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Sick Buildings or Not: Indoor Air Quality and Health Problems in Schools

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Key Words

Indoor environment · Air quality · Sick Building Syndrome (SBS) · Measurements · Furnishing and materials · Particle implications

Abstract

Poor indoor air in schools has become a wide-spread problem with serious effects on occupant health. Resultant costs can be considerable at both local and national government levels. These include absenteeism and rehabilitation as well as building alterations and even demolition and rebuilding. This project aims to show factors contributing to health problems in Swedish schools. It includes a literature survey and particle measurements taken during various activities. Due to the fact that today there is no standard for indoor air quality (IAQ) in schools, in this project we used the outdoor air surrounding the building as an indicator. Results showed that indoor school environments had high airborne pollution levels, to a degree that probably causes health problems for many people. Regarding IAQ, this project shows the importance of taking into consideration choices in activities and furnishing of the building.

Introduction

During recent decades, poor indoor air quality (IAQ) has become a widespread problem in Swedish schools with health problems affecting occupants. Resultant costs can be considerable at both local and national government levels. These include absenteeism and rehabilitation as well as building alterations and even demolition and rebuilding. Symptoms that may be experienced by occupants are irritation of eyes, nose and neck, dry mucous membranes, skin rashes, tiredness, headache, and nausea. These symptoms are often described as Sick Building Syndrome (SBS). However, the terminology SBS is misleading since it is not a question of the construction materials themselves being sick, but more that a specific building is the focus of the problem. An appropriate division is:

1. *Nonspecific health effects symptoms;* meaning that people are affected by the above mentioned health problems while staying in a building or in a certain part of the building. The symptoms disappear shortly after leaving the building.
2. *Specific building-related health effects;* meaning that there are well-known building related factors causing health problems. Examples of this are increased levels of radon that are known to cause cancer, formaldehyde that presents a risk for its effect on the eyes and bacteria that contaminate fresh water [1].

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This project deals with *nonspecific health effects symptoms* and causes of health problems in humans. Emissions and airborne pollution in normal school environments were studied, excepting those where special activities such as handicrafts and chemistry were carried out. The aim was to study what influenced the number of particles in the indoor air and how a better air quality could be achieved. Particles can be carriers of negative health agents and the objective was to investigate:

- levels that can be found in the school environment
- the possibility of decreasing the particle concentration and the possibility of defining a reference level
- whether humidity levels indoors were high enough to be favorable for microbial development.

People inhale approximately 10,000 L of air in 24 h. In consequence we also inhale large quantities of airborne particulate matter including our own skin spores, other people's skin spores, the skin spores from animals and other dust from the environment, through both direct and indirect contacts [2]. Humans play a central role in indoor environmental issues whether the concern is air quality or comfort evaluation. In studying any indoor environment problem, it is most important, therefore, to clarify the relationship between the human body and the surrounding environment [3]. Results from one study [4] supported the hypothesis that among adolescent school children, an independent association exists between molds in floor dust and building-related symptoms. Similar associations were not found for moisture and mold growth in the buildings. Results show that different accommodation habits influence the indoor environment and that one cannot find connections between parameters that describe the patient's asthma disease and the indoor environment. On the other hand, indirect links have been demonstrated between different parameters in the indoor environment and between different symptoms of the patients and their families. The hypothesis that the homes of those allergic to molds contain more molds than the homes of other people when subjected to experiment has not been confirmed. It shows, however, that those patients with higher sensibility scores than the median value have twice as much contact with animals and animal owners in their homes than those with a low score. This contact contributes to a considerably increased content of allergen in the room and in the report, the importance of taking into consideration people's total environment is stressed [5]. This knowledge is useful when it comes to the occurrence of allergens from mite and domestic animals in rooms, schools and offices. A number of studies demonstrate that significant allergens also occur in environments where animal or mites do not occur. The allergen is carried with people from homes to schools and offices so that the concentrations, also in these environments, become sufficient to cause bronchial reaction [2]. Where people complain about the IAQ in a building thought to give rise to health problems, the combination of allergies and contacts with both domestic animals and smoking often occur. Material presented by Alsmo [6] was statistically incomplete since the number of people interviewed was limited and there was no control group, but results indicated connections between user-habits and health problems, in all cases where there were contacts with health-affecting environments that put susceptible people at risk.

Indoor Contaminants

The objective of this study was to demonstrate factors that influence air quality. In the workplace, in residential buildings and in other indoor environments, people are continuously exposed to different particulate pollutants. Both in the airborne form and when deposited on surfaces these pollutants can be harmful. Better tools for predicting particle dispersion and deposition, as well as more knowledge regarding exposure control need to be developed. The modern work environment and the way of working have changed with technical developments in our society. Better IAQ has been the aim and this is today an important measure of our development. The environmental requirements are now higher than they were when the traditional industrial ventilation concepts were developed. It is important for us to be able to predict the movements of contaminants in air and to find out how to minimize total exposure. The movements of passive contaminants such as gases are already quite well understood from an engineer's point of view and are not the topic of this investigation. To be able to solve the indoor environmental health and contamination problems, it is important to identify the potential sources of indoor particles, and size and typical particle concentrations in the air [7].

Micro-organisms

Results from earlier measurements [6] showed that the environment and the activities for which people used buildings influenced the micro-organisms in the indoor air. See Figure 1 for results from, on the one hand, a stable

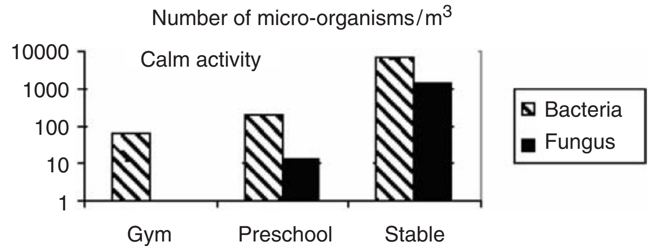

Fig. 1. Number of micro-organisms [6].

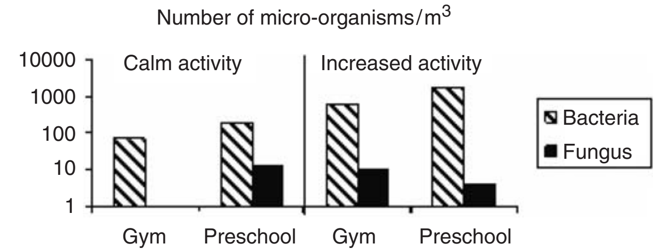

Fig. 2. Number of micro-organisms [6].

and on the other, a gym and pre-school. Micro-organisms found were:

- Bacteria: Gram positive cocci, Gram positive spore-forming rods, Gram positive nonspore- forming rods.
- Micro-fungi: *Penicillium* sp., *Cladosporium* sp., *Botrytis* sp., *Phoma* sp., *Trichoderma* sp., and *Ulocladium* sp. (sp. indicates that the micro-organisms are not species defined but only family specified).

An environment with animals is strongly microbial and gives high concentrations of both micro-fungi and bacteria. This indicated that choice of environment would have influenced IAQ. It was also apparent that activity influenced IAQ. Figure 2 shows results for the gym and preschool. In conclusion:

- Bacteria concentration was influenced by choice of environment and activity.
- Activity did not influence concentration of fungi.

Fungi, including molds, are disseminated through small spores. When these are airborne they can enter buildings in many ways, such as through ventilation systems, on clothing, equipment, or by daily intake of goods. The plentiful occurrence of fungi means people are unavoidably exposed to them. Of the approximately 100 000 species that are known to exist, approximately 30 are considered to be allergy-inducing. The common species in Sweden belong to the families *Cladosporium* and *Alternaria*. Of less importance are *Penicillium* and *Aspergillus*. Inhalation of spores from fungus can cause atopic allergy, but this is not usually a problem indoors. Exposure to high concentrations of fungal spores happens primarily in the air outdoors during the summer half-year [8].

Bacteria are a group of micro-organisms that propagate through division. In order to be transported in air, bacteria usually require a "dead" particle of a certain size as means of transportation. Bacteria of different types occur normally on people's skin. Bacterial flora comprises normally resident species that do not constitute any threat to people. They are a necessary component for the skin's total function. New bacteria that are continually transferred from the ambient environment to the skin are normally removed by competition with the resident organisms. People are major particle-spreaders. Quite naturally, hundreds of thousands of particles are shed from human beings every minute, particles of all sizes ranging from microscopically small particles to millimetre-large flakes and long hairs [9]. A particle's size and weight decide how long it remains airborne. In rooms with ventilation, where people are in motion, particles of some tens of microns in size may remain airborne for a considerable time.

Particles >5.0 and >10.0 μm

Airborne particles are often carriers of health-negative substances such as allergens and micro-organisms, including bacteria. They are often found on particles in the size range 5.0–10.0 μm [9–11]. Ordinary indoor activities, including walking and housekeeping, can cause re-suspension of settled particles, see Figure 3 [12]. Such activities may also generate new particles through abrasive wear of surfaces [13]. IAQ is strongly related to airborne particle concentration, size and chemical or biological composition. Airborne particulate pollutants have not yet been sufficiently investigated, however, it is well known that these are often conveyors of allergens. Particle pollutants often consist of substances from natural cycles, for example dust, pollen, fungi and bacteria.

Gaseous Air Pollutants

Gaseous air pollutants are considered of minor concern in this paper. Where research has been carried out during recent decades, these pollutants are often found but at low levels. If gaseous pollutants are present at a level that can affect health it has often been shown that this is a consequence of some process that is happening in the room, e.g., see [14]. This is often the case in discussions about individual volatile organic compounds (VOC) or the concentration of the total VOCs (TVOC). The concentration of an individual VOC or the TVOC varies strongly

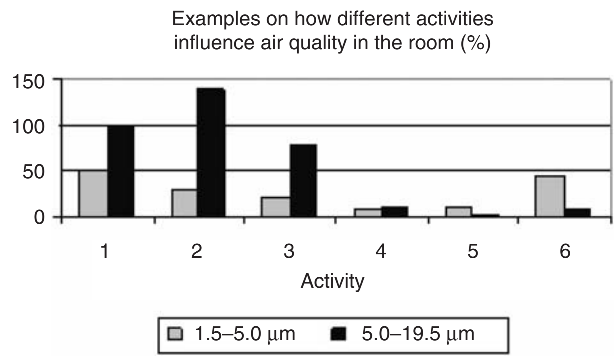

Fig. 3. Relative increase of dust particles in the air up during different activities [12]: Walking into the room; Sitting down on a sofa; Making the bed; Vacuuming, central suction; Vacuuming, with filters; and Vacuuming, without filters.

between times and rooms. Average values in Swedish homes and offices have been measured to vary between 10 and 1500 $\mu g \cdot m^{-3}$. Peeling an orange can mean that the concentration over several hours is increased by 100 times [2]. In reference [15] the conclusion is that it is difficult to find a correlation between health and results from VOC measurements, whatever their source. Formaldehyde is a VOC that normally is not counted as such because of the different techniques required to measure it. This substance is the best studied of the VOCs mainly because it can cause nasal irritation even at very low concentrations. A large number of sources of formaldehyde exist indoors including chipboard, clothing and tobacco-smoking [2]. The Swedish Work Environment Authority's level for formaldehyde is:

- 0.5 ppm for a threshold value, mean during an 8-h working day and
- 1.0 ppm for short time value, time weighted mean for 15 min. exposure [16].

1. Regarding carbon dioxide, a number of studies have been carried out showing that measured carbon dioxide levels in schools vary from 600 ppm to approximately 2000 ppm [17,18] (also: Runge P (2006) Alingsås's municipality, Personal commun.). Carbon dioxide is an odorless, colorless gas that normally occurs in the atmosphere with a concentration of approximately 0.0325% (325 ppm). In a city environment the concentration can reach 0.1%. A healthy person can tolerate up to 1–1.5% carbon dioxide for a long time with no other noticeable effect than increased respiration. Where people work in places with poor ventilation, problems can arise because of high carbon dioxide concentrations from the exhaled air [19] (Final Rule on Air Contaminants Project was remanded by the U.S. Circuit Court of Appeals and the limits are not currently in force). The Swedish Work Environment Authority's level for carbon dioxide is

- 0.5% (5000 ppm) for threshold value, mean during an 8-h working day at normal pressures and
- 1% (10 000 ppm) for short time value, time weighed mean for 15 min exposure [16].

Methods

In this project we investigated levels of airborne particles in typical Swedish schools. One important aspect was to find out whether it was possible to find a reference level for IAQ. This could, for example, be the air surrounding the building, so any difference between outdoor and indoor air quality was of interest. The measuring instruments used were the following.

1. For total airborne particles a laser diode-based portable instrument, Climet 4120 (Climet Instruments Co., Redlands, California) was used. The air sample was drawn through an inlet tube on the top of the unit by a pump at a rate of 1.0 cubic feet$\cdot min^{-1}$ (0.028 $m^3 \cdot min^{-1}$). The particles were sized and counted in four categories, >0.5, 5.0, 10.0, and 25.0 respectively [20]. Apart from particle diameter at the moment of measurement, no deeper study of the particle size was done in this project, even though the particles probably changed over time because of their inherent nature or through evaporative changes which would depend on temperature and humidity.
2. For micro-biological measurements a BIAP slit sampler (MBT AB, Malmo, Sweden) was used. Approximately 6 $m^3 h^{-1}$ air was sucked through a narrow column. Micro-biological constituents in the stream were collected on an underlying, rotating 14 cm Petri dish with damp agar (153 cm^2 surface area). For bacteria, Tryptic Soy Agar (TSA) was used and for micro-fungi, Malt Extract Agar (MEA). After sampling, the dishes were taken for analysis to a specialist laboratory. Petri dishes were incubated at 32°C (+/−2°C), for the bacteria and 20–25°C for the micro-fungi, they were incubated in darkness at a relative humidity between 30 and 50%. Viable micro-organisms quickly grew by division and after a few days it was possible to see the colony-forming units. The first examination was after 2–4 days and the last one after 7 days for bacteria and 10 days for micro-fungi. [6,9,21]. The micro-biological measurements of school environments were complemented with measurements taken similarly in a "normal standard" apartment.

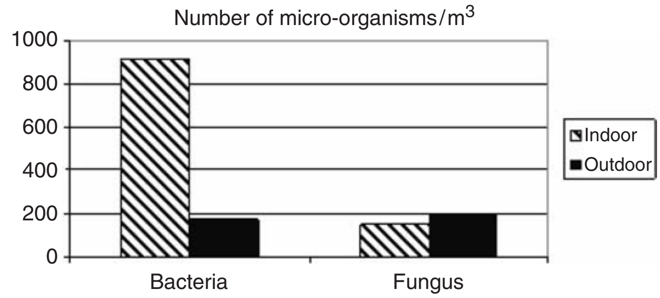

Fig. 4. Number of micro-organisms, average value from 14 schools and one apartment.

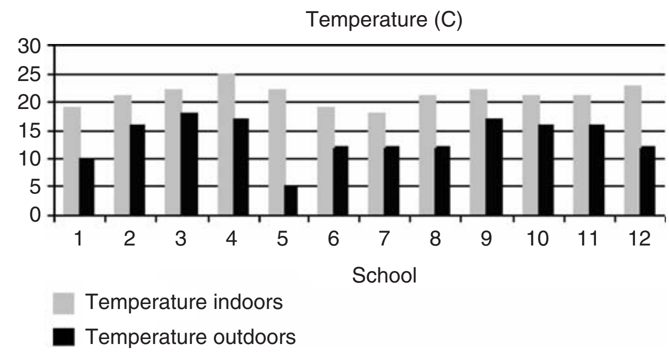

Fig. 5. Air temperature in 12 schools and in air surrounding the buildings.

Results

In nonindustrial indoor environments there have been difficulties at the level of individual occupants in establishing that their health was affected by materials used in building construction, and this has been reported by many researchers [22–31].

Micro-organisms

Figure 4 presents microbial results, with average values from measurements of IAQ in 14 different school buildings and one apartment, together with those from the outdoor air surrounding the respective buildings. The analytical laboratory could only analyze up air concentrations up to 1000 cfu·m^{-3}. Regarding the bacterium tests, this maximum was exceeded in 60% of the measurements taken indoors. Results from measurements of bacteria readily demonstrate how the air quality differed between the air outdoors and that indoors. For micro-fungi the results show that the levels (calculated as cfu·m^{-3}) were no different between outdoor and indoor air. In order to take into consideration the possibility of growth in situ for bacteria and fungi in the school environment, the air temperature and humidity were measured in 12 school buildings. The results are presented together with temperature and humidity (RH) measured at the same time in outdoor air surrounding the respective buildings; see Figure 5 (temperature) and Figure 6 (humidity). Results show that the air temperature indoors varied between 18 and 25°C and the humidity between 20 and 45%. The critical relative humidity necessary for fungal growth is >67% RH [32,33]. That is to say, the humidity levels measured in the schools environment were not favorable for fungal development.

In two school environments and one apartment selected from the 15 environments in Figure 4, measurements were made with the objective of identifying how to decrease airborne particle concentrations. The concentration of bacteria (cfu·m^{-3}) before removal of extraneous furnishing and materials averaged 1000 cfu m^{-3} and after removal, 681 cfu·m^{-3}; see Figure 7. One should, however, take into consideration that the highest concentration of micro-organisms the laboratory could analyze was 1000 cfu·m^{-3}. The results regarding the bacterial concentration showed differences in air quality.

The classification of the microbial flora was as follows:

1. Bacteria: Gram positive cocci, Gram positive non spore-forming rods, gram positive spore-forming rods, gram negative rods (oxidase negative), Actinomyceter
2. Fungus: *Aspergillus* sp., *Aureobasidium pullulans*, *Cladosporium* sp., *Mucor* sp., *Paecilomyces* sp., *Penicillium* sp., and occasional yeast cells.

This classification result indicated nothing wrong with the indoor environment [33–35].

Particles >5.0 and >10.0 μm

In measurements it was concluded that for particle content >5.0 and >10.0 μm the air quality clearly differed between outdoor and indoor air. The study covered IAQ in 18 school buildings, including pre-schools, classrooms and corridors in normal Swedish schools. Results presented in Figure 8, shows the average number of particles within a size range per metre cubed was:

- >5.0 μm for indoor, 1.8×10^6 m^{-3} and for outdoor, 6.8×10^4 m^{-3}
- >10.0 μm for indoor, 8.9×10^5 m^{-3} and for outdoor, 1.9×10^4 m^{-3}

The results indicate that airborne pollution levels were considerably lower outdoors than indoors and there was a large variation in air quality between different schools. We related this difference to the occupants and the activities carried out in the buildings. This has a central role since the air quality depends on activities that take place in a room,

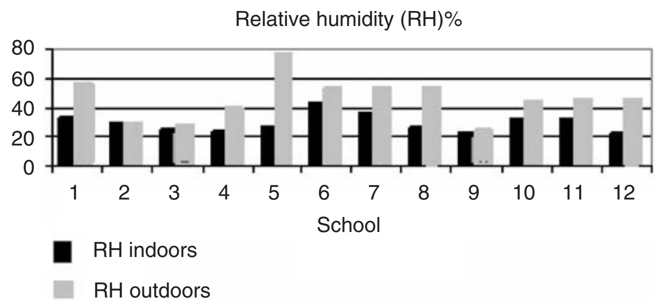

Fig. 6. Humidity (RH) in 12 schools and in air surrounding the buildings.

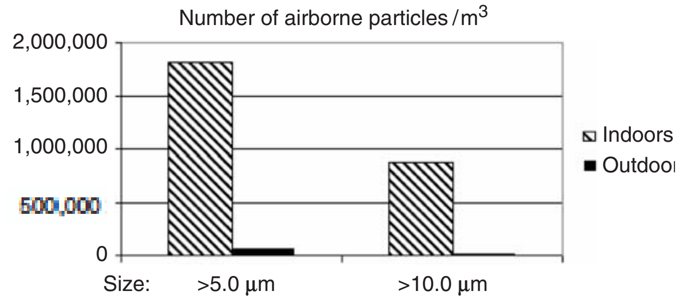

Fig. 8. Difference in particle concentration, average value from 18 schools.

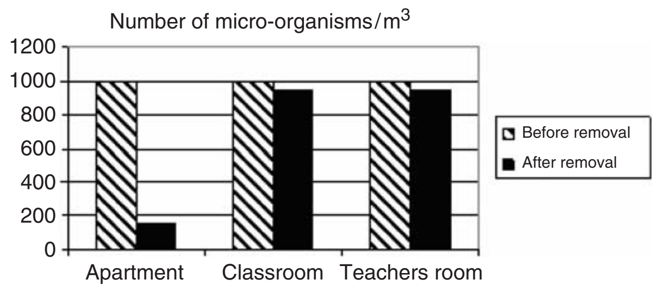

Fig. 7. Number of micro-organisms (bacteria), average value from two schools and one apartment.

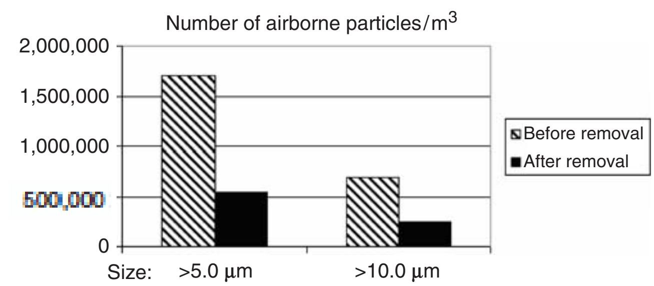

Fig. 9. Difference in particle concentration, average value from three schools.

the length of the lessons, how often the classroom is emptied for necessary airing and how furnishing and materials are handled. At inspections in the schools it was found there were large variations in these parameters. For example, cleaning was an important aspect for air quality and the situation in any school environment is often such as to prevent adequate cleaning due to there being too much furnishing and materials present in the rooms. In order to make the cleaning effective it is important that as much of the particulate load as possible has settled position and is not airborne when the cleaning is implemented. In 3 out of the 18 school environments (Figure 8) measurements were made with the objective of reducing particle pollution indoors. These measurements were aimed at taking into consideration those factors where human beings have a central role. This meant taking into consideration the planning of furnishing in the room, how material was handled in various activities, and making the room easier to clean. Results showed obvious differences in the air quality. These presented in Figure 9 give average values in the three school environments, both before and after measurements. The results are given as number of particles per cubic metre:

- >5.0 µm before remedial action, $1.7 \times 10^6\,m^{-3}$ and after remedial action, $5.5 \times 10^5\,m^{-3}$
- >10.0 µm particles indoors after remedial action, 7.0×10^5 and after remedial action, $2.4 \times 10^4\,m^{-3}$.

Discussion

In view of the high airborne particle levels measured in schools it would be understandable to find some overall health effects that occur as a consequence. In order to correct this it is important to focus on users of the building, both regarding behavioral patterns and how buildings are handled. The results of the measurements show that large quality differences arise, to the disadvantage of the indoor environment, this is seen particularly when the high levels indoors in the school environment contrast strongly with the air outside the school buildings. One can improve the air quality indoors by relatively simple means. In this connection occupant use of the building plays an important role, such as the activities undertaken there, extent and layout of furnishing, spatial planning and handling of materials and processes. Cleaning and the possibility of better cleaning are important factors for IAQ, since they strongly influence the number of particles that swirl up from floors, walls, and furnishings. The results of measurements have also shown that animals created environments with high particle levels. This should be taken into consideration in circumstances where contacts with domestic animals happen since fomites brought into the school environment through contact with animals can affect other because of the allergens they may carry. This results, for example, from people who have been in stables or who have pets at home. The concentration of micro-fungi found indoors followed levels in outdoor air, despite the fact that large variations in particle concentration were measured between the two spaces. This is a not unexpected result since measurements made show that the low humidity in the school environment was not favorable for the development of fungi, including molds. The current situation regarding airborne particle numbers and type may mean a risk of unnecessary suffering for many people, and also that society is burdened with costs in the form of absenteeism and production losses. In this context the economic aspects should also be evaluated. In everyday work in schools high particle levels may have negative effects through, for example, increasing tiredness in both students and staff and thereby making the daily routine less effective. This project has demonstrated that one can achieve good air quality in buildings by decreasing airborne particle levels through handling the buildings in a better way. Through measures that more clearly take into consideration those factors where people have a central role: planning of furnishing, activities, materials in the room, effective airing, and increased cleaning, significant positive results for the air quality should be achieved.

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