CHEMICAL CONTAMINATION OF INDOOR AIR IN SCHOOLS AND OFFICE BUILDINGS IN MILAN, ITALY

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ABSTRACT

Air samples, collected indoors and outdoors from naturally ventilated schools and mechanically ventilated office buildings, were studied for: VOCs, formaldehyde, NO_2, particulate matter and fiber concentrations. Indoor inorganic contaminants were found to be directly related to outdoor pollution. Indoor VOC concentrations greatly exceeded the recommended values and the indoor/outdoor ratio ranged from 1 to 15. The presence of VOC was related to indoor emission sources represented by cleaning materials in schools and by carpeting and furnitures in office buildings. Results of the study indicate that mechanical ventilation system reduce the particulate matter, but does not affect the concentration of other contaminants with respect to outdoor air. Particularly in urban areas with high outdoor air pollution, HVAC systems should be designed to decrease the levels of all indoor pollutants.

INTRODUCTION

Pollutants in confined spaces may affect human health and worker productivity (1). Levels of indoor air contaminants are mainly influenced by building design, ventilation systems, human activities, and presence of indoor sources of emission such as carpeting, furniture, and combustion appliances. The relation of indoor air contamination to the presence of specific sources is of great interest, in order to plan remedial actions aimed at improving air quality in the buildings (2).

In this study, indoor air quality of naturally and mechanically ventilated buildings was assessed to characterize chemical indoor air pollution related to specific sources, and test the efficiency of the heating, ventilation, and air conditioning system (HVAC) to control the levels of indoor air contaminants.

MATERIALS AND METHODS

The investigation was carried out in wintertime in ten schools and seven office buildings located in the centre and in suburbs of Milan. Schools were naturally ventilated whereas offices were in buildings with HVAC system.

Schools included nurseries, kindergardens, primary and secondary schools : forty rooms with different use (class room, gymnasium, refectory and technical room) were selected and investigated. Eightyeight indoor environments (single offices, open spaces, refectory, meeting rooms and copy rooms) were selected and tested in office buildings. Thirtyeight air samples collected at different sections (core unit and distribution ducts) of the HVAC systems were also tested.

Air samples collected inside the buildings and outdoors were analyzed to assess pollutants as follows :
Volatile Organic Compounds (VOCs) were captured on carbotrap tubes by means of active samplers at a constant flow of 15 ml/min for 300 min. Samples were thermically desorbed and analysed. Quantitative evaluation (total VOCs) was performed by GC/FID; samples showing high VOCs concentrations were re-analysed by GC/MS for qualitative evaluation.
Formaldehyde and other aldehydes were captured on DNPH-amberlite tubes by means of active samplers at a constant flow of 500 ml/min for 300 min. Samples were eluted with acidified methanol and analysed by HPLC equipped with a Diode Array detector.
NO_2 was sampled in water solution of N,N'-naphtilendiamine by means of passive samplers for 300 min and measured by spectrophotometric method.
Particulate matter < 10 μm (PM 10) was collected on membranes by means of active samplers equipped with Lippmann selector, at a constant flow of 2.4 l/min for 300 min. Cellulose nitrate membranes were conditioned before and after sampling and analysed by gravimetric method.
Mineral fibres were collected on membranes by active samplers at a constant flow of 1 l/min for 300 min. Membranes were diaphanized, treated with a specific solution and analysed by optical microscopy. Only asbestos fibres were considered and counted.
Information concerning indoor sources of pollutants were collected with a standardized form.

RESULTS

Data obtained in naturally and mechanically ventilated buildings are presented in tables 1 and 2. Table 1 shows the concentrations of VOCs and formaldehyde; since the distribution of values was not normal, the results are expressed as median and extremes. Table 2 shows the concentrations of particulate matter, NO_2 and asbestos; the values are expressed as means, SD and extremes.

School buildings. Indoor values of particulate matter (range 35-103 μg/m³), asbestos (range 0.5-1 ff/l) and NO_2 (range 60-296 μg/m³) were similar to outdoor levels. Indoor VOC concentration ranged from 5 to 13600 μg/m³; the indoor/outdoor ratio for the median concentration ranged from 1 to about 15. Indoor formaldehyde concentration ranged from 8 to 210 μg/m³; the indoor/outdoor ratio ranged from 3 to about 5.

Office buildings. Particulate matter (range 14-97 μg/m³) and NO_2 (range 38-388 μg/m³) concentrations were lower indoors. Asbestos levels were generally higher indoors (range 0.5-6.9 ff/l) than outdoors (ratio from 1 to about 3). Indoor VOC concentration ranged from 9 to 3610 μg/m³; the indoor/outdoor ratio was about 5. Indoor formaldehyde concentration ranged from 1.5 to 71 μg/m³; the indoor/outdoor ratio ranged from 0.5 to 3.
No correlation was observed between VOC concentrations and concentrations of any other contaminat in buildings.

Indoor VOC sources in school and office buildings were identified in wall and floor coatings, and furniture in offices and in residues of detergents and disinfectants in schools.
HVAC system. Particulate matter ranged from 16 to 273 μg/m³, asbestos fibres from 0.2 to 1.1 ff/l and NO_2 from 87 to 777 μg/m³. VOC concentrations ranged from 5 to 4560 μg/m³ and formaldehyde from 4 to 68 μg/m³.

DISCUSSION

This IAQ study was carried out in order to characterize the chemical pollution of indoor air of buildings with different use and with different ventilation systems. It was also of interest to evaluate the efficiency of HVAC system to control the levels of indoor air contaminants. HVAC system was found to reduce indoor concentrations of particulate matter (<10 μm), while indoor VOC concentrations were markedly higher than outdoor levels, also in the buildings with mechanical ventilation.

Indoor NO_2 concentration was strongly influenced by the elevated outdoor levels and indoor sources were not generally appreciable.

Unexpected findings concerned the extremely high VOC values found in schools, particularly in nurseries and kindergardens. Two principal patterns of chromatographic profiles were observed in these samples, characterized respectively by predominance of more and less volatile compounds (see figure 1).

In spite of a thorough search for indoor sources of emission, no important permanent sources of VOC were detected by inspection. GC-MS analysis of several samples showed a very wide spectrum of VOC compounds, inluding alkanes, aromatic hydrocarbons, some alkenes, alcohols, and aldehydes. The presence of compounds such as lemonene and other substances typically used in cleaning and detergent products suggested that these materials were the likely sources of indoor VOC contamination, particularly in nurseries.

We conclude that VOC concentrations exceeded the recommended guidelines in most cases (3), and were probably related to the presence of indoor emission sources either in the form of cleaning materials (schools) or of carpeting and furnitures (offices). The mechanical ventilation system was found to reduce the particulate matter, but as observed in other studies (4) the concentration of the other contaminants was not affected. Particularly in the urban areas with high outdoor pollution, the design of HVAC systems effective in decreasing the levels of all the indoor pollutants should be considered.

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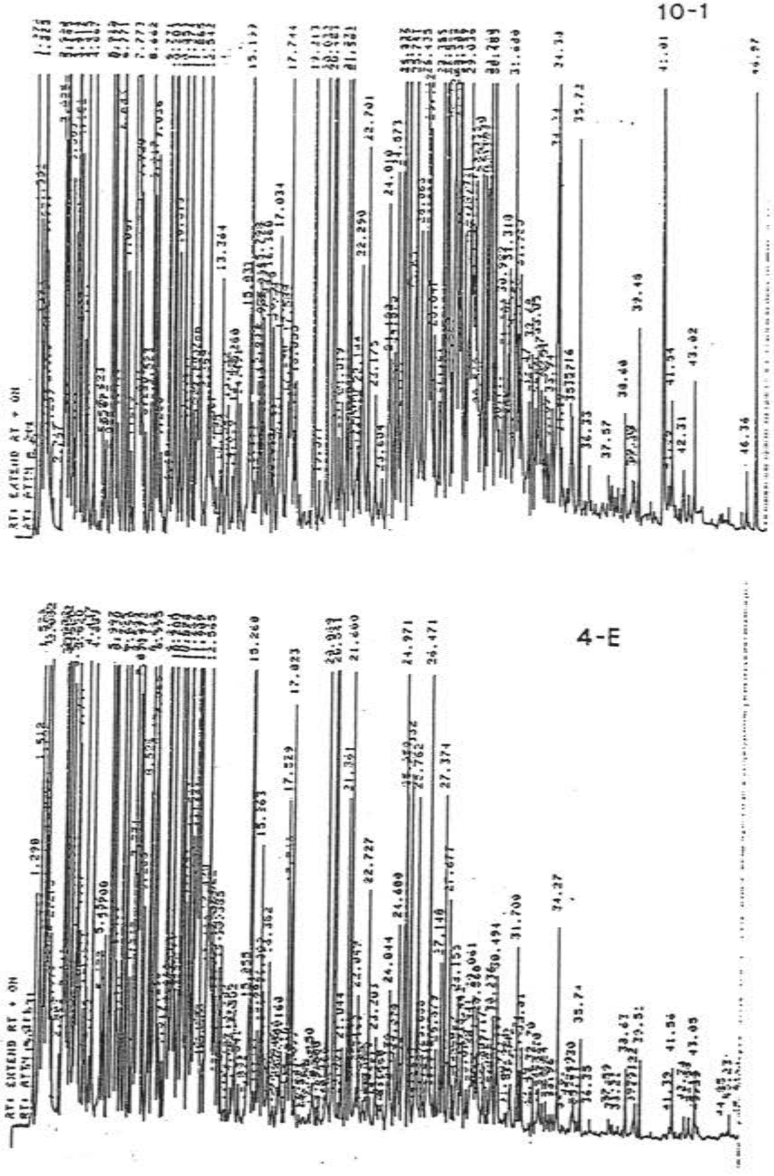

Figure 1. Chromatograms obtained with GC-FID in two different rooms of a school building.

Table 1. VOC and formaldehyde concentrations in office buildings and schools.

Building	No. samples in	No. samples out		VOCs ($\mu g/m^3$) indoor	VOCs ($\mu g/m^3$) outdoor	Formaldehyde ($\mu g/m^3$) indoor	Formaldehyde ($\mu g/m^3$) outdoor
Offices A	6	1	Median Min Max	260 59 3610	47 - -	63 35 71	23 - -
Offices B Rooms	19	16	Median Min Max	298 9 1591	324 98 3101	15.5 5 55	17.0 7 39
Offices B HVAC	23	16	Median Min Max	287 5 4560	324 98 3101	14.3 4 39	17.0 7 39
Offices C Rooms	63	16	Median Min Max	430 114 2855	488 86 1332	15.6 1.5 59.5	28.3 14.1 59.5
Offices C HVAC	15	2	Median Min Max	984 109 2508	1094 50 2138	33.2 6.5 67.6	12.7 2.5 23
Schools Nurseries + kindergardens	16	4	Median Min Max	3625 280 11300	270 100 1580	80 10.2 168	28 7 75
Schools Primary + secondary	24	6	Median Min Max	265 5 13600	220 23 1580	82 8 210	17 7 220

Offices B include 5 buildings managed by the same company.

Table 2. PM10, asbestos NO_2 concentrations in office buildings and schools.

Building	No. samples in	No. samples out		PM 10 (<10 μm) ($\mu g/m^3$) indoor	PM 10 (<10 μm) ($\mu g/m^3$) outdoor	Asbestos (ff/l) indoor	Asbestos (ff/l) outdoor	NO_2 ($\mu g/m^3$) indoor	NO_2 ($\mu g/m^3$) outdoor
Offices A	6	1	Mean SD min-max	32.0 10.2	54 - -	0.80 0.1	0.9 - -	166 14	138 - -
Offices B Rooms	26	16	Mean SD min-max	37.3 16.5 14-67	86 40 36-148	1.56 0.5 0.8-2.6	0.42 0.2 0.2-1.0	206 106 93-388	397 170 97-1900
Offices B HVAC	26	16	Mean SD min-max	40.8 19.7 16-72	86 40 36-148	0.42 0.2 0.2-1.1	0.42 0.2 0.2-1.0	214 160 93-777	397 170 97-1900
Offices C Rooms	63	16	Mean SD min-max	57.6 15.2 29-97	130.9 18 109-187	0.90 0.8 0.5-6.9	0.60 0.1 0.5-0.9	58.5 13.0 38-90	98.5 24.8 71-148
Offices C HVAC	15	2	Mean SD min-max	141.7 60.6 48-273	126.5 - 126-127	0.69 0.1 0.5-1.0	0.60 - 0.5-0.7	94 5.4 87-102	94.5 - 78-111
Schools Nurseries + kindergardens	16	4	Mean SD min-max	79.4 17.7 35-103	77 26.8 -	0.70 0.1 0.5-1.0	0.80 0.1 -	224 49 159-296	231 54 -
Schools Primary + secondary	24	6	Mean SD min-max	56.5 15.5 36-100	65.5 23.6 -	0.67 0.1 0.6-0.8	0.77 0.1 -	157 49 60-217	163 61 -

Offices B include 5 buildings managed by th any.