AIR POLLUTION SOURCES AND INDOOR AIR QUALITY IN SCHOOLS

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Pollution sources and indoor air quality were studied in ten schools. The investigation comprised a trained panel's evaluation of the air quality, physical, chemical and biological measurements and a questionnaire study of 602 students aged 14 to 16 years. The pollution from materials in the classroom and from the ventilation system totalled on the average (for six mechanically ventilated schools) one and a half times as much as the pollution from the occupants. A correlation was found between perceived air quality in decipol judged by the trained panel and the complaints from the students expressed by the prevalence of both mucosal irritation and general symptoms (headache, abnormal fatigue and malaise).

INTRODUCTION

Standards in most countries prescribe ventilation as outdoor air supply per person. This applies to schools also. The standards assume that people are the only sources of pollution. Fanger *et al.* (1) have documented in 15 office buildings that the building itself and even the ventilation system can be a major source of pollution, often much more important than the persons. These hitherto ignored pollution sources (hidden olfs) vary considerably from building to building. This variation in pollution sources is the probable reason why several field studies (2,3,4) found that the air quality varied much between schools although the ventilation rate per student was the same.

The aim of this field study is to quantify the pollution sources in schools. Furthermore the purpose is to relate the students' complaints and symptoms to physical, chemical, biological and sensory measurements of indoor air quality.

MATERIALS AND METHODS

The field study took place in ten schools in Greater Copenhagen. The schools were selected to represent a variety of building design and ages, ventilation systems and interior decorations. A population of 602 students aged 14 to 16 years (2-9 classrooms per school) was studied. Specifications for each school are given in table 1.

School	Floor area (m^2)	Volume (m^3)	Flooring	Mechanical ventilation	Age of building (yrs)	Time since last renovation (yrs)	Number of students
A	58	208	linoleum	exhaust/supply	19	4	33
B	62	211	linoleum	exhaust/supply	9	9	39
C	61	187	linoleum	exhaust/supply	24	>9	24
D	78	244	linoleum	exhaust/supply	18	2	52
E	55	255	linoleum	exhaust	8	4	52
F	66	201	needlefelt	exh./supply/recirculation	14	14	96
G	55	157	needlefelt	none	9	9	123
H	63	189	linoleum	none	20	2	74
I	72	219	linoleum	exh./supply/recirculation	17	1	56
J	62	185	needlefelt	exhaust/supply	13	3	53
Mean	63	206			15	6	60
							Σ=602

Table 1. Description of the ten classrooms.

One characteristic classroom in each school was visited three times by a panel trained to judge air quality like an average of the population. The visits took place while unoccupied and with no mechanical ventilation to quantify pollution sources in the classroom, Condition [1]; while unoccupied and with mechanical ventilation (if available) to determine pollution sources in the ventilation system, Condition [2]; and while normally occupied and ventilated to determine pollution caused by the students, Condition [3]. A panel of six hired students, 20 to 30 years old, was trained to evaluate the perceived air quality directly in the decipol unit by comparison to a reference gas (5). During the experimental period the panel was re-trained daily in a climate chamber. Before entering each building the panel judged the outdoor air quality.

In Condition [3] the air quality was also judged by the occupants in a questionnaire study. The student's questionnaire comprised questions about the instantaneous perception of indoor air quality, the frequency of school-related irritation of mucous membranes (eye, nose and/or throat) and general symptoms (*i.e.* headache, abnormal fatigue and/or malaise), and some personal data.

In each of the ten classrooms measurements were conducted of ventilation rates, carbon dioxide, airborne bacteria and microfungi, airborne dust, accumulated dust on the floor, immunogenic components (MOD) in the floor dust, total volatile organic compounds (TVOC), air temperature and air humidity.

The measurements were performed during a five-day period in March 1989, with the exception of the ventilation rates which were measured two months later under similar conditions.

The procedure in Condition [3] was as follows; having received instructions the students filled in the questionnaires during the last five minutes of a lesson. When they were properly started, the carbon dioxide concentration was measured. Then the panel entered the room, made its judgement, and immediately afterwards the equipment to measure airborne dust, bacteria and microfungi, TVOC, air temperature and air humidity was installed in the middle of the classroom and set to run (10 to 120 minutes depending on parameter). The students remained in the classroom during these measurements. Three or four schools a day were investigated. Measurements in Conditions [1] and [2] were performed the following weekend.

RESULTS

In table 2 is presented a survey of the results from the measurements in Condition [3], *i.e.* normal use. These results correspond to levels normally found in these kind of buildings. The measurements from the Conditons [1] and [2] with no occupants generally indicated lower levels as expected (not illustrated here). The outdoor climate during all the measurements was moderate and fairly stable.

		Mean	Max.	Min.
Outdoor air temperature	°C	5.2	7.3	4.3
Relative air humidity outdoors	%	77	90	59
Wind velocity	m/s	6	9	4
Air temperature in classroom	°C	21.6	23.5	19.5
Relative air humidity	%	36	44	27
Outdoor air change	h^{-1}	0.85	2.47	0
Outdoor air supply per person *)	l/s·p	5.5	10.0	1.5
Outdoor air supply per olf *)	l/s·olf	2.3	3.1	1.9
Carbon dioxide concentration **)	%	0.13	0.26	0.05
Airborne dust	mg/m^3	0.13	0.23	0.06
Airborne bacteria	cfu/m^3	519	1429	47
Airborne microfungi	cfu/m^3	51	193	3
Accumulated dust on the floor	$g/12m^2$	4.46	14.43	0.88
Macromolecular organic components (MOD) in the floor dust ***)	mg/g	2.30	5.86	0.55
Volatile organic compounds (tenax)	mg/m^3	0.31	0.53	0.19

Table 2. Mean values of measurements in Condition [3] (while normally occupied and ventilated) in the ten schools. *) In six mechanically ventilated schools (A, C, D, F, I and J). **) Concentration above the outdoor level. ***) Measured in six schools.

		Mean	Max.	Min.
<u>Pollution sources</u> *)				
Materials in space	olf/m^2	0.11	0.15	0.08
Ventilation system	olf/m^2	0.20	0.44	0.02
Occupants	olf/m^2	0.20	0.43	0.03
Total pollution load	olf/m^2	0.51	0.81	0.19
<u>Perceived air quality</u>				
Condition [1] - no occup. no ventilation	decipol	4.2	5.8	3.1
Condition [2] - no occup. mech. ventilation	decipol	2.9	4.4	1.8
Condition [3] - occup. normal ventilation	decipol	5.0	6.5	3.4
Outdoors	decipol	0.2	1.0	0

Table 3. Mean values of pollution sources and perceived air quality judged by the panel. *) In six mechanically ventilated schools (A, C, D, F, I and J).

The ventilation rate was moderate in most of the schools: in six of the mechanically ventilated schools (A, C, D, F, I and J) on an average 2.3 l/s per olf and 5.5 l/s per person. The pollution sources in these six schools (table 3) were calculated using Fanger's comfort equation (6), expressed in the new olf unit and normalized per m² floor area. In the other schools the outdoor air supply measured was low, which made the calculation of pollution sources rather uncertain.

In table 3 are also given the panel's judgements of the air quality in the different conditions.

The concentration of carbon dioxide was high in several of the schools, especially in the two naturally ventilated where the indoor air quality also in other aspects proved to be worse. In general it is recommended to keep the carbon dioxide concentration below 0.07% above outdoor level. The panel's dissatisfaction with the indoor air quality tended to increase with the concentration of carbon dioxide as shown in fig. 1 (Condition [3]).

The reported school-related symptoms were only categorized as symptoms if they occurred twice a week or more in school. The prevalence of these symptoms for each school is shown in fig. 2.

A statistically significant correlation (fig. 3) was found between the panel's judgement of the air quality and the school-related prevalence of mucosal irritation ($p<0.04$) and general symptoms ($p<0.003$) among the students. The panel's judgements in fig. 3 refer to the conditions with normal ventilation, but unoccupied. Weighted regression was used with respect to the number of students in each point. The relationship includes seven of the schools, while data were missing or previous campaigns for improved indoor environment biased the data for the other schools.

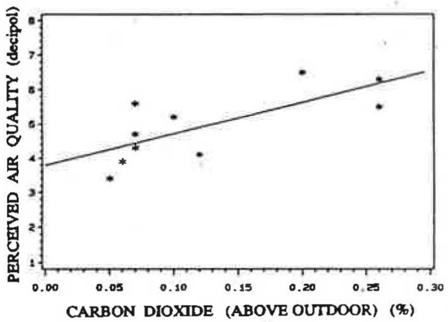

Figure 1. Relation between carbon dioxide concentration above outdoor level and perceived air quality in Condition [3]; normal use.

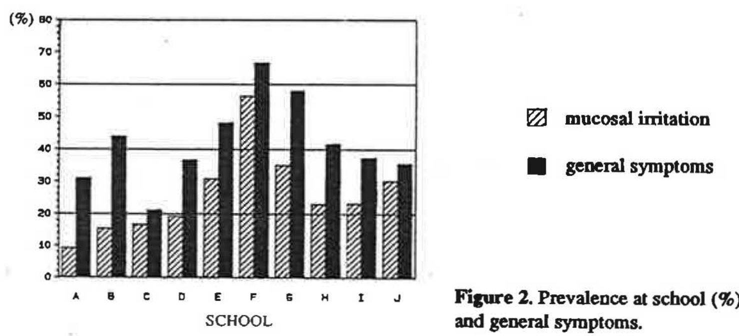

Figure 2. Prevalence at school (%) of mucosal irritation and general symptoms.

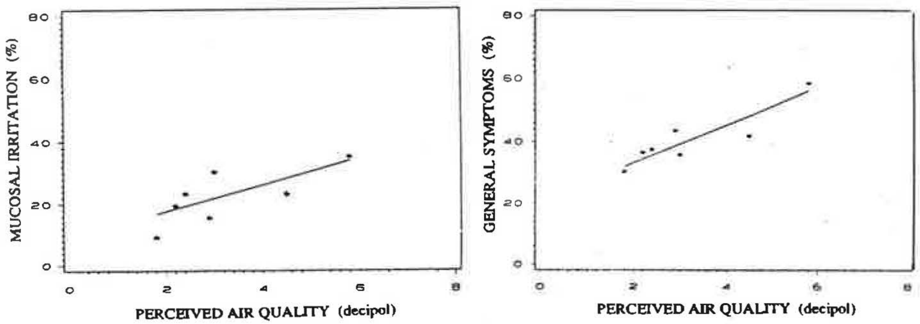

Figure 3. Correlations between perceived air quality, judged by the panel, and the prevalence at school of a) mucosal irritation and b) general symptoms among the students in seven of the schools (A, B, D and G-J).

Only the main results are reported here. During the analysis other observations were made, *e.g.* that the highest prevalence of mucosal irritation occurred in schools with needlefelt on the floors, where the floor dust contained larger amounts of immunogenic components and in more recently constructed buildings. Regarding general symptoms, a higher prevalence occured the newer the building was.

DISCUSSION

The results show a considerable variation between the schools; especially in the prevalence of symptoms among the students, but also in the physical and sensory measurements and in pollution load. The aim of this study was to identify the reasons for the differences in complaints from the occupants.

In six mechanically ventilated schools (A, C, D, F, I and J) materials in the classroom produced on average 20% of the perceived air pollution, 40% was caused by the ventilation system and 40% by the occupants. Because of low outdoor air supply, it was difficult to estimate the pollution sources in the remaining schools. The results imply, as for the offices (1), that the background pollution load from the building should be considered when modelling ventilation requirements; ventilation standards today assume that the occupants are the exclusive polluters of the indoor air.

Comparison between the independent panel's judgement of the air quality in decipol and the prevalence of symptoms among the students results in a significant correlation. This indicates that the prevalence of symptoms is related to the building factor.

The comfort equation used is based on the instantaneous perception of the air quality, when people (here: the panel) enter a room. Recent research has shown that humans adapt only slightly to irritants from building materials, while there is a considerable adaptation to human bioeffluents (7). In contrast to the panel, the occupants were therefore adapted to human bioeffluents, while none of the groups were adapted to the irritants from the building materials. This is why the best correlation (fig. 3) was established by relating occupant symptoms to the panel judgement in unoccupied, normally ventilated schools with no bioeffluents.

On an average the ventilation rate was only 2.3 l/s per olf for the six mechanically ventilated schools (A, C, D, F, I and J), with a small range of variation: 1.9 - 3.1 l/s per olf. If a room is to be regarded as acceptable corresponding to 80% satisfied every olf has to be ventilated by 7 l/s (6). Thus, the ventilation requirement is 2-3 times larger than the actual ventilation.

It is recommended in future renovation of schools to examine critically rooms and ventilation systems in order to find the pollution sources. A systematic removal or reduction of the hidden pollution sources (olfs) will result in an improved indoor air quality. When choosing materials high-polluting materials should be avoided.

CONCLUSIONS

- The pollution from materials in the classroom and from the ventilation system varied considerably from school to school with an average of 0.4 olf/m^2 or one and a half times as much as the pollution from the occupants (for six schools with mechanical ventilation).

- A correlation was found between perceived air quality in decipol judged by a trained panel and the complaints from the students expressed by the prevalence at school of both mucosal irritation (in eye, nose and/or throat) and general symptoms (*i.e.* headache, abnormal fatigue and/or malaise).

- The outdoor air supply was moderate: on an average 5.5 l/s per person and 2.3 l/s per olf (for six schools with mechanical ventilation).

- The low ventilation rates combined with the rather high pollution load hidden in the building explain the high prevalence of complaints in many of the schools.

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