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On the estimation of characteristic indoor air quality parameters using analytical and numerical methods

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Abstract

Indoor exposure to air contaminants penetrating from the outdoor environment depends on a number of key processes and parameters such as the ventilation rate, the geometric characteristics of the indoor environment, the outdoor concentration and the indoor removal mechanisms. In this study two alternative methods are used, an analytical and a numerical one, in order to study the time lag and the reduction of the variances of the indoor concentrations, and to estimate the deposition rate of the air contaminants in the indoor environment employing both indoor and outdoor measurements of air contaminants.

The analytical method is based on a solution of the mass balance equation involving an outdoor concentration pulse which varies sinusoidally with the time, while the numerical method involves the application of the MIAQ indoor air quality model assuming a triangular pulse. The ratio of the fluctuation of the indoor concentrations to the outdoor ones and the time lag were estimated for different values of the deposition velocity, the ventilation rate and the duration of the outdoor pulse.

Results have showed that the time lag between the indoor and outdoor concentrations is inversely proportional to the deposition and ventilation rates, while is proportional to the duration of the outdoor pulse. The decrease of the ventilation and the deposition rate results in a rapid decrement of the variance ratio of indoor to outdoor concentrations and to an increment of the variance ratio, respectively.

The methods presented here can be applied for gaseous species as well as for particulate matter. The nomograms and theoretical relationships that resulted from the simulation results and the analytical methods respectively were used in order to study indoor air phenomena. In particular they were used for the estimation of SO_2 deposition rate.

Implications of the studied parameters to exposure studies were estimated by calculating the ratio of the indoor exposure to the exposure outdoors. Limitations of the methods were explored by testing various scenarios which are usually met in the indoor environment. Strong indoor emissions, intense chemistry and varying ventilation rates (opening and closing of the windows) were found to radically influence the time lag and fluctuation ratios.

Keywords: Mass balance equation; Analytical solution; Deposition rates; Ventilation rate; Exposure; Indoor chemistry; Urban Aerosol

1. Introduction

During recent years, the understanding of the mechanisms that control indoor pollution is of increasing interest among the scientific community, as a result of the growing concern related to the effects of indoor

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exposure on human health (Jones, 1999). Indoor exposure to air contaminants, especially to those that penetrate from the outdoor environment, depends on a number of key processes and parameters such as the ventilation rate, the geometric characteristics of the indoor environment, the outdoor concentration and the indoor removal mechanisms. A number of theoretical models have been developed for the assessment of indoor air quality (Shair and Heitner, 1974; Nazaroff and Cass, 1987, 1989; Switzer and Ott, 1992). The basis of these models is the mass balance equation, which describes the relationship between sources emitting pollutants into an enclosed well-mixed compartment, the physical parameters of the compartment, and the pollutant concentrations as a function of time. Applications of theoretical models have led to useful conclusions regarding indoor air quality (Freijer and Bloemen, 2000).

One of the main indoor removal mechanisms results from the interactions between the pollutants and the fixed indoor surfaces (walls, floor), and is parameterized with the deposition velocity (Nazaroff and Cass, 1987), or the first order decay rate (Shair and Heitner, 1974). Deposition of a specific pollutant indoors depends on the material of the surfaces, indoor parameters related mainly to humidity and temperature, and the ratio of the indoor surfaces to the volume of the indoor environment (A/V ratio). Even though technologies exist to directly measure the deposition rate, they are often difficult to implement due to the large number of the contributing factors, or their cost. Thus many studies have focused on the determination of the deposition rates using experimental data of simultaneous indoor and outdoor measurements that are often available in indoor air quality studies and they are based on the application of the mass balance equation under specific assumptions (Jamriska and Morawska, 2003; Yang et al., 2003; Smolik et al., 2005; He et al., 2005; Thatcher and Layton, 1995; Thatcher et al., 2003).

On the other hand, a number of specific parameters concerning indoor pollution still remain unclear. One of the above parameters is the time lag between indoor concentrations and outdoors when a rise of outdoor concentrations is detected. A time lag of this type is often observed in experimental data and has been regularly reported (Zhu et al., 2005; Hussein et al., 2005; Morawska et al., 2001; Koponen et al., 2001; Jones et al., 2000; Freijer and Bloemen, 2000; Ekberg, 1996) but not studied in detail. Another aspect that has been rarely studied is the "smoothing" of the indoor concentrations, i.e. the reduction of the fluctuation of the indoor concentrations compared with the respective outdoor values (Freijer and Bloemen, 2000). This particular aspect of the indoor environment was employed in order to theoretically deduce the ventilation rate between the indoor and outdoor environment for a totally inert pollutant (Switzer and Ott, 1992).

Time lag and indoor to outdoor fluctuation reduction have been recognized and extensively studied in other fields of building physics, with respect to thermal comfort (Yam et al., 2003), but their influence on indoor air quality with respect to indoor pollution has not been explicitly described. The objective of this work was to demonstrate two methods, an analytical and a numerical one, in order to study the time lag and the fluctuation reduction of the concentrations in the indoor environment. The differences between the two methods were explored with the aid of statistical methods. A second goal was to utilize the results of both methods in order to create nomograms and theoretical relationships that can be used in order to describe indoor air phenomena and estimate the deposition rates in the indoor environment. The methods were applied to a dataset obtained from the Urban Aerosol project in order to estimate the indoor deposition rate of sulphur dioxide in a one room apartment. The significance of the studied parameters was examined from the exposure assessment perspective.

2. Numerical approach

The numerical method involved an application of the indoor air quality model MIAQ (Multichamber Indoor Air Quality model), which has been used in indoor air studies (Nazaroff and Cass, 1987, 1989; Drakou et al., 1998). MIAQ is a general mathematical model for both indoor aerosol dynamics and the concentrations of chemically reactive compounds in indoor air. It accounts for the effects of ventilation, filtration, direct emission, deposition onto surfaces, and coagulation for particles. It also accounts for heterogeneous removal, and photolytic and thermal chemical reactions

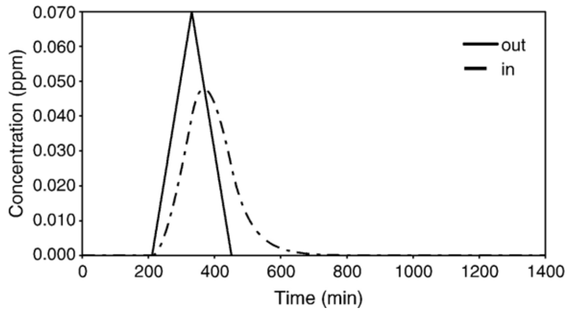

Fig. 1. Time evolution of the indoor concentrations, given by the MIAQ model, along with the outdoor concentrations.