Available online at www.sciencedirect.com
ScienceDirect
Atmospheric Environment 40 (2006) 6362–6379
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

INDAIR: A probabilistic model of indoor air pollution in UK homes

C. Dimitroulopoulou[a,1], M.R. Ashmore[b,*], M.T.R. Hill[b,2], M.A. Byrne[c], R. Kinnersley[d,3]

[a]T.H Huxley School of Environment, Earth Sciences and Engineering, Imperial College, London, UK
[b]Department of Geography and Environmental Science, University of Bradford, West Yorkshire, UK
[c]Department of Physics, National University of Ireland, Galway, Ireland
[d]Division of Environmental Health and Risk Management, University of Birmingham, Birmingham, UK

Received 6 September 2005; received in revised form 9 May 2006; accepted 16 May 2006

Abstract

A probabilistic model (INDAIR) has been developed to predict air pollutant concentrations in home microenvironments in the UK. The model has been parameterised using probability functions for four pollutants simultaneously (NO_2, CO, PM_{10} and $PM_{2.5}$), under three emission scenarios (no source, cooking, smoking). Model predictions are broadly consistent with data on indoor concentrations in UK homes. Modelled mean concentrations were most sensitive to variation in outdoor concentrations, air exchange rate and deposition velocity in no-source scenarios, while modelled peak concentrations in source rooms were most sensitive to variation in emission rate and room size. Under model assumptions, smoking and cooking made a significant contribution to annual mean indoor concentrations of PM_{10} and $PM_{2.5}$, gas cooking made a significant contribution to annual mean indoor NO_2 concentrations, while annual mean CO concentrations were dominated by infiltration of outdoor air. The modelled frequency distributions of 24 h mean values showed 95 percentile concentrations that were typically twice the mean concentrations in no-source scenarios, and 3–4 times the mean concentration during emission peaks. The higher exposure of residents in homes at the upper ends of the frequency distributions may be associated with adverse health outcomes, and probabilistic modelling approaches can contribute to identification of the characteristics of homes with high indoor concentrations.

Keywords: Indoor air quality; Modelling; Carbon monoxide; Nitrogen dioxide; Particulate matter; PM_{10}; $PM_{2.5}$

1. Introduction

The major focus of public concern, and government policy, in terms of air pollution impacts on human health continues to be outdoor air. However, over the last two decades, indoor air quality has gradually received increasing concern due to the adverse effects that it may cause on human heath.

*Corresponding author. Present address: Environment Department, University of York, York YO10 5DD, UK.
Tel.: +44 2904 434070; fax: +44 1904 432998.
E-mail address: ma512@york.ac.uk (M.R. Ashmore).
[1]Present address: BRE Environment, Garston, Watford WD25 9XX, UK.
[2]Present address: Recycling Action Yorkshire, Green Sand Foundry, Leeds LS11 5QN, UK.
[3]Present address: Environment Agency, Solihull B92 7HX, UK.

1352-2310/$ - see front matter
doi:10.1016/j.atmosenv.2006.05.047

Its importance is recognised in Europe, and has been identified as an important element within the European Environment and Health Action Plan (CEC, 2004). The State of California had an active programme to reduce indoor air pollution for the last two decades, including a range of policy instruments (Waldman and Jenkins, 2004). In many developing countries, exposure to indoor air pollution causes a major health burden (Smith, 1993). It is increasingly recognised that air quality management needs to be considered within the wider framework of human exposure. Indoor exposure to pollutants of both indoor and outdoor origin is an important element of exposure assessment due to the length of time spent indoors (typically 80–90% in western Europe and North America), and especially in the home (McCurdy et al., 2000; ECA, 2003).

In the UK, the National Air Quality Strategy only regulates outdoor air pollutants and their sources. Over recent years, important steps had been made towards setting indoor air quality standards and guidelines in the UK (e.g., Short, 2001). Recently, the UK Department of Health Committee on the Medical Effects of Air Pollutants (COMEAP, 2004) launched a guidance document on the effects of indoor air pollutants. This document considers only the home indoor environment. It provides advice on how to minimise the production of pollutants indoors and, for the first time in the UK, recommends air quality guidelines for pollutants found in indoor air, including nitrogen dioxide (NO_2) and carbon monoxide (CO).

In the UK, as in other countries, there is a need for predictive models of indoor air pollutant concentrations to support national and local policy development. In the absence of indoor sources, indoor pollutant concentrations are lower than outdoors due to attenuation by buildings, but, in the presence of indoor sources, indoor air pollutant concentrations may well exceed the local outdoor levels. Hence, such models need to incorporate both the processes determining infiltration of outdoor-generated pollutants, and the emissions and fate of indoor-generated pollutants; this is particular important for pollutants such as CO, NO_2 and particulates, for which there are both significant indoor and outdoor sources. For national policy assessment, these models also need to evaluate not only mean concentrations, but also the variation in concentrations experienced within the national housing stock.

Microenvironmental models to simulate indoor concentrations as a function of key building parameters (e.g., infiltration, ventilation), outdoor concentrations, indoor source strength and physical properties of the air pollutants (e.g., deposition, re-suspension) have been available since the mid-1980s. These models have taken a variety of forms and been used in a variety of applications (e.g., Nazaroff and Cass, 1986; Hayes, 1989; Koutrakis et al., 1992; Schneider et al., 1998; Kulmala et al., 1999; Chao and Tung, 2001; Fischer et al., 2002), as described by a recent review (Milner et al., 2005). Such models need to be fit for purpose; for example, although sophisticated modelling of air flow around buildings, penetration into buildings, and indoor transport are possible using CFD models (e.g., Chang et al., 2003), these are not appropriate for generic application in modelling indoor exposure across populations.

Most of these models consider only one pollutant and use a deterministic approach. In the context of generic assessment of indoor exposure, probabilistic models, which incorporate both the variation in building characteristics and the uncertainty in model parameterisation, provide a stronger basis for policy assessment than do deterministic models. Progress has been made towards such probabilistic modelling approaches. For example, Burke et al. (2001), as a part of a probabilistic exposure model, developed a probabilistic single compartment, steady-state mass-balance model for predicting 24 h mean $PM_{2.5}$ concentration in the home environment. However, there are no models of indoor air quality available for application in modelling population exposure, which combine the capacity for probabilistic modelling of particulate matter (PM) and gaseous pollutants simultaneously over short averaging times. This is particularly important when evaluating the significance of intermittent indoor sources in relation to the locations and exposures of populations at risk.

In a previous study (Dimitroulopoulou et al., 2001), we reported the results of a deterministic two-compartment model used to predict indoor and personal exposure of individuals to nitrogen dioxide (NO_2). Our aim in this study was to develop this previous deterministic model to a probabilistic indoor air model (INDAIR), which can predict the frequency distributions of concentrations of up to four air pollutants simultaneously (NO_2, CO, PM_{10}, $PM_{2.5}$). The INDAIR model was designed with the specific objective of providing inputs into a