Air Pollution Sources in Kindergartens

J. Pejtersen   G. Clausen   J. Sørensen   D. Quistgaard

G. Iwashita   Y. Zhang   T. Onishi   P.O. Fanger

ABSTRACT

Pollution sources were investigated in 10 kindergartens. Measurements in the kindergartens comprised sensory assessments of the air quality by a trained panel and measurements of air change as well as of thermal parameters and selected chemicals. Each kindergarten was visited three times: while unoccupied without mechanical ventilation to quantify pollution sources in the space, while unoccupied with the ventilation system in operation to quantify pollution sources in the ventilation system, and while normally occupied and ventilated to quantify the pollution caused by the children and their activities. The pollution load from the building itself in the 10 kindergartens ranged from 0.02 olf/(m² floor) to 0.74 olf/(m² floor) with an average of 0.39 olf/(m² floor). The average pollution load from the occupants was 0.38 olf/(m² floor). The average ventilation rate was 6.9 L/s per person but only 3.6 L/s per olf. The average pollution source strength of the 194 children in the kindergartens was 1.2 olfs per child. There is a significant potential for improving indoor air quality by reducing superfluous pollution sources in buildings.

INTRODUCTION

Several investigations have documented that compliance with existing ventilation standards does not guarantee good indoor air quality (Fanger et al. 1988; Valbjørn and Skov 1987; Woods et al. 1987; Finnegan et al. 1984). The standards are based on assumptions that are no longer valid. It is, for example, assumed that the building itself, including furniture and ventilation system, does not pollute the indoor air, and the required ventilation rate is, therefore, expressed in terms of L/s per person. However, numerous studies have shown that the building itself often contributes to the pollution of the indoor air (Fanger et al. 1988; Valbjørn and Skov 1987; Woods et al. 1987; Finnegan et al. 1984). The introduction of the sensory units, the olf and the decipol, made it possible to quantify all pollution sources (Fanger 1988). When determining the ventilation requirements of a building, it is important to consider all pollution sources, not only those of the occupants. Previous investigations have quantified the pollution load from materials, the ventilation system, and the occupants in offices (Fanger et al. 1988), assembly halls (Fanger et al. 1988), schools (Thorstensen et al. 1990), and bars (Pejtersen et al. 1988). The aim of the present study was to quantify all pollution sources in kindergartens.

METHOD

Experimental Design

A field study was performed in 10 kindergartens in the Copenhagen area. In each of the 10 kindergartens, two or three rooms occupied by children were selected. Each kindergarten was visited three times on three different days: while unoccupied without mechanical ventilation to quantify pollution sources in the space, while unoccupied with the ventilation system in operation to quantify pollution sources in the ventilation system, and while normally occupied and ventilated to quantify the pollution caused by the children and their activities. The investigation of these three conditions included assessments of the perceived air quality by a trained panel and measurements of concentrations of carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), and the thermal parameters—operative temperature, air temperature, relative humidity, and air velocity. The supply of outdoor air to the spaces was measured by the tracer gas technique.

Kindergartens

The 10 kindergartens were selected to represent a wide range of buildings in terms of age and building design. The age of the buildings varied from 2 to 100 hundred years with an average age of 25 years. Nine of the kindergartens were equipped with mechanical ventilation. On average, 24 children of three to six years occupied each kindergarten.

Sensory Panel

Eight women and five men ranging in age between 20 and 42 years (mean, 27 years) performed the sensory judgments. The judges were trained to evaluate the perceived air quality in decipols (Bluyssen et al. 1989). Before the field study, the judges had all received 10 hours of intensive training in a climate chamber. During a five-day period, they were trained to judge air quality in comparison to four known references of 1, 5, 10, and 20 decipols. The references were established using 2-propanone as the reference gas (Bluyssen et al. 1989). A calibration curve for the panel was obtained based on the panel's judgments of different concentrations of the reference gas.

Procedure

The field study was carried out in November 1990. The unoccupied spaces were visited on weekends, while the occupied spaces were visited on working days. In order to obtain steady-state conditions on the days when experiments were performed with the mechanical ventilation system in operation, the ventilation system was kept running during the night prior to the experiment. In the occupied building, the measurements were carried out several hours after the children had arrived. In the experiments carried out in the unoccupied spaces without mechanical ventilation, the ventilation system was turned off at least 12 hours prior to the measurements.

Each morning during the experiment, the sensory panel was given 90 minutes re-training in the climate chamber. After

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the training, the panel was transported to the first kindergarten. The panel visited each space in the kindergarten and assessed the air quality immediately after entering. Between the assessments, the judges went outdoors for two minutes to refresh their olfactory and chemical senses before continuing to the next space. The panel visited three to five kindergartens per day.

Just before the sensory evaluations, the concentrations of CO_2, CO, and TVOC were measured indoors and outdoors with a portable gas monitor based on infrared photoacoustic spectroscopy. The repeatability of the instrument was 1% of the measured value, and the instrument was calibrated with certified calibration gases. When the panel had left the rooms, the thermal parameters were measured. A few hours before or after the sensory assessments, the outdoor air supply to the spaces was measured with tracer gas using the constant concentration method. The number of children and adults was counted every 15 minutes.

RESULTS

In the occupied kindergartens, the air temperature ranged from 20.5 °C to 24.1 °C, the air velocity ranged between 0.06 and 0.13 m/s, and the relative humidity was between 35% and 52%. The concentrations of CO_2, CO, and TVOC above outdoor concentrations during occupancy are shown in Table 1. Also shown in the table are the operative temperatures and the outdoor air changes. All values are area-weighted means of the investigated spaces in each kindergarten. With a mean outdoor CO_2 concentration of 460 ppm, the measured CO_2 concentration exceeded the ASHRAE comfort limit of 1,000 ppm (ASHRAE 1989) in the majority of the kindergartens. As smoking was limited to designated smoking rooms, the measured CO concentrations were likely to originate from other sources than tobacco smoking.

The panel's assessments of the perceived air quality in the 10 kindergartens are shown in Figure 1. The values in the figure are area-weighted means of the investigated spaces above outdoor level. An estimated value of 0.3 decipol was used for the outdoor air quality based on assessments of the outdoor air quality in a previous field study in the Copenhagen area (Fanger et al. 1988).
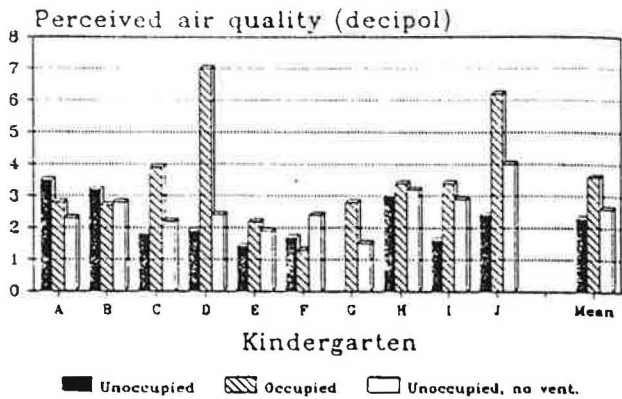

Figure 1 Perceived air quality above outdoor level for the 10 kindergartens

No significant correlation was found between the panel assessments of the perceived air quality and the concentrations of CO_2 and CO above outdoor level in the occupied spaces. Although a significant positive correlation was found between the perceived air quality and the relative humidity (F-test, P = 0.02) and between TVOC and the relative humidity (F-test, P = 0.04), no significant correlation was found between the perceived air quality and TVOC. There was a significant positive correlation between the perceived air quality and the operative temperature (F-test, P = 0.0001).

The pollution source strength was calculated from the perceived air quality and the supply of outdoor air by using the comfort equation (Fanger 1989):

$$C_i = C_o + 10 \cdot G/Q$$

where

C_i = perceived air quality in the space (decipol)
C_o = perceived air quality outdoors (decipol)
G = pollution source strength (olf)
Q = outdoor air supply (L/s).

The equation applies for steady-state conditions and complete mixing of the air.

TABLE 1
Physical Measurements for the 10 Occupied Kindergartens

Kinder-garten	ΔCO_2* [ppm]	ΔCO [ppm]	$\Delta TVOC$ [ppm]	Operative temperature [°C]	Air change [h⁻¹]
A	636	0.3	0.66	22.9	2.8
B	677	0.3	0.65	22.4	4.1
C	667	0.1	1.42	22.8	3.8
D	1316	0.0	1.63	23.2	2.1
E	455	0.0	0.97	20.7	2.8
F	852	0.5	0.51	21.6	2.1
G	2130	0.4	3.58	22.5	0.3
H	963	0.7	0.00	21.1	0.9
I	1014	0.9	5.18	22.7	2.2
J	917	0.2	0.98	23.7	2.6

*Δ: Concentration above outdoor level

Based on the three experimental conditions in the present study, the pollution load in each kindergarten was split into contributions from building materials and furniture, from the ventilation system, and from the occupants. The results are shown in Table 2. For comparison, the values are normalized with the floor area of the spaces. Also shown in the table is the outdoor air supply per person and per olf.

From the calculated pollution load caused by the occupants in eight of the ten kindergartens with a steady-state level of bioeffluents, the average source strength for the 194 children was calculated to be 1.2 olfs per child. In the calculations, the pollution generated by the adult staff was subtracted assuming a source strength of 1 olf per person. From the measured CO_2 concentrations, the outdoor air supply to the spaces, and the number of occupants and their average residence time, the average production rate of CO_2 per child was calculated to be 18 L CO_2 per hour corresponding to an activity level of 2.7 met.

DISCUSSION

The average pollution loads found in the investigated kindergartens are shown in Table 3 together with the pollution loads in other building categories found in previous investigations. In the kindergartens, the average pollution load from the building itself was 0.39 olf/(m² floor), while the average pollution load from the occupants was 0.38 olf/(m² floor). This means that for each occupant there was one hidden olf. The pollution load from materials was lower in the kindergartens than in the other building categories. An explanation for this could be that hard surfaces were used for floor covering and furniture in the kindergartens to facilitate cleaning. The pollution load from the ventilation systems was, on average, quite high in the kindergartens and larger than in the other building categories. It is obvious that there is a significant potential for improving the indoor air quality in some of the kindergartens by reducing the pollution sources in the ventilation system.

TABLE 2
Average Pollution Load in the 10 Kindergartens

Kinder-garten	Pollution load [olf/(m² floor)]				Ventilation rate	
	Materials	Venti-lation system	Occupants	Total	L/s per person	L/s per olf
A	0.18	0.56	0	0.50	7.8	3.7
B	0.14	0.36	0.57	1.02	11.8	3.8
C	0.07	0.21	0.87	1.16	8.4	2.5
D	0.06	0.22	0.75	1.03	4.0	1.4
E	0.06	0.25	0.19	0.50	9.5	4.6
F	0.02	0.22	0	0.18	3.9	8.0
G	0.02	*	**	0.06	***	***
H	0.04	0.16	**	0.24	***	***
I	0.05	0.25	0.23	0.52	5.8	2.9
J	0.06	0.63	0.41	1.08	3.6	1.6
Average	0.07	0.32	0.38	0.63	6.9	3.6

* Natural ventilation
** Not steady-state conditions
*** Data not available

TABLE 3
Pollution Load from Materials, Ventilation Systems, and Occupants for Different Building Categories

	Pollution load [olf/(m² floor)]		
	Material	Ventilation system	Occupants
Kindergartens	0.07	0.32	0.38
Schools	0.11	0.20	0.20
Offices	0.12	0.25	0.08
Assembly halls	0.32	0.28	0.11

The average pollution source strength of 1.2 olfs/child for the children at their natural activity level of approximately 3 met is quite remarkable. Although the weight of the children is only about one-fourth and their surface area only one-half the values of an adult, the pollution source strength is similar to the pollution source strength of adults. Similar results are found in a previous study of schoolchildren 14 to 16 years old, as shown in Table 4.

The average outdoor air supply of 6.9 L/s per person in the kindergartens was similar to the minimum supply rate of 8 L/s per person prescribed by ASHRAE (1989). When all pollution sources were considered, the outdoor air supply of 3.6 L/s per olf was clearly insufficient.

The applied method assumes that steady-state conditions are achieved. This is also the case in eight of the kindergartens with respect to the buildup of CO_2 from the persons. However, by changing the conditions of the ventilation system, the time for reaching steady state due to adsorption and desorption processes in the space might be lengthy. Further research is required to study the mechanism of the adsorption and desorption processes.

CONCLUSIONS

* The average pollution load in the 10 kindergartens was 0.07 olf/(m² floor) [range 0.02–0.18] from materials in the space, 0.32 olf/(m² floor) [range 0.16–0.63] from the ventilation system, and 0.38 olf/(m² floor) [range 0–0.89] from the children. There was an average of one hidden olf per child.
* The average pollution source strength of the 194 children three to six years old was 1.2 olf per child at their natural activity level of 2.7 met.
* The ventilation rate in the 10 kindergartens was, on average, 6.9 L/s per person and 3.6 L/s per olf.
* There is a significant potential for improvement of indoor air quality by decreasing superfluous pollution sources.

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TABLE 4
Activity Level, Production Rate, and Source Strength for Three Age Groups

	Activity level [met]	Production rate of CO_2 [L/h person]	Source strength [olf/person]
Children 3-6 years	2.7	18	1.2
School children 14-16 years (6)	1.2	23	1.3
Adults (1)	1.0	16	1.0