IAQ assessment in a large school of arts—worker exposure to fine particulate matter and VOCs

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ABSTRACT
The aim of this work was to assess the influence of the ambient air quality and some indoor sources on the concentration levels of airborne fine particles and volatile organic compounds in a large school of arts. Measurements were conducted, for both indoor and supply air, in eight office rooms in four floors controlled by four separate air handling units (AHU). Fine particle measurements by SMPS in the size range 15–700 nm indicate that the placement of the HVAC air feed points and different AHUs affect the total particle concentration and size distribution in the supply air. Concentrations of VOCs were not affected by the air handling unit. Instead, indoor VOC sources, such as paintwork classes, affected significantly the offices' VOC concentrations as well as indoor particle distributions. The location of offices within the school building and ventilation of offices affected indoor air quality attributes.

INDEX TERMS
Aerosol; Particle size distribution; VOCs; Indoor air quality; Art

INTRODUCTION
In art schools those who practise the art or otherwise work in shared facilities are exposed to a wide variety of the toxic properties of art material (Ryan *et al*., 2002). The materials used include highly volatile substances often hazardous to health. Even though steps have been taken to prevent the exposure with safe work practices and using less hazardous materials, the effectiveness of ventilation is still crucial in controlling the exposure via airways.

Indoor air quality (IAQ) in the buildings is strongly dependent on the ambient air in the surrounding atmosphere, pollution generated by indoor activities and by the smoothing effect which the mechanical ventilation system has on both (Rubino *et al*., 1998). There are also several studies that have consistently reported an association between fine particulate pollution and adverse health effects (e.g. Oberdörster, 2001).

The aim of this work was to assess the influence of the ambient air quality and some indoor sources on the concentration levels of airborne fine particles and volatile organic compounds (VOCs) in a large school of arts. The personnel had complained about the poor IAQ for several years before the measurements were made. The office rooms selected for this case study were rooms of those people who had complained of the most severe symptoms.

METHODS
The study building, a large 10-storied school of arts, is located near a ceramics factory. Aerosol measurements, in 10 offices, and VOC measurements, in eight offices, were conducted for both indoor and supply air. The rooms studied were located in four floors and were controlled by four separate air handling units (AHU). Three AHUs were located at the roof of the tenth floor (AHU 5, AHU 6 and AHU 23) and one AHU 23 was located at the second floor. At the same time, the outdoor particle concentrations were also measured with Electrical Low Pressure Impactor (ELPI) (Dekati Ltd) in the size range of 0.03–10.2 μm. Indoor particle concentrations and size distributions were measured using a Scanning

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Mobility Particle Sizer (SMPS) (TSI Inc.). For these measurements SMPS was set up to measure particles in the size range between 15 and 700 nm. In this paper, indoor total particle concentration refers to SMPS size range.

VOC samples were collected onto Tenax GR (Chromatography Research Supplies Inc.) adsorbent. Samples were analysed by an automatic thermal desorption system (Perkin Elmer ATD400) and a gas chromatograph (HP-GC 6890) equipped with a mass selective detector (HP-MSD 5973). Compounds were identified by retention times and GC-MS data library and quantitated as toluene equivalents.

RESULTS AND DISCUSSION

Particle measurements

The outdoor total particle concentrations and wind directions during the measurements are presented in Figure 1. The total particle concentrations were measured with ELPI near the air handling unit 23 (AHU 23) at the tenth floor.

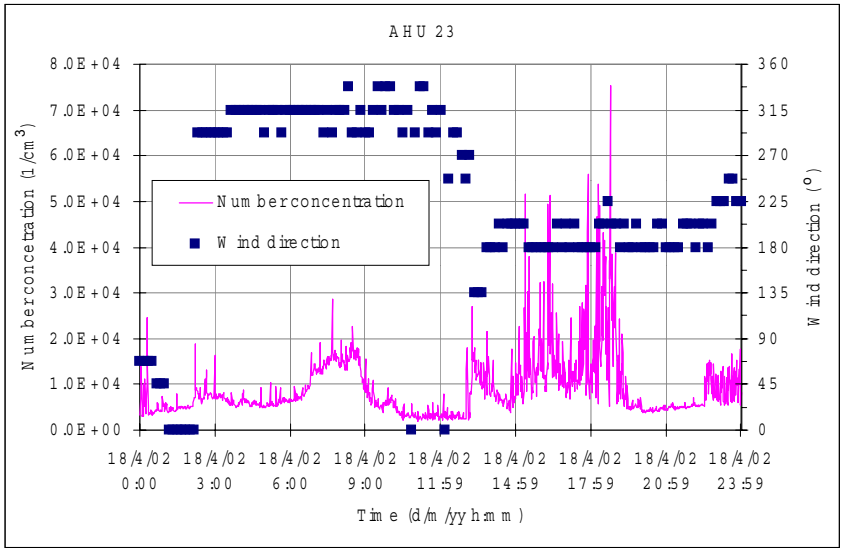

Figure 1 Outdoor particle concentration and wind direction measured near the AHU 23 air feed point.

The average outdoor particle concentration was ca. 9000 per cm^3 (range 1900–75 500 per cm^3). The particle concentration varied strongly depending on the wind direction (Figure 1). During the time range 1 pm to 7 pm, wind from south brings a high concentration of particles (average 14 800 per cm^3) to the measurement site. In earlier studies, the outdoor particle concentrations have been reported to be in the magnitude of 10^4 per cm^3 in the Helsinki area, Finland (Asmi, 2000; Ruuskanen *et al*., 2001).

Although the mechanical ventilation systems smooth the outdoor pollution effect, large fluctuations of outdoor particle concentration levels affect the supply air and thus the IAQ. Especially, if indoor air particle concentrations are measured transitorily, measuring outdoor particle concentrations is necessary in determining the sources of indoor particles and in evaluating the exposure to these contaminants.

Figure 2 represents the particle size distributions measured in four different offices controlled by different air handling units. The size distributions were measured by SMPS from the indoor and supply air of the offices.

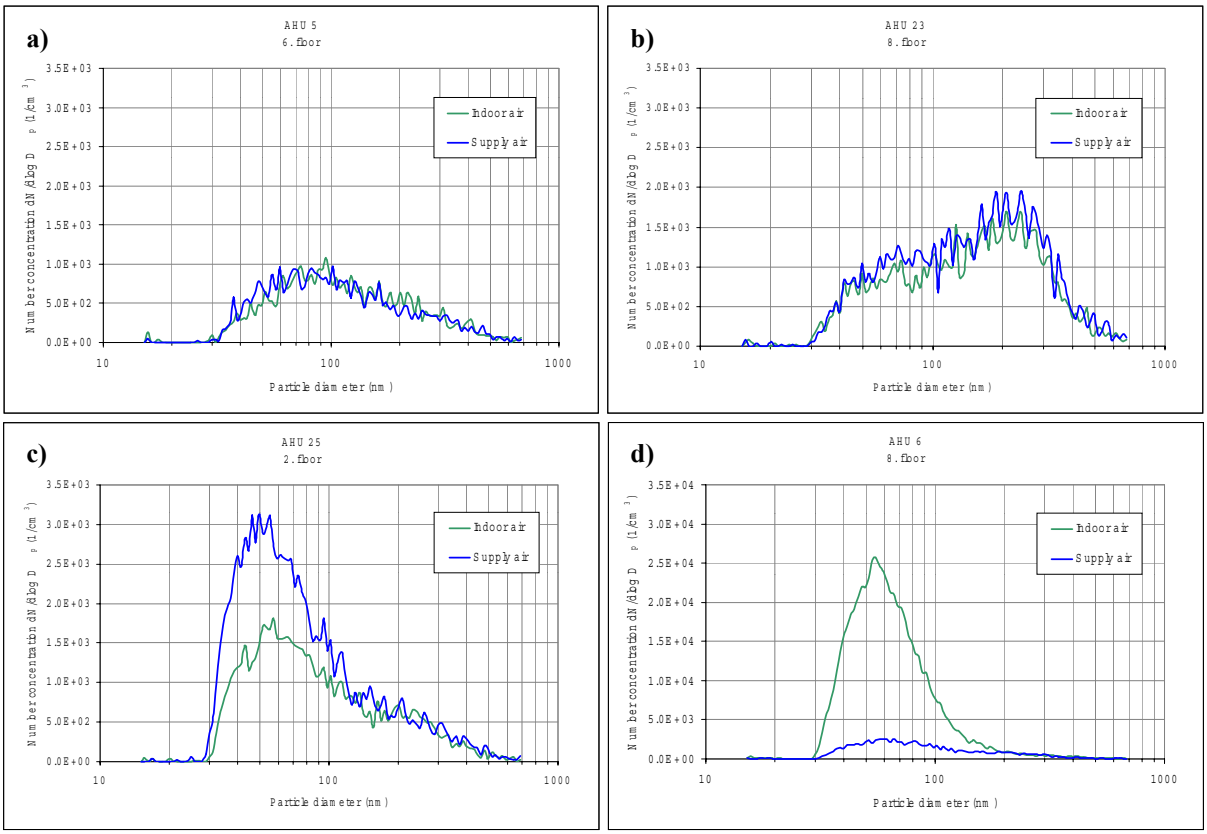

Figure 2 Particle size distributions measured in four different office rooms.

The size distribution presented in Figure 2a represents the typical effect of fine filter (F7) on the supply air particle size distributions (Hyttinen *et al*., 2003). Also, in our earlier measurements (data not shown) in the office buildings with mechanical ventilation, the peak of the particle size distribution and concentration typically vary between 50 and 200 nm and 500–2000 per cm^3. The bimodal size distributions, as shown in Figure 2b, have been measured in indoor air also in earlier studies (Morawska *et al*., 1998). The bimodal size distribution of the indoor air is usually a sign of several particle sources or of the ageing of the aerosol.

In this study, the size distributions measured from the supply and indoor air generally behaved similarly. The supply air particle distribution shown in Figure 2c was similar to the size distribution measured from the outdoor air. The concentration of particles is about half of the outdoor concentration. The higher particle concentrations in the supply air from AHU 25 can be explained with the use of a lower efficiency filter (F5) than in other AHUs. The supply air from AHU 6 to the room in Figure 2d has a similar distribution and concentration than, e.g. AHU 5. The indoor air particle concentration shown in Figure 2d was about tenfold compared to other measurement sites. The large number of ultrafine particles suggest the existence of an internal particle source within or near the office room. In this case, the proposed sources of the formation of fine particles are the chemical reactions between unsaturated VOCs (e.g. terpenes) and ozone. The concentration of terpenes measured in this room was over 400-fold compared to other rooms. The actively used shared laser printer was

also located in this room. Weschler and Shields (1999) have demonstrated that reactions between ozone and various terpenes can produce sub-micron particles in indoor settings.

Table 1 presents the average total particle concentrations for both supply and indoor air of the offices served by different AHUs. The air feed points of AHU 23 and AHU 25 were located nearest to the ceramic factory chimney stacks.

Table 1 The average total particle concentrations in office rooms served by different air handling units

Floor	AHU	Indoor air ($1/cm^3$)	Supply air ($1/cm^3$)
2^{nd} floor (n = 1)	25	1020	1580
6^{th} floor (n = 3)	5	720	650
7^{th} floor (n = 1)	5	940	470
8^{th} floor (n = 1)	6	9370	1410
8th floor (n = 2)	23	1010	1060

VOC measurements

The average VOC concentrations of the supply and indoor air measured in the office rooms are presented in Tables 2 and 3.

Table 2 The average VOC concentrations of the supply air in the rooms served by different air handling units

Compounds	AHU 23 8^{th} floor (n = 2) ($\mu g/m^3$)	AHU 6 8^{th} floor (n = 1) ($\mu g/m^3$)	AHU 5 7^{th} floor (n = 1) ($\mu g/m^3$)	AHU 5 6^{th} floor (n = 3) ($\mu g/m^3$)	AHU 25 2^{nd} floor (n = 1) ($\mu g/m^3$)
Aromatic hydrocarbons	11.7	19.1	9.8	23.2	9.3
Terpenes	0.7	12.0	1.2	1.4	–
Aliphatic hydrocarbons	2.3	5.7	5.4	4.7	2.9
Aldehydes	4.0	3.5	1.8	4.6	1.3
Cycloalkanes	–	0.6	–	–	–
Esters	–	0.3	–	0.6	–
Ketones	–	–	–	0.2	–
Alcohols	–	–	–	–	–
Ethers	–	–	–	–	–
Halocarbons	–	–	–	–	–
Acids	–	–	–	–	–
TVOC	20.5	54.7	20.7	40.7	18.4

–: Compounds not detected

Table 2 shows that VOC concentrations in office rooms were not significantly affected by incoming supply air in different AHUs.

Table 3 The average VOC concentrations of the indoor air in the rooms served by different air handling units

Compounds	AHU 23 8^{th} floor (n = 2) ($\mu g/m^3$)	AHU 6 8^{th} floor (n = 1) ($\mu g/m^3$)	AHU 5 7^{th} floor (n = 1) ($\mu g/m^3$)	AHU 5 6^{th} floor (n = 3) ($\mu g/m^3$)	AHU 25 2^{nd} floor (n = 1) ($\mu g/m^3$)
Aromatic hydrocarbons	21.2	408.3	31.9	22.6	17.8
Terpenes	2.1	1255.8	6.5	2.7	1.2
Aliphatic hydrocarbons	5.8	589.8	264.2	6.8	3.3

Aldehydes	4.7	4.7	4.4	6.3	–
Cycloalkanes	–	154.9	6.9	0.2	–
Esters	0.5	1.2	0.8	1.5	–
Ketones	–	64.9	–	0.3	–
Alcohols	6.3	3.1	–	–	–
Ethers	2.8	–	–	–	–
Halocarbons	–	1.1	–	0.1	0.3
Acids	0.7	–	–	–	–
TVOC	62.6	3167.3	326.5	56.6	28.0

–: Compounds not detected

The most abundant VOCs measured were aromatic hydrocarbons, terpenes, aliphatic hydrocarbons and aldehydes (Tables 2 and 3). The concentrations of the individual compounds were generally below 2 $\mu g/m^3$, except for one office room in the eighth floor controlled by AHU 6. Of the individual compounds, the concentrations of toluene (1–22 $\mu g/m^3$) and xylene (3–10 $\mu g/m^3$) were generallythe highest. In the seventh floor room (served by AHU 5), the concentrations of alkanes (3-methylhexane 144 $\mu g/m^3$ and heptane 93 $\mu g/m^3$) and aromatic hydrocarbons (toluene 22 $\mu g/m^3$) were exceptionally high. In the eighth floor (AHU 6) concentrations of terpenes (e.g. delta-3-carene 694 $\mu g/m^3$ and beta-pinene 225 $\mu g/m^3$), aromatic hydrocarbons (trimethylbenzene 125 $\mu g/m^3$ and ethylmethylbenzene 101 $\mu g/m^3$), aliphatic hydrocarbons (decane 176 $\mu g/m^3$ and nonane 117 $\mu g/m^3$) and cycloalkanes (propylcyclohexane 74 $\mu g/m^3$) differed remarkably from the concentrations of those in the other rooms. In both of these floors, art and craft studios were in active use during the measurements.

The VOC concentrations in and nearby art and craft studios may be very high, when these premises are actively used. Sometimes personnel offices are located near the class rooms, and if the transfer of VOCs from the art studios to personnel offices is not prevented, personnel may be exposed to strong airway irritants. These can be formed in chemical reactions between unsaturated VOCs, such as terpenes, and oxidants, such as ozone from printers and photocopy machines (Wolkoff and Nielsen, 2001).

CONCLUSION AND IMPLICATIONS

In this case study indoor particle concentrations and size distributions seemed to differ between the different air handling units and locations of offices within the school building. VOC concentrations in offices were significantly affected by indoor sources, such as the activity of art and craft studios, but also by the location of the building and the ventilation balances between the studios and office rooms.

These VOC measurements show clearly that it is important to control the transfer of VOCs from the emission site to adjacent rooms and areas with proper ventilation.

It is evident, as already stated by Sekher *et al*. (2002), that the large size of building and complexity of HVAC system hamper the extrapolation of the results of single measurement sites over the whole building. Also, in this study, it was clear that each floor and room had its own unique IAQ and ventilation characteristics.

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