CHILDREN EXPOSURE TO TRAFFIC-RELATED POLLUTION: ASSESSMENT OF A TYPICAL SCHOOLDAY

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Abstract:
One of the major challenges to urban sustainability is the threat posed by the exposure to air pollutants, which is associated with a high rate of premature deaths. Therefore, the study of the exposure of people, and in particular of vulnerable population groups such as children, to air pollution is a subject of paramount importance. Concern should focus also on indoor air quality, due to the time people spend in those environments.

This paper evaluates the exposure of 4 children to carbon monoxide (CO) in 2 different classrooms during the time spent in school in a typical school day. The study is focused on an area of 550 x 550 m2 centred at a primary school of the city of Aveiro, in central Portugal, which is located close to a road with significant traffic and has natural ventilated rooms. Air quality data were measured in the school yard. Traffic emissions were estimated with TREM model, using traffic counts data. Simulations of CO concentrations in the study domain were performed with the CFD model VADIS, considering the influence of buildings and trees over the dispersion. Indoor concentrations were simulated using mass transfer rates.

Simulated CO concentrations (outdoor and indoor) were compared with measured values showing a good agreement. Individual exposure was calculated using a microenvironmental approach, knowing the CO concentrations and time spent in each of the considered microenvironments. Results show that the individual exposure of children is spatially dependent, as a consequence of the wind flow and air pollutant dispersion patterns. The variability of the estimated exposure values for individuals from different classrooms shows the magnitude of the error that can be committed when using a single value of air quality as a surrogate for air pollution exposure. Modelling results indicate that even in the absence of indoor sources of CO, the exposure in these spaces has to be taken into account, since indoor CO concentrations have the same magnitude as outdoor concentrations. These results point out the importance of air quality and exposure studies when planning new infrastructures, such as schools and hospitals, where susceptible population groups spend significant amounts of time.

Key words: *CO exposure; urban pathways; microenvironment approach; CFD modelling*

INTRODUCTION

Air pollution is the environmental factor with the highest impact on health in Europe and is responsible for the largest burden of environment-related diseases (EEA, 2005). Since the 1990's numerous studies have demonstrated the association between outdoor air pollutants concentration, and the occurrence of health related problems (Seaton et al., 1995; Samet et al., 2000; WHO, 2010; Pope et al., 2006). In particular, some authors (Finkelstein et al., 2004; Hoek et al., 2002; Hoffmann, et al., 2007; Tonne et al., 2007) have found associations between exposure to traffic and adverse health effects, such as hypertension, myocardial infarction, stroke, atherosclerosis, heart disease and mortality. Most studies on health effects of traffic exposure mostly rely on associations between hospital records and data from air quality monitoring stations, considered as representative of exposure in a large geographical area.
Indoor air quality appears with a high importance for two main reasons: the time people spend in those environments (more than 90%), and the nature and concentration of the pollutants on these spaces.

Different methodologies can be applied to determine the individual exposure, using direct measurements or estimations based on exposure concentration data and the period of time during which contact occurs. The mathematical basis of human exposure estimation lies down on the microenvironment concept. This happens because different microenvironments contribute differently to the exposure estimation, due to both microenvironmental concentration and the time fractions spent in each.

Due to the limitations of exposure measurements, in terms of representativeness and cost, exposure modelling, using air quality models is a reliable and useful tool (Wilson and Zawar-Reza, 2006).

METHODOLOGY

Personal exposure to CO of 4 children was calculated for a typical school day, including the time spent walking to school and the time spent in the school (from 9h00. to 15h30). The 3D fields of wind and CO concentration were calculated with the CFD model VADIS, while the personal exposure was estimated using the MEB model. An air quality monitoring (outdoor and indoor) campaign was performed in order to validate the results of model applications.

Study area

The study domain is a small area at the centre of Aveiro, a medium size town, in Northwest Portugal. The selected study domain is characterized by residential buildings and schools (figure 1) and it is located in one of the most important thoroughfares of the town. This area has building blocks of similar height, several secondary roads, and a main Avenue.

Figure 1. Satellite image (from Google Earth) of the study area (the simulation domain is defined in the yellow rectangle, and the school is located within the red line).

Since the model uses a structured grid the shape of buildings has to be simplified as regular blocks. Also, neighbouring buildings are assembled based on their configuration and height. Trees are defined as porous blocks, in which the porosity is proportional to the leaf area density.

2.1.1 Walking routes and classrooms

Four alternative pathways to the secondary school, which is centred in the domain, have been selected. To have a time profile for each route we have walked through each pathway carrying a GPS. Figure 2 illustrates the 4 chosen pathways within the domain and the location of the classrooms (A and B) that the children attended. Children 1 and 2 attended room A and 3 and 4, attended room B.

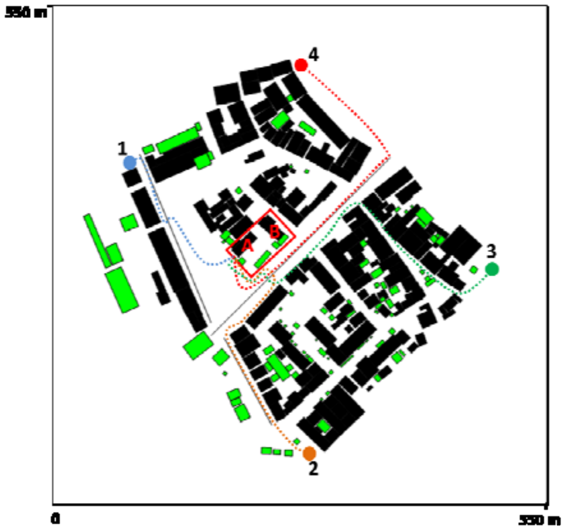

Figure 2. Domain with representation of the 4 pathways to the school and the location of the classroom of each one.

Air quality and exposure modelling

Local scale air quality modelling was performed using the CFD model VADIS (Borrego et al., 2003; Amorim et al., 2010), which has two main modules. In the first, the 3D wind flow is simulated applying a RANS prognostic model with a standard k-ε turbulence closure, which has been extended for the simulation of green canopy effects (Amorim et al., 2010), and in the second the dispersion of the air pollutants is performed applying a Lagrangian approach. The needed input information (Borrego et al., 2003) on road traffic emissions was estimated using the TREM model based on vehicles counting and average speed, together with the Handbook Emission Factors for Road Transport, (HBEFA, 1999) for stop-and-go and traffic-lights situations. For the exposure calculation the background concentration of CO calculated by EURAD was added to the local contribution estimated with VADIS.
In the core of the exposure model MEB (Miranda et al., 2011) is the calculation of the individual exposure through the application of the microenvironment approach from (Hertel et al., 2001):

$$\exp_i = C_i \times t_i \tag{1}$$

where exp_i is the total exposure for the person i over the specified period of time; Ci is the pollutant concentration in a given location, and ti is the time spent by the person i in that specific location. As a result, the exposure value is expressed in concentration x time (e.g., $\mu g.m^{-3}.h$), and thus can be interpreted as the mean pollutant concentration value to which the individual has been exposed during a given period of time.

To take into account exposure in indoor microenvironments (in this specific case, classrooms) the MEB model has been modified. MEB is now able to read from an input file if the individual is in an indoor or outdoor microenvironment. If the child is outdoors, it calculates exposure directly, otherwise, if the child is indoors, MEB calculates the indoor concentration according to equation 2 (Guo, 2002):

$$E_i(t) = Q_{0,i} \times f \times C(t) \tag{2}$$

Where E is the pollutant infiltration flow rate, f is the penetration factor, Q is the ventilation, C is the outdoor concentration and t is time.

The inputs of MEB are: a) the temporal variation of the individual location (provided by the GPS); and b) the temporal variation of the spatial distribution of concentrations at an average inhalation height. Combining, in each time-step, the georeferenced positioning of the individual with the corresponding concentration, the model tracks the time evolution of the exposure. The output data produced by MEB are both instant and mean exposure values.

RESULTS AND DISCUSSION

Air quality simulations were conducted for the 24 hours of January 10th, 2012. Model accuracy was evaluated applying the results acceptance criteria defined by Chang & Hanna (2005) for air quality models assessment. The statistical analysis indicates a good modelling performance when compared to observations on what concerns ambient air and a fair performance for indoor air. Results for a selected hour can be seen on figure 3.

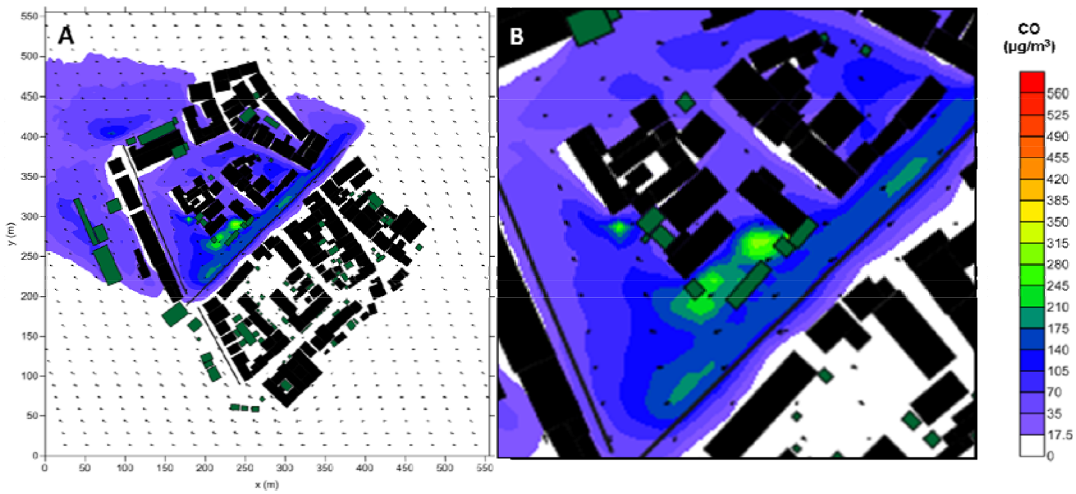

Figure 3. 1.5 m high horizontal CO concentration field for the period between 8 and 9 a.m. on January 10th 2012. Buildings are shown as black rectangles and tree blocks as green rectangles. Figure A represents the simulated domain and figure B a zoomed detail over the school building

From the analysis of this particular hourly period it shows the clear influence of the traffic in the main avenue in the northwest of the domain. The CO is actually transported t the school yard creating hot-spots in the school.

In Table 2 the hourly CO exposure is presented for the 4 children. Exposure at 9h and 16h includes the time spent walking between home and school; the other hours correspond to time spent in school.

Table 2. CO exposure (µg.m-3.h) for the 4 considered children, for a typical school day.

	9h	10h	11h	12h	13h	14h	15h	16h	average
Child 1(RA)	224.3	90.5	66.4	163.0	568.0	90.3	90.3	180.2	202.9
Child 2 (RA)	218.1	207.6	91.5	163.0	568.0	90.3	90.3	182.2	201.3
Child 3 (RB)	203.2	156.6	90.5	66.4	568.0	90.1	101.1	184.	182.1
Child 4(RB)	200.7	156.6	90.5	66.4	568.0	90.1	101.1	189.	183.5

As it can be seen from the analysis of Table 2, children 1 and 2 have higher exposures than children 3 and 4. This results from the fact that the CO concentration in room A was 2 times higher than room B, during most of the day. This happens because the recirculation created in the school yard promotes higher concentrations in front of room A. During the most part of the day (except for peak hours at lunchtime, (12h to 13h) and at noon (18h to 20h)) the background concentrations were higher than the local contribution being more important to exposure.

When the exposure to and from school are analysed, it can be concluded that children have quite different exposures along the way, resulting from the spatial distribution of concentrations. From the health point of viewh studies this fact suggests that even in a small domain a significant error can potentially occur if a mean air quality value is used as a proxy for the exposure of the individuals that use that specific microenvironment. From the modelling point of view, this conclusion shows the importance of using detailed 3D city models for this type of analysis. The accuracy and resolution of the virtual domain used by the model will ultimately affect the behaviour of the wind flow in the street-canyons, the dispersion of the emitted air pollutants and, finally, the concentration (and its distribution in the 3D space) to which individuals are exposed.

This study shows, through a local scale computational approach, that the individual exposure of pedestrians in an urban area is extremely spatially dependent, as a consequence of the wind flow and air pollutant dispersion patterns and characteristics. Also, their exposure in the indoors varies along with the outdoor concentration's. In this sense, exposure studies can be of extreme importance in planning studies, particularly in the location of buildings such as schools and hospitals, where susceptible population groups spend a high amount of time.

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