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Occupant exposure to indoor air pollutants in modern European offices: An integrated modelling approach

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HIGHLIGHTS

- Hot summers can increase occupant exposure to harmful indoor air pollutants.
- Indoor ozone concentrations generally lower during early morning than late afternoon.
- Poor office ventilation may exacerbate occupant exposure to harmful indoor pollutants.
- Lower exposure to indoor pollutants for cleaners before rather than after office hours.
- Office workers benefit from lower exposure if cleaning performed after office hours.

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ABSTRACT

A new model (INDAIR-CHEM) has been developed by combining a detailed indoor air chemistry model with a physical and probabilistic multi-compartment indoor/outdoor air exposure model. The detailed indoor air chemistry model was used to produce a simplified chemistry scheme for INDAIR-CHEM, which performs well for key indoor air pollutants under a range of conditions when compared to the parent model. INDAIR-CHEM was used to compare indoor pollutant concentrations in naturally ventilated offices in 8 European cities for typical outdoor conditions in summer, with those experienced during the European heat-wave in August 2003 for different air exchange rates. We also investigated the effect of cleaning with limonene based products on the subsequent exposure to secondary reaction products from limonene degradation.

Extreme climatic conditions, such as a heat-wave which often leads to poor outdoor air quality, can increase personal exposure to both primary and secondary species indoors. Occupant exposure to indoor air pollutants may also be exacerbated by poor ventilation in offices. Reduced ventilation reduces maximum exposure to ozone, as there is less ingress from outdoors, but allows secondary species to persist indoors for much longer. The balance between these two processes may mean that cumulative exposures for office workers increase as ventilation decreases. Cleaning staff are at lower risk of exposure to secondary oxidation products if they clean before office hours rather than after office hours, since ozone is generally at lower outdoor (and hence indoor) concentrations during the early morning compared to late afternoon. However, from the viewpoint of office workers, reduced exposure would occur if cleaning was performed at the end of the working day.

1. Introduction

Many people, particularly in developed countries, spend their working days in offices. Consequently, the indoor air quality in these locations must be maintained to a high standard to avoid adverse impacts on health. Following the energy crisis in the 1970s, energy efficiency measures became more focused and adverse

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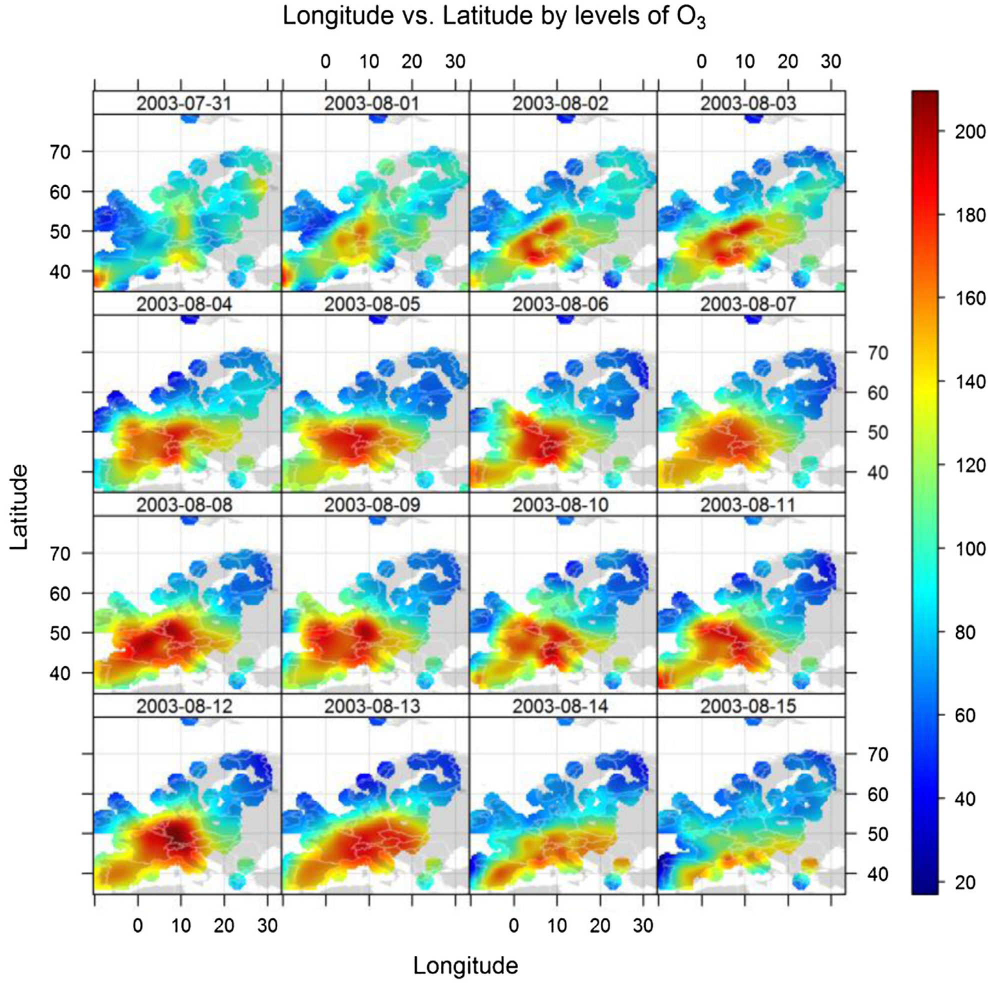

Fig. 1. Interpolated surface ozone concentrations (in ppb) across Europe during the heat-wave period in 2003 from July 31st to August 15th. The plot shows hour 15:00 GMT each day (when ozone concentrations are at or near peak values), from 417 Airbase (http://www.eea.europa.eu/themes/air/air-quality/map/airbase) rural monitoring sites.

health effects were more frequently reported indoors (Ashmore and Dimitroulopoulou, 2009). Questionnaire studies (e.g. Bluyssen et al., 1996; Brightman et al., 2008) show that the three most frequently reported symptoms in offices are tiredness, headaches and irritated, dry or itchy eyes (Wolkoff, 2013). It has been estimated that such building related symptoms (BRS) are responsible for a 2% reduction in productivity and consequent economic loss (Buchanan et al., 2008). The significance of indoor air quality for human health has also been recently recognised through the provision of guidelines for selected pollutants indoors (SCHER, 2007; WHO, 2010).

Ideally, it would be beneficial to measure the concentrations of all pollutants of concern in offices, and personal exposure of office workers to such pollutants. However, it is widely recognised that indoor air contains a wide mixture of pollutants, which are often chemically complex and extremely challenging to determine analytically. For this reason, models are often used to predict indoor air pollutant concentrations and exposure to them and to assess the benefits of measures to improve the office environment.

Exposure models for indoor air pollution have traditionally focused on primary pollutants (Dimitroulopoulou et al., 2006), although there is increasing evidence that secondary pollutants are more likely to cause health and comfort effects in office buildings (Carslaw et al., 2009). Conversely, whilst models of indoor air chemistry (e.g. Sarwar et al., 2002; Carslaw, 2007) elucidate key chemical degradation pathways indoors, they do not consider exposure to predicted pollutant concentrations.

This paper describes a new modelling package called INDAIR-CHEM, which utilises an existing indoor air exposure model and a detailed indoor air chemistry model, to provide a new approach to assessing exposure indoors to relevant pollutants indoors. INDAIR-CHEM links emissions of the major pollutants indoors (NO_x, ozone, primary VOCs and ultra-fine particles) to the concentrations of key secondary indoor pollutants with suspected adverse health effects.

In order to demonstrate the application of INDAIR-CHEM, the impact on office air quality and likely occupant exposure to harmful pollutants is quantified, for the 'heat-wave' summer of 2003 and a more average summer (2009). During the first half of August 2003 many parts of Europe were affected by a strong and persistent heat-wave, which resulted in record-breaking temperatures in many locations (WMO, 2003; WHO, 2004). The impacts of this heat-wave included a large number of excess deaths particularly in France (more than 15,000 people), but with 35,000 deaths across the whole of Europe (WHO, 2003; Stedman, 2004; Vandentorren et al., 2004). In the UK, over 2000 excess deaths were reported during the heat-wave period, with 400–800 of them directly attributed to poor air quality (ONS, 2003; Stedman, 2004). Such heat-waves are expected to become more common with further climate change (Beniston, 2004; Solomon et al., 2007). The measured ozone concentrations were extremely high over Europe during the heat-wave