MODELLING POPULATION EXPOSURE TO URBAN AIR POLLUTION

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ABSTRACT

Within any city, there is a large variation from individual to individual in their personal exposure to air pollution, depending on location, indoor and outdoor concentrations and activity patterns. The health benefits of policy measures to improve urban air quality are currently assessed by reference to outdoor concentrations at particular locations, but actually are more closely linked to changes in personal exposures within the population. More specifically, there is a need for tools to assess the impacts of different policy interventions on the frequency distribution of personal exposures within urban populations. This paper describes a new modelling framework that simulates the frequency distributions within an urban population of indoor concentrations and personal exposures to four pollutants (CO, NO_2, $PM_{2.5}$ and PM_{10}). The results of applying the model for NO_2 in the city of Leicester (UK) demonstrate how the mean and the 95%ile of the frequency distribution of modelled indoor home concentrations in the city differ significantly with levels of indoor cooking activity and between roadside and urban background sites. The model will allow an assessment to be made of the impacts of policy interventions targeted at specific areas within a city with high vehicle-related concentrations on the exposure to air pollution within both local and city-wide populations.

INTRODUCTION

Health effects of air pollution are related to personal exposure [1]. However, current assessments of the health benefits of air pollution control policies rely on estimates of outdoor concentrations rather than personal exposures. In the UK, local authorities have declared Air Quality Management Areas (AQMAs), where measures need to be taken to reduce local concentrations below national air quality guidelines. Most of these measures relate to traffic management and vehicle emission control, as the majority of such areas are associated with road sources. However, the actual benefits of such measures in terms of personal exposures both within the AQMA and in the wider urban population are uncertain, and appropriate modelling tools to address such questions have hardly been developed. This paper describes the development of an innovative modelling framework that will simulate personal exposure frequency distributions (PEFDs) as a function of urban background and roadside concentrations, under different traffic conditions. The modelled relationships between PEFDs and outdoor concentrations will provide a basis from which to estimate the potential health benefits of measures to reduce concentrations at both roadside and urban background locations.

Our approach links modelling of roadside concentrations (summarised in [2]) at different locations within a city with a new probabilistic modelling framework of population exposures (INDAIR/EXPAIR-2), which is the focus of this paper. The exposure modelling has been carried out by linking a microenvironmental with a time activity model. The current work is the development of the original INDAIR/EXPAIR modelling framework, which probabilistically simulated exposure of the UK population to four air pollutants (nitrogen dioxide, carbon monoxide, and particulate matter (both PM_{10} and $PM_{2.5}$)). The original microenvironmental model both in deterministic form (INTAIR, [3]) and in probabilistic form (INDAIR, [4,5]), used a detailed physical model to simulate frequency distributions of concentrations in the major rooms of a home (kitchen, lounge and bedroom). The model parameters for the analytical home simulations, and the indoor/outdoor ratios for the empirical non-home simulations, were defined in the probabilistic version as probability density functions to provide frequency distributions of personal exposures in different microenvironments.

In the previous versions, only a single outdoor concentration profile was used. The new modelling framework (INDAIR/EXPAIR-2) provides a new and flexible approach to modelling population exposures across a city with a large variation in traffic conditions and roadside pollution concentrations. This paper describes the modelling approach and presents some preliminary results for nitrogen dioxide (NO_2), the pollutant for which most AQMAs have been declared in the UK.

MODEL DEVELOPMENT

The new INDAIR-2 model predicts the frequency distribution of concentrations in each microenvironment as a function of the outdoor concentration and four regression coefficients. Two of these coefficients define the relationship between indoor and outdoor concentrations in the absence of any significant indoor source, on the basis of log-transformed variables. The remaining two coefficients describe the incremental effect of differing activities, appropriate to each microenvironment, on the modelled concentrations. Each coefficient is defined as a probability density function, while the input concentrations are defined as log-normal distributions for each road category. Importantly, the INDAIR-2 code allows the values of these coefficients to be varied over the course of the day, to reflect different levels of activities such as cooking and smoking. Table 1 summarises the microenvironments selected for simulation, and the coefficient terms for each ME in the current version of the model; additional terms can be added as required.

Microenvironment	**Base parameterisation**	**Additional factor 1**	**Additional factor 2**
Home – kitchen	No source	Cooking	Smoking
Home – living room	No source	Cooking	Smoking
Home – bedroom	No source	Cooking	Smoking
Transport	Bicycle/walk/ public transport	Car	Underground
School	No source	-	-
Office	Naturally ventilated	Mechanically ventilated	-
Shops/large buildings	No source	-	-
Bars/restaurants	No smoking	Smoking	-

Table 1: Summary of model terms included in INDAIR-2

MODEL PARAMETERISATION

The original version of INDAIR was designed to simulate home concentrations and personal exposures at specific locations, using an assumed and fixed activity pattern, in terms of smoking and cooking. INDAIR-2 provides a more flexible version of the model, which includes variation in cooking and smoking activity across the population over the course of a day.

Results from the original INDAIR model were used to derive the home parameterisations for INDAIR-2. The first stage of the analysis was to define probabilistic indoor/outdoor relationships of vehicle generated pollutants for situations with no active indoor source, a definition which includes the impact of cooking or smoking activity one or two hours previously. The modelled home concentrations show a linear relationship between outdoor and indoor levels with high values of R^2. The second stage of the analysis was to introduce the effect of cooking and smoking, as time-dependent factors. The process for cooking impacts on NO_2 is presented here for illustration. The concentration frequency distributions for hours with current cooking activity, and for hours with cooking one or two hours previously, were examined, and the sensitivity of these frequency distributions to time of day, season, weekend/weekday and location, were evaluated. The results showed that cooking source concentrations, expressed as the difference from the no-source simulations, are effectively independent of both time of day and outdoor concentrations. Figure 1 shows the relationship between values of indoor and outdoor concentrations of NO_2 for the kitchen for one hour's cooking at 18.00h. The symbols represent outdoor data from different UK

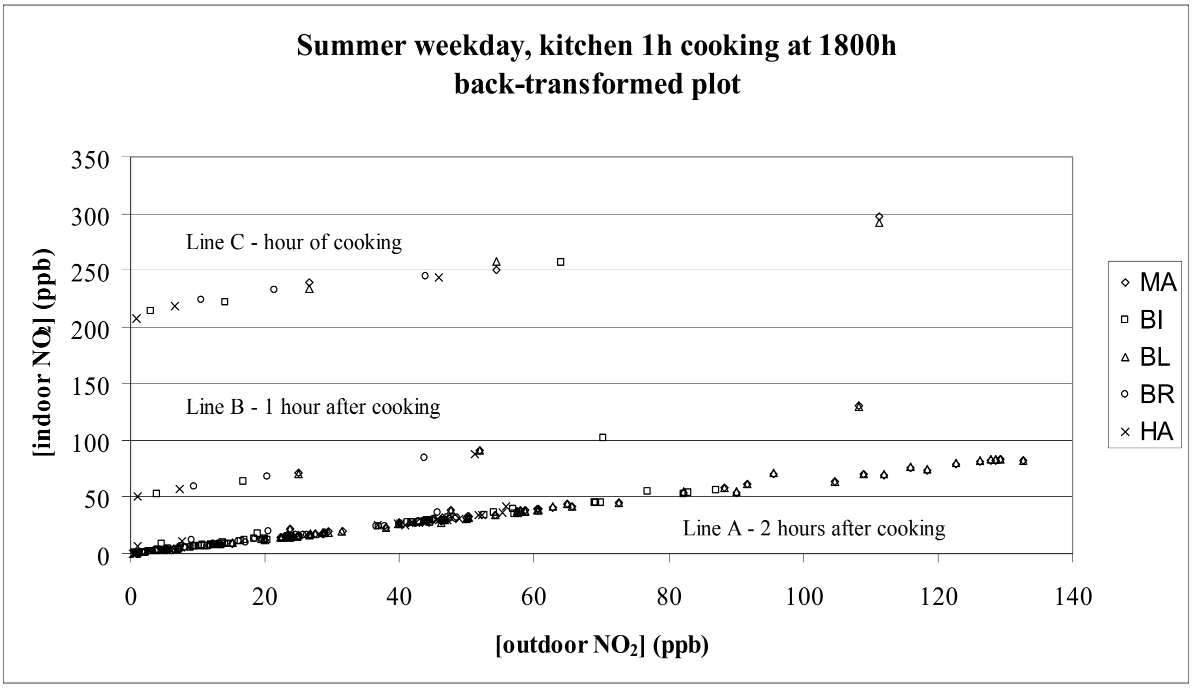

Figure 1. Relationship between indoor and outdoor NO_2 concentrations for 1 hour of cooking with gas at 1800h.The parallel lines represent different lengths of time after cooking.
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network monitoring sites (MA = Marylebone Road; BI = Birmingham; BL = Bloomsbury; BR = Bradford; HA = Harwell). Mean indoor concentrations on the hour of cooking (line C) are raised by about 200 ppb, one hour after cooking (line B) by about 50 ppb and by the second hour after cooking (line A) are almost back to background levels of the no source runs.

The next step was to combine frequency distributions of 1000 iterations for no cooking, the hour of cooking, cooking 1h previously, cooking 2h previously etc. in proportion to the probabilities of each event derived from a national survey to create a new combined frequency distribution for each hour. The geometric mean and standard deviation of the fitted log-normal frequency distributions are for concentrations of each source pollutant above background (no source) concentrations. Values for cooking times of 15, 30, 45 and 60 minutes in the hour together with combinations of cooking times and the cooking hour/cooking 1h previously/2h previously etc. are then used as the input data to INDAIR-2 as a function of time of day for each room. The original INDAIR model was only parameterised to allow explicit physical simulations to be made for homes and offices. Therefore, the parameters for other microenvironments were derived from an analysis of measurement data from published and unpublished sources, after appropriate quality evaluation.

DEVELOPMENT OF THE EXPAIR MODEL

The previous version of the EXPAIR model considered outdoor concentrations from a single site, which was used to simulate population exposures from appropriate time-activity data. However, this approach assumed that all microenvironments (homes, schools, offices, etc.) have the same outdoor concentration, which is clearly inappropriate for complex urban environments and for modelling the effects of changes in roadside concentrations. The new EXPAIR-2 model allows simulations based on simultaneous outdoor concentration frequency distributions representing four types of roadside location within a city, instead of a single location. Population time-activity profiles for the EXPAIR model are already available for children, home workers, office workers and elderly people, based on UK census data [6] and a national survey of personal activity [7].

COMPARISON OF HOME EXPOSURE TO NO_2 IN BACKGROUND AND ROADSIDE LOCATIONS

To illustrate our modelling approach, Figure 2 presents a comparison of the modelled frequency distributions of NO_2 concentrations in the living room using geometric mean outdoor concentrations for two types of location. The outdoor concentrations represent the diurnal profiles of geometric mean summer weekday concentrations for (a) urban background locations (UB) in Leicester, based on data from the national network station which is located in a pedestrian precinct and (b) locations on busy roads (BR) with a high proportion of heavy goods vehicles, based on analysis of data from four roadside pollution monitors. In these particular simulations, no allowance is made for decrease of NO_2 concentration with increased distance of home frontages from the roadside. The INDAIR-2 simulations of exposure frequency distribution only consider cooking, as INDAIR simulations, consistent with measurement studies in the UK, show little significant effect of smoking on home NO_2 concentrations. Contributions to indoor NO_2 concentrations from cooking were generated by combining five individual INDAIR-2 runs using frequency distributions with combined cooking times of 15 and 30 minutes and 45 and 60 minutes both for the hour of cooking and for the hour after cooking, and for no cooking activity. Outputs from these five categories of INDAIR-2 runs were then combined in proportion to the time activity profiles for cooking with gas for homemakers for each 15 min time-step throughout the day.

Figure 2 shows that the mean indoor concentrations of NO_2 are lower than the respective outdoor concentrations for both urban background and busy road sites, but most notably for the latter more polluted site. However, the effects of NO_2 emissions from gas cooking activity based NO_2 sources can clearly be seen superimposed on the diurnal indoor concentrations around the main meal times of breakfast, lunch, and in particular, evening meal when cooking times are generally longer. The peaks of cooking activity are reflected in the indoor concentrations based on the 95 percentile outdoor concentrations with values generally double those based on the outdoor geometric means.

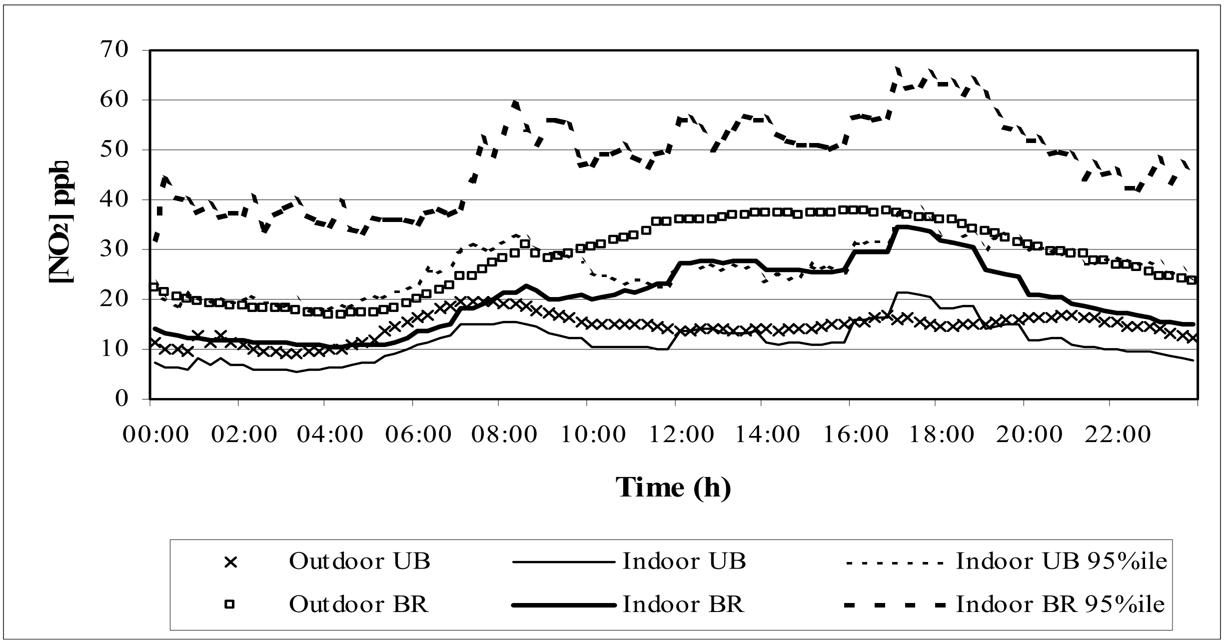

Figure 2. Diurnal profiles of indoor NO_2 concentrations in the lounge with geometric mean and 95 percentile outdoor concentrations typical of urban background (UB) and busy roadside (BR) sites. Indoor concentrations include NO_2 from cooking sources based on time activity profiles for homemakers.

DISCUSSION

This paper has described part of the methodological approach to the development of a modelling tool that can play an important role in interpreting population-based epidemiological studies of the health impacts of traffic related air pollution and in quantifying the benefits of reducing roadside air pollution in terms of the frequency distribution of personal exposure in an urban population. To meet these objectives, the

INDAIR model has been substantially recoded and the EXPAIR model has been enhanced to allow four types of roadside location to be modelled rather than a single one. The fact that the model aims to simulate probabilistically exposures within a population raises some important issues in terms of model validation. While the INDAIR/EXPAIR framework produces results for individual microenvironments and exposures that are consistent with measured values in the UK, there have been no large-scale measurements studies of the distribution of personal exposures within UK cities against which the modelling framework can be evaluated.

The new INDAIR/EXPAIR-2 modelling framework is not designed to simulate particular locations and individuals, with specific traffic flow characteristics, pollution dispersion, indoor characteristics or activity profiles. Its unique feature is the ability to assess personal exposure patterns across a whole city, for which such detailed location and individual data is simply not available. By considering traffic flows and air pollution concentrations, microenvironments and activity patterns in terms of limited numbers of broad types, within all of which air pollution concentrations and exposures are treated as frequency distributions, new insights will be provided on the impact of a wider range of policy interventions on personal exposure and health impacts within a city.

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