CONNECTION BETWEEN ULTRA-FINE AEROSOLS INDOORS AND OUTDOORS IN AN OFFICE ENVIRONMENT

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ABSTRACT

Measurement campaign was conducted in a controlled office environment during January 1999 to get indoor/outdoor ratio for particles less than 0.5 micrometers in diameter. Aerosol concentrations for diameters between 7-500 nanometers were measured simultaneously indoors and outdoors with two DMPS systems. Other continuously measured quantities included temperature, ventilation rate, relative humidity, air pressure and four inorganic gases (SO_2, NO, NO_x and O_3). The measured room was practically airtight and had a mechanical ventilation system. A model that incorporates both aerosol dynamics and indoor air parameters has also been created to both analyse the data and test the effect of different indoor parameters to the aerosol concentration and surface accumulation.

KEYWORDS: particle size distribution, office building, indoor/outdoor ratio, aerosol, modelling

INTRODUCTION

Recent studies suggest correlation between number concentration of ultra-fine aerosols outdoors and adverse health effects. These studies correlate the concentration of a centrally located measurement site and the health effects of population on surrounding area. People spend however very little of their time generally in outdoors, so the observed effect of outdoor particulate pollution could be a result of pollutant transport from outdoors to indoors. The relationship between outdoor and indoor particle concentration is important to determine the actual dose of the general population.

METHODS

Measurements of indoor concentrations

The measurements were concentrated on aerosol number concentrations, but many other parameters and pollutants were also measured in both indoors and outdoors. Measurement period was from 7th of January to 1st of February 1999. The measurements took place in an office room and on the rooftop near ventilation inlet point. The measurement location was chosen to be an office for several reasons: (1) the pollution levels are usually highest during the working hours when large portion of people are inside office buildings; (2) largest pollution concentrations are often detected in dense urban areas, where offices are common; (3) offices have usually good ventilation system, which makes the approximation of ventilation parameters in analysis easy; (4) offices do not seem to have many sources for aerosols of the measured size range (diameter 7-500 nm); (5) office buildings are usually

well-maintained and (6) the activities inside the office were easier to control than in residential building. The measurement site was in central Helsinki (Pasila) in a large governmental office building near heavily used traffic lines and other office and residential buildings. The roof measurement point was approximately 30 m above the street level. The VOC samples were taken from the outside and office air directly. [6][7]
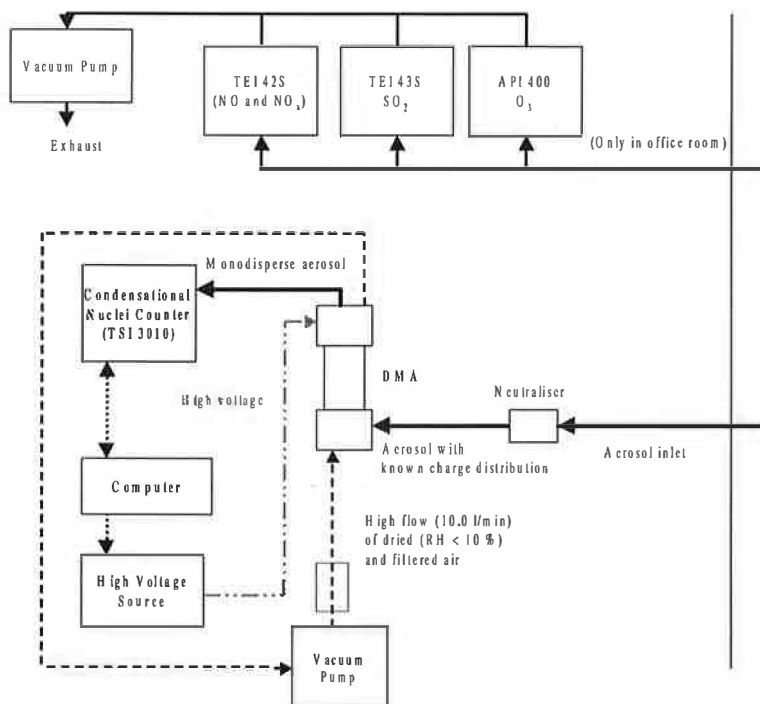

Figure 1. Measurement set up

The aerosol size distribution measurement instrument was Differential Mobility Particle Sizer (DMPS) [1]. The instrument separates the aerosols by the electrical mobility of different sized aerosols. The separated, almost monodisperse, aerosols are counted using condensational nuclei counter (CNC). By changing the voltage in differential mobility analyser (DMA) in DMPS different sizes of aerosols can be extracted and thus the aerosol size spectrum is obtained. In these measurements the size spectrum was obtained from around 7nm (0.007 μm) to 500nm (0.5 μm) with the time resolution of 10 minutes. The specifications of measurement devices are on table 1. Both of the DMPS systems were carefully intercalibrated before and after measurements to make sure that both systems were as identical as possible. The results of the comparison tests were incorporated to the data analysis.

Concentrations of several inorganic gases were monitored continuously with commercial instruments. Nitrogen oxides were measured with a chemilunescence based instrument (TEI 42S, Thermo Environmental Instruments, Frankin, MA; USA). One measurement cycle consisted of measuring NO, NOx and background signal in succession. SO2 was measured with fluorescence based instrument (TEI 43S, Thermo Environmental Instruments, Frankin, MA; USA) and ozone with ultraviolet light absorption based instrument (API 400, San Diego ; USA). The instruments were carefully calibrated prior use.

Table 1. Specifications of DMPS- measurement instruments used in measurements

Item	DMPS1 (indoors)	DMPS2(outdoors)
DMA	"Vienna" type 28cm (1)	"Vienna" type 28cm (1)
CNC	TSI 3010	TSI 3010
Charger	Bipolar ^{55}Fe	Bipolar ^{147}Pm
Sample flow	1.0 l/min	1.0 l/min
Sheath flow	10.0 l/min	10.0 l/min
Number of channels	20	20
Diameter range	7-500 nm	7-500nm
Measurement cycle	10min	10min
Temperature & humidity control	Vaisala Humicap HMI 32	Vaisala Humicap HMI 32
High Voltage source	FUG 12500V	FUG 12500V
(1) see [5]		

Modelling of indoor concentrations

Measurements of indoor air concentrations give information of the measurement site during the measurement period. The information gained is not very useful without the ability to generalise them to be used in different environments. One method to increase the usefulness is modelling of the data with physically consistent models. Modelling of indoor air is often made by calculating the mass balance of the pollutants. For aerosols the modelled parameter is usually aerosol mass below some size limit, such as PM_{10}. In the case of number concentration and especially the size spectrum number concentration the situation is somewhat more difficult than basic mass balance calculations.

Modelling of indoor aerosol dynamics requires the use of some simplification to the aerosol composition. The aerosols used in our model are all composed of some very soluble material, similar in all aspects to sulphuric acid (H_2SO_4). There are several reasons for this simplification: (1) Nanometer scale aerosols in urban areas are often sourced from combustion and so they can have a significant water-sulphur content; (2) The chemical and physical properties of pure sulphuric acid particles are well known; (3) similar models have been successfully used for sulphuric acid-water particles in outdoor stratospheric and tropospheric situations.

All aerosols in the model are assumed to belong to one of discrete size (diameter) classes. In the current version of the model aerosols inside one class are identical in composition. Condensation rates are calculated using the continuum regime theory with additional corrections (see.[2]). The increase of the pollutant concentration results in immediate condensation of water into the particle due the high hygroscopicity of particles; the particles are assumed to always be in equilibrium with their surroundings. The actual calculation of concentration is done by calculating set of differential equations numerically. The equations to be solved are of form of differential equations in [2] and [3] with additional corrections from indoor environment such as indoor deposition based on [4] , re-emission, air flow rates, indoor sources and filtration.
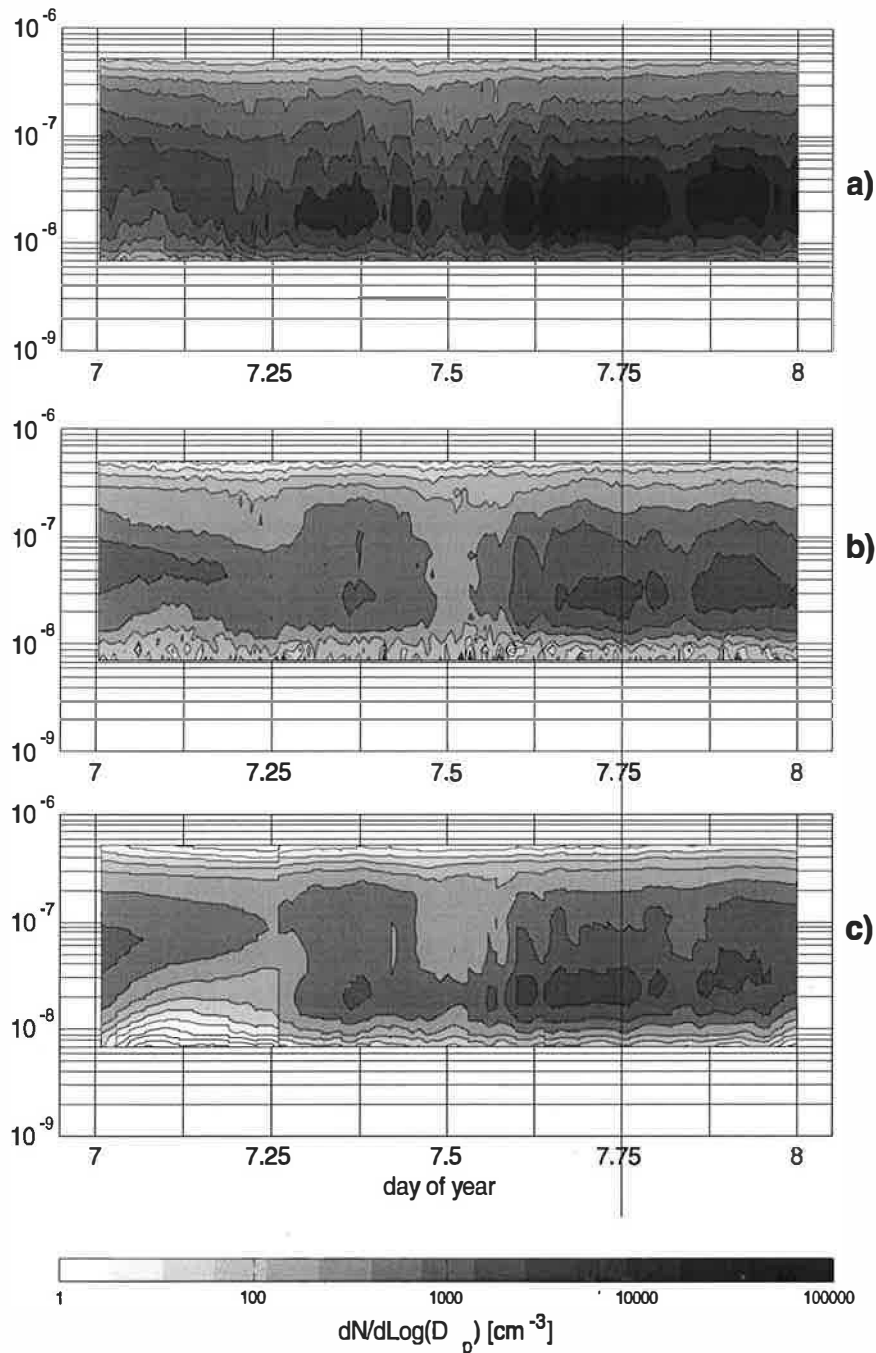
Figure 2. Example of measured and modelled aerosol particle data. X-axis is time (in days), y-axis is particle diameter (electrical mobility) and the darkness of the plot describes the concentration in channel per logarithmic channel width ($dN/Dlog(D_p)$). Fig. 2a) shows measured outdoor aerosol spectra from the roof of the building in 7th of January 1999. Fig. 2b) shows measured indoor size spectra in the same time scale. Fig. 2c) shows the modelled indoor size spectra from fig. 2a) with constant condensable vapour concentration of 10^7 sulphuric acid equivalent molecules per cubic centimeter. Line shows the time of spectra in figure 2.

RESULTS

The results indicate that due the absence of actual indoor sources for particles within measured room, indoor particle concentration followed the same trend as outdoor concentrations. However partly due filter properties and deposition the indoor/outdoor concentration ratio was not uniform in all particle sizes. Analysis of air samples showed that almost all analysed gaseous organic compounds were of indoor origin. The indoor/outdoor ratio (I/O ratio) of the total aerosol number concentration in the measured size interval was around 10% all of the measurement period. I/O ratios of different sized aerosols were not similar and the maximum of the ratio was usually encountered with aerosols of diameter greater than 90 nm. Fig 2 a)-b) show representative size distribution data of one of the measurement days. The outdoor concentrations were typically relatively low during the night-time. After 6:00 in the morning the aerosol number concentrations increased sharply to the range of 10^4-10^5 particles per cubic centimetre. The indoors clearly follows the outdoor concentration especially as the ventilation rate increases from around 0.3 h^{-1} night-time rate to around 3.5 h^{-1} in day time. The basic behaviour of the aerosol size distribution was similar in all working days. Weekends usually had lot smaller concentration in both outdoors and indoors. Statistical analysis showed sufficiently good correlation between combustion products (NO, NOx, indoor and outdoor particles between sizes of 25-500 nm). Indoor and outdoor particles under 25 nm of diameter did not correlate well with each other or with any other measured quantity.

Monitoring of the indoor inorganic gases proved to be a good addition to the aerosol measurements. Typically the concentration of SO2 increased in the morning as the ventilation went to daytime rate. The SO2 concentrations varied between 0.5 and 8.0 ppb. Ozone concentrations were usually near the detection limit of the instruments, but the a few episodes of increased concentrations to as far as 17ppb were observed. The NO and NOx behaved very similarly and they had a strong anticorrelation with ozone levels.

The results of model studies show a very good resemblance between measured indoor concentration and modelled concentration. In figure 2c) is one representative model run using the outdoor concentrations of fig. 2a). The model parameters were either directly measured or estimated on the basis of the knowledge of the office environment. The size distribution in 18:00 on the 7th of January is shown if figure 3. The results are preliminary, but show that the model gives reliable results in the known office environment.

CONCLUCIONS

The indoor measurements clearly show the importance of outdoor pollution for indoor air quality. The result is in good agreement with the observed health effects of outdoor pollution in the perspective of the fact that humans usually spend most of their time indoors. The results also indicate that indoor concentrations of ultra-fine aerosols are significantly lower in indoors, at least if the building is equipped with modern ventilation system.
With models such as the model used in this work, indoor concentrations can be relatively well approximated. Models can be used to analyse the effect of changes in indoor environment and different ventilation or air cleaning systems and the they can also be used to help the estimations of the pollution hazards to general population and the evaluation of epidemiological data.
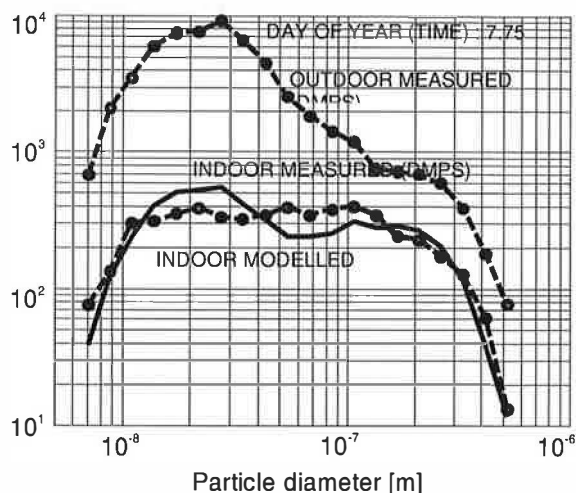
Figure 3. The concentration spectra of measured outdoor concentration, indoor concentration and modelled indoor concentration on the evening of 7th of January 1999 in the measurement room.

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