose European Union FUMAPEX (2005), HEARTS, EXPOLIS (Jantunen et al., 2003) projects, developed in recent years on the topic, have been examined in detail to select the methodological approach more suitable to be developed, in relation to the existing input datasets and models availability.

2. Methodology and the modelling tool

Several models are presently available to calculate population exposure to air pollution. Two major categories of exposure models can be defined: empirical models and theoretical models. The first ones are based on statistical analysis of exposure data and the factors supposed to be determinants of exposure (regression analysis is applied to develop statistical relationships); the second ones are based on the underlying physical processes that determines exposure (Seigneur C., 1993). Theoretical models are based on the micro-environment approach, which itself is based on the algorithm of Equation 1:

$$E = \frac{1}{t_{avg}} \sum_{i=1}^{n} t_i \times C_i = \sum_{i=1}^{n} f_i \times C_i \qquad (1)$$

where E is a time-weighted average exposure level across the visited microenvironments (*i)* calculated as the sum of partial exposure in each one of them. The partial exposures are calculated by multiplying the microenvironment concentration by the fraction of time (*f*) spent in there. This approach assumes that a person's time-integrated exposure is the product of the concentrations of a specific set of micro-environments, concentrations that are considered to be constant and homogeneous.

Indoor microenvironment concentration can be obtained by experimental data or can be modelled as the sum of additional concentrations caused by indoor sources (C_{gi}) and a contribution from ambient concentration (C_a) multiplied by an infiltration factors (F_{inf}):

$$C_i = F_{inf} C_a + C_{ig} \qquad (2)$$

Then Equation 1 becomes:

$$\overline{E} = \frac{1}{t_{avg}} \sum_{i=1}^{n} t_i \times C_i = \sum_{i=1}^{n} f_i \times (F_{\inf} C_a + C_{ig}) \qquad (3)$$

The outdoor ambient concentrations can be estimated from monitoring data or simulated by an air quality model. The infiltration factor is a parameter that determines the contribution of the outdoor air concentration to the indoor air concentration and depends both on the specific micro-environment and the pollutant considered. In some models an additional level of detail may be added by computing the infiltration factors as functions of a set of parameters – such as information on the building insulating characteristics, home or vehicle ventilation habits, seasonal factors, etc. – but generally they are computed from experimental data. In probabilistic models, instead of applying the equation with deterministic values for input variables (one given concentration for each micro-environment and time period), probability distribution of the input variables are set and probability distributions for the outcome variables are provided by the model. Final purpose of the project was to develop an integrated modelling tool, thus allowing a complete integration from emission, meteorology, air pollution to population exposure.

The proposed exposure model is based on equation 3 with deterministic input data. It's a dynamic population exposure model with the following main characteristics:

- population is divided into several groups with specific activity patterns;
- the study area is spatially divided into several zones and the model allocates population to the air quality field grid cells using coordinates of municipality borders;
- the population dynamics follows the movement of a population group both through different microenvironments and different zone as a function of time (unit: hour);
- average hourly outdoor air concentrations are calculated by the use of assimilation procedures to take into account both data from monitoring measurement and from the application of a chemical-transport model;
- several micro-environments can be considered;
- infiltration factors can be specified both for zones and micro-environments.

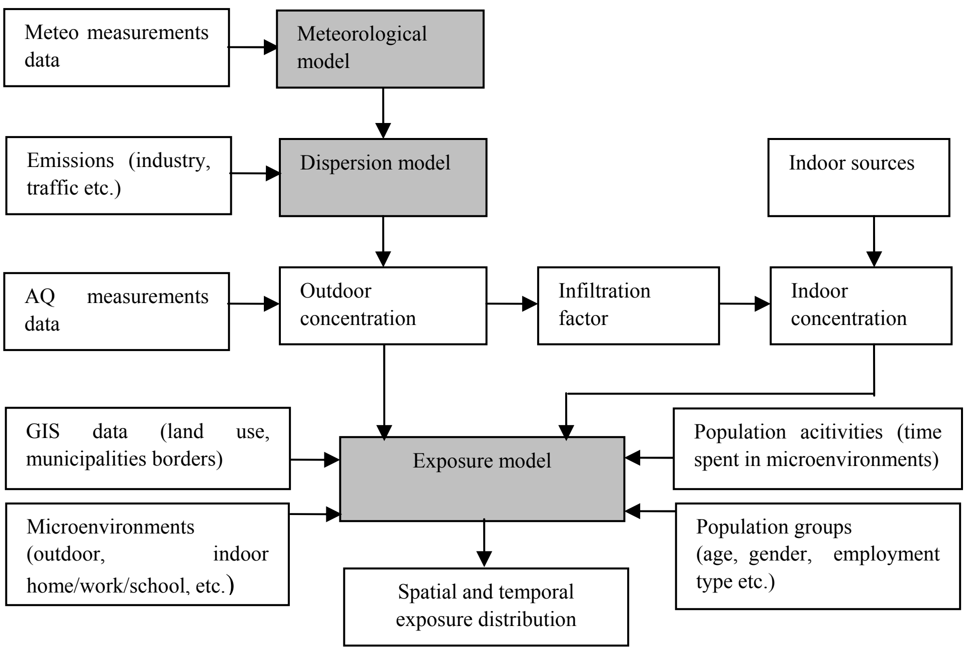

Figure 1: input data required by the integrated modelling tool

3. The test case

The developed tool has been applied to a domain (244 x 236 km^2, 4 km cell size, 11 vertical levels up to 6000 m) including the Lombardy region, located in the Northern Italy in the North-West side of the Po-Valley Basin. The outdoor concentration field has been obtained from a hourly run of the CTM (Chemical Transport Model) FARM, developed by ARIANET s.r.l., over the whole 2006 year (Silibello C. et al., 2008). The hourly input meteorological fields were obtained from ARPA Lombardia measured data and from ECMWF synoptic output modelled fields; the boundary and initial conditions were provided by Prev'air system (CHIMERE model); the emission inputs were derived from the regional INEMAR 2003 emission inventory. Different assimilation procedure have been tested and introduced to guarantee consistency with measured data.
In this application the tool was run for six different population groups:

- “class 1”: Infants (0-3 years),
- “class 2”: Schoolchildren (3-14 years),
- “class 3”: Youth (15-24 years),
- “class 4”: Younger adults (25-34 years),
- “class 5”: Older adults (35-64 years),
- “class 6”: Elderly persons (over 64 years).

The following four microenvironments have been considered:

- “0” indoor home
- “1” indoor work/school/other
- “2” transit
- “3” outdoor

In the absence of local measured data, concentrations for each indoor microenvironment have been derived as a function of ambient concentrations plus a contribution due to indoor sources. The infiltration parameters and indoor sources concentrations were chosen from relevant literature data, gathered during the preliminary bibliographic study. The infiltration factors selected for the application were: 0.8 for indoor micro-environments, 0.9 for transit, 1.0 for outdoor. The time profiles for each micro-environment and for each population group were inferred from the survey carried on by the Italian National Statistical Institute (ISTAT, 2005).

Table 1: hours spent outside buildings

Population class	Hours spent outdoors (F_{inf} = 1)	Hours spent in transit (F_{inf} = 0.9)
0-3 years	3	0
3-14 years	3	1
15-24 years	2	2
25-34 years	2	2
35-64 years	2	1
65+ years	3	1

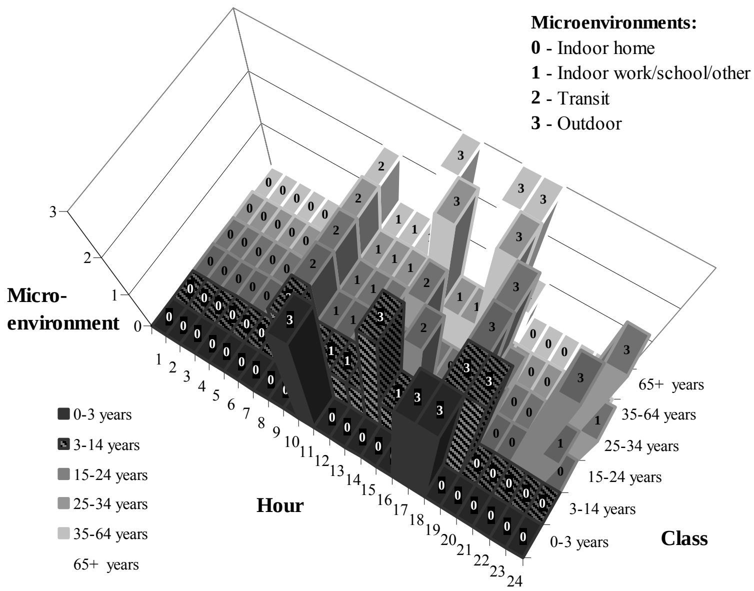

Figure 2: time profiles for the different population classes

4. Results

The described application of the tool has been carried out in a base case configuration (F_{inf} < 1 for transit and indoor microenvironments, no indoor sources), in order to obtain a first representation of the exposure levels in the different geographical areas for each population class. The resulting exposure map is consistent with the original concentration map, and the average exposure values correctly reflect the characteristics of the time profiles used for each class. Despite very low differences, Figure 3 shows that, under the base case hypotheses, the population classes spending more time indoors (Table 2) experience lower exposure levels when compared to other classes in the same zone.

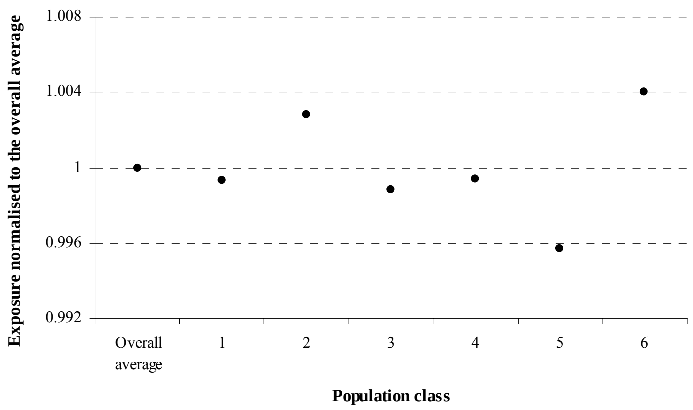

Figure 3: population class average exposure, normalised to the overall average

In order to set up more detailed test cases than the base one, some values of indoor source concentration due to household activities have been included and taken from the work of Wallace (1996). They are probably not well related to the Italian lifestyle, but they can help to understand the effect of indoor sources to the total exposure. A total of 12 model runs divided into three groups have been performed. For each group, only one kind of source was separately activated in the first three tests, while on the fourth all of them were taken into account in calculating the exposure.

Tests in group A consider the following sources and concentrations:

- Cooking: a 50 μg/m^3 PM10 source between 7 pm and 8 pm for all classes.
- Personal care: a 20 μg/m^3 PM10 source between 7 am and 8 am for all classes.
- Household cleaning: a 30 μg/m^3 PM10 source in the morning working hours for classes 4 and 5. This choice describes the exposure for adults whose main occupation is homemaking.

Tests in group B consider a 50% reduction of the concentrations and the same time spanning of the sources of tests in group A. For the tests in group C the same concentrations as those in group A have been kept, while sources activity and time spanning have been varied as follows:

- Cooking: the source is active from 7 to 8 am and from 7 to 8 pm.
- Personal care: the source is active from 7 to 8 am and from 9 to 10 pm.
- Household cleaning: the source is active from 8 to 9 am for all classes.

Figure 4, on the left, shows that the exposure values (normalised to the base case, where no indoor sources were included) correctly reflect the presence of different indoor sources. Kitchen and personal care ("bathroom") activities take just one hour, causing only a slight and homogeneous increment in the exposure of all classes. In case A, household cleaning hours have been supposed to span a longer interval for class 4 and 5, and the exposure consequently rises more for the concerned classes, even if the concentration value due to this indoor source is lower than that due to other activities.

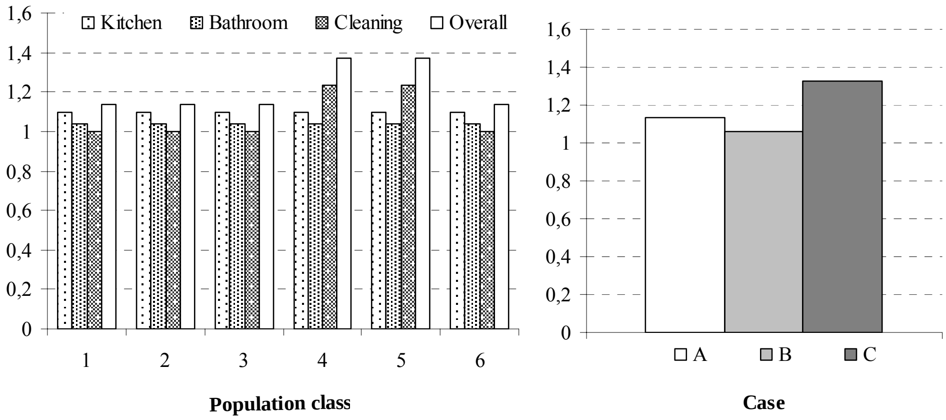

Figure 4 household activities: exposure normalised to the base case considering different indoor sources under case A assumptions (left), comparison between overall exposure for class 6 in the cases A, B, C (right).

Two tests have been performed to investigate the effect on indoor exposure due to Environmental Tobacco Smoke (ETS) PM10. The contribution of smoking to indoor PM concentrations depends on ventilation rate and building volume, among other factors. ETS contribution had been investigated by Brunekreef. The estimated contribution per cigarette smoked has been evaluated equal to 5,3 μg/m^3 for indoor PM2.5 and according to the authors this value was consistent with previous studies (Brunekreef et al., 2005). The estimated contribution to indoor 24-hour PM10 concentrations was 2.3 μg/m^3 per cigarette smoked according to Janssen (1998). In that study the estimated contribution to 24-hour personal PM10 concentration per hour exposed to ETS was 5.7 μg/m^3, which is similar to the value of 4.6 μg/m^3 found for PM2.5 by Brunekreef.

In the first test, test D, in the base conditions a source with a 5 μg/m^3 concentration was activated in indoor microenvironments 0 (home) and 1 (public places: work/school), excluding night hours and children under 15 years of age (it is assumed that they never stay in places attended by active smokers). In the second test, test E, the same source was only active in microenvironment 0 and not in microenvironment 1, to estimate the effect of a measure that prohibits smoking in public places, such a law was introduced in Italy in 2005.

Table 2: ETS indoor source activity and percentage reduction in test E versus test D overall exposure

Population class	Hours spent in public places (microenvironment 1)	Reduction in overall exposure
15-24 years	7	6.1 %
25-34 years	6	5.2 %
35-64 years	6	5.2 %
65+ years	4	3.5 %

The results in Table 2 confirm the expectations: the reduction in exposure values is greater for the classes that spend more time in smoke-free places.

5. Conclusions

The proposed results give insight into indoor source contribution to PM10 exposure.

The developed tool proved itself sensible to the variations introduced into the input data. The need of more detailed information on time profiles and indoor sources is evident, as these factors control the dependency of exposure on outdoor measured or modelled concentration. It must be said that the required information on people habits and home characteristics is expected to vary depending on the country/region where the tool is going to be applied; for this reason a great effort is needed in order to obtain quality data from local measuring campaigns and population surveys.

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