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A Study of Sources of Airborne Pollutants and Poor Hygiene in Schools

Thomas Alsmo Sture Holmberg

Fluid and Climate Technology, KTH - Royal Institute of Technology, Stockholm, Sweden

Key Words

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

Abstract

Poor indoor air quality is a large problem in Swedish schools, since the health of occupants may be affected. Resources are consumed without identification of utility indicators and there is risk of problems, even after remedial measures have been taken. This can mean both unnecessary suffering for many people and considerable resources being wasted. The building itself is often in focus and other building-related problems may be neglected. The hypothesis of the present work is that other factors than the building itself have decisive influence on indoor air quality. An assessment of these nonbuilding-related reasons for bad indoor air quality has been made in the present study using particle measurements. Results show that it is possible to decrease emissions in indoor air by over 90% through identifying and eliminating activity-related sources of airborne contaminants.

Introduction

Poor indoor air quality is a widespread problem in Swedish schools since the health of regular occupants may be affected. One or more symptoms may be experienced, such as irritated eyes, nose and throat, a feeling of dryness in mucous membranes and skin, acne, tiredness, headache, and nausea. In a Swedish national environmental health survey 18% of the adult population, corresponding to a million people, was found to suffer from such symptoms related to indoor air quality, e.g., in schools [1]. The World Health Organisation (WHO) specifies that if more than 20% of the occupants of a building report health problems, the building is classified as problematic. Indoor air quality is not only affected by the building's layout, facilities, and choice of materials, but also by how it is used and maintained. A suitable classification is:

- Nonspecific building-related health effects: meaning that people suffer from the above-mentioned symptoms, while staying in a building or in a certain part of it. The symptoms disappear once they have left the premises.
- Specific building-related health effects: meaning known building-related factors that imply health problems. Two examples are too high levels of radon which

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Thomas Alsmo,
Fluid and Climate Technology, KTH - Royal Institute of Technology,
Stockholm, Sweden. E-Mail thomas.alsmo@sth.kth.se

increase the risk of cancer, and bacterial contamination of water supply [2].

As to the first item above, *nonspecific building–related health problems*, which are the subject of this study, it is usually a specific building that is brought into focus. When health-related problems in schools are discussed it is necessary to take a holistic view encompassing all factors that could affect the indoor environment. Bad hygiene in school buildings may give rise to such high levels of airborne contaminants that health problems arise. The hypothesis of this study is that other factors than the building itself have a decisive influence on such health problems.

Many participants as well as authorities issued statements in this field through reports [1,3], on web pages [4], and the media [5]. They all have in common a strong focus on buildings as static units. Thus there is a risk that other factors of importance for air quality and hygiene are misinterpreted or totally neglected [6–8]. Many people are, for example, afflicted by problems from environments they cannot tolerate, both via indirect and direct contacts. A number of studies have shown significant incidence of allergy also in environments where the allergen is not supposed to be found. What happens is that people bring the allergen from the allergenic environment to schools causing the level of allergens to be high enough to keep a bronchial reaction going; whether the level is also high enough for sensitization is a matter of discussion [9]. Sensitization is the process by which the body develops an allergy. Antibodies are formed in some people when their bodies come into contact with some 'common' substance. The substance then becomes an allergen for that person; the next time the person comes into contact with the substance mast cells in nose, throat, lungs, and eyes release histamine and the allergy is established. The body then becomes sensitized [10].

A sound indoor environment is of course important and the manner of attaining this may vary. The cost of eradicating problems and shortcomings in indoor environments may often be largely due to interruption of activities, sick leave, rehabilitation, and technical measures such as alterations and rebuilding. There is a risk that these factors are not considered sufficiently when the problems are to be dealt with. An important aim of this project is to investigate the sources of airborne contaminants and inadequate hygiene indoors. Concerning air quality, particles in the size interval 5.0–10.0 μm transport agents that impact adversely on health, such as bacteria and cat allergens; this means that increased amounts of particles correlate with people's health problems [11,12]. Studies show that the dynamic behavior of particles makes it difficult to find both the source where they have been formed and the locations where they are finally deposited. Indoors, particles are affected by air currents that regularly arise and results indicate that particles up to 10 μm are infiltrated from lower levels up to the human breathing zone. The particles >5.0 μm exhibit strongly sedimentary behavior and come to rest, while the smaller particles tend to follow air currents [13]. Other than consideration of particle size no further study of particle behavior has been made in this study though concentration and type probably vary with time both in density and due to climatic conditions. There are no threshold limit values for air quality inside schools. Previous studies have shown that outdoor air surrounding a building constitutes a practical basis for comparison, see Figure 1 [14]. In this study three types of measuring devices have been compared to strengthen the hypothesis and to evaluate how their results correlate when comparing indoor and outdoor air.

Methods

This project consists of three sub-studies:

- A school building where health problems had been reported.
- Comparison of measuring devices to assess whether results correlate.
- A survey directed to Swedish local authorities to gain further knowledge about incidence of problems related to indoor air quality in schools.

The buildings included in this project had ventilation systems approved by the Swedish Law on Technical Requirements for Construction Works (OVK) [15]. The measurements of air quality were made under equivalent conditions with regard to type of building usage and activities within that usage. The instruments used for these measurements were the Climet 4120 (Climet Instruments Company, Redlands CA. USA) for the number of airborne particles >5.0 μm and >10.0 μm, Testo 175 for humidity and temperature logger and Testo 400 (Testo AG, Lenzkirch, Germany) for logging the carbon dioxide levels.

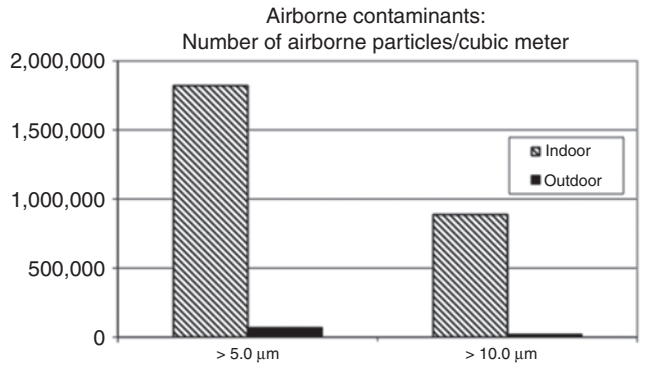

Fig. 1. Difference in particle concentration, average value from 18 schools [14].

A School Building Where Health Problems Had Been Reported

Over a long period, since the end of the 1980s, people who have spent some time in this particular building have been suffering from health problems. This has caused considerable suffering for many and the local authorities have considered closing the school, demolishing it, and replacing it with a new building. Since the local authorities did not feel confident about the reports which formed the basis for measures taken, external assessments of the measures taken were commissioned. The assessment showed a strong focus on the building itself and there was a risk that other factors of importance for air quality and hygiene were misinterpreted or not taken into account at all [16]. In co-operation with the local authorities that run and own the school a new method for confronting the problem was initiated within the context of this project. This study abided by the hypothesis that other factors than the building itself are quite important when problems occur. Inspections, dialogue with personnel and measurements were all included, the point of departure being greater consideration of the sources of airborne pollution and inadequate hygiene.

Comparison of Measuring Devices Used

Three devices, measuring the fraction of airborne pollutants between 5.0 and 10 µm, were compared. The first device was a Climet 400 which examines 0.01 ft^3 air/measurement; the second was a Climet 4120 which examines 100 L air/measurement and, lastly, a TSI 8220 (TSI Incorporated, Shoreview, MN, U.S.A.) which examines 10 L air/measurement. The measurements were performed during January and February 2008 in the following environments:

- A school building where activities were adapted to pupils with extra high requirements.
- In an office that also functioned as the place for printing internal messages and postal communications for the local authorities.
- In a school building used for education.

The goal of this activity was an evaluation of whether the results from the different instruments correlated when indoor and outdoor air contaminants were measured. Currently there are no threshold values for these contaminants. When the measuring devices were compared results differed by no more than 10%. There was a clear difference between indoors and outdoors, with indoors at a disadvantage, see Figure 2. It should be borne in mind that the instruments examine different volumes of air, but the results still correlate. If the sum of particles indoors and outdoors is taken for each measuring device, the percentages indoors to outdoors are nearly identical for the three devices.

Survey Addressed to Swedish Local Authorities to Gain Insight Concerning the Problems of Indoor Climate

A survey was carried out by means of personal contacts. The goal of this activity was to ascertain the frequency of this type of disturbance. In total 81 of the 290 local authorities were visited [17]. The choice of authorities was not made statistically, but rather through contact by telephone. The authorities showing interest were visited. It is judged that this number of local authorities should be enough to obtain results that may serve as reliable basis for analysis.

Results

School Buildings Where Health Problems Had Been Reported

The reports and actions taken in the school since the 1980s have focused on the building, but the method of assessment used lacks necessary validation. Other factors affecting air environment and hygiene that can have a negative impact on human health were scarcely considered [16]. In spite of considerable expenditure, problems remain for the users; among the personnel, 21 out of a total of 58 were affected by health problems. This means that about 36% of those who worked in the school had problems, i.e., above the 20% limit defined by WHO for a problem building. Some people problem's were supported by medical evaluation, their condition was such that medication was needed. Others felt uneasy at spending any time at all in the school for fear of becoming afflicted by health problems in the future. Through meetings with parents it

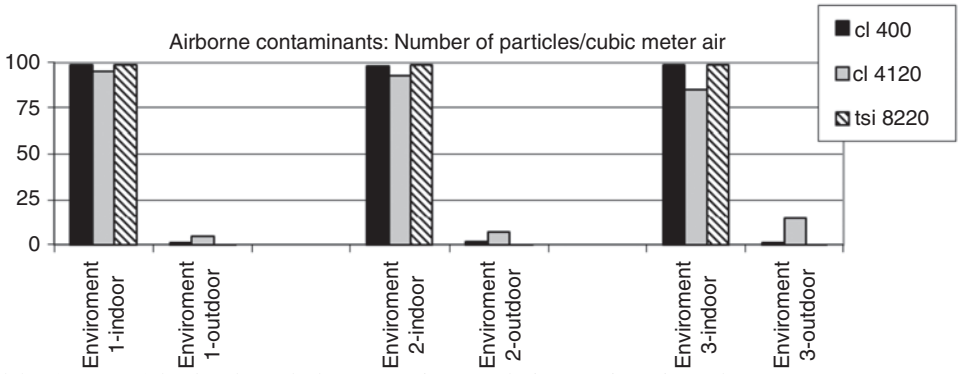

Fig. 2. No. of particles (> 5.0 μm) in the air, ratio in percent between indoor and outdoor air.

has surfaced that most pupils suffered considerable health problems, both while at school and after having been to school. Health problems recognized by both parents and personnel were both allergic and asthmatic, as well as nonspecific symptoms such as irritated ears, nose and throat, a feeling of dryness of the mucous membranes and skin, acne, tiredness, headaches and general queasiness, symptoms which diminished the longer the afflicted person stayed away from school.

Inspections indicated that school areas were overloaded with regard to furniture and equipment. This indication was strengthened by results from measurements which showed large emissions in a school environment, see Figure 3. Results from the literature [14], where the same type of measuring equipment was used, have been used as reference level, see Figure 4. Our assessment was that the poor hygiene prevalent in schools could not be improved unless more notice was taken of sources of contamination and inadequate hygiene. The severe load put on the school environment was emphasized. The school functions as a place for dust storage and the amount of dust stored was ever-increasing since new dust is regularly brought in by various activities. It was impossible, due to the equipment and furnishings, to clean sufficiently well to get rid of the dust present. This problem was caused both by the amount of dust in the school and the way the various rooms were used. When somebody moves in a room dust whirls up giving rise to large amounts of pollutants, prerequisites for ill health. School personnel declare that teaching requirements make it necessary to keep the equipment/supplies present in the classrooms and that these supplies, furthermore have to be easily accessible for the pupils. After talking to the school personnel it became evident that the sources of airborne pollutants must be addressed if hygiene was to be improved. Studies have shown that a large part of the equipment present in Swedish schools

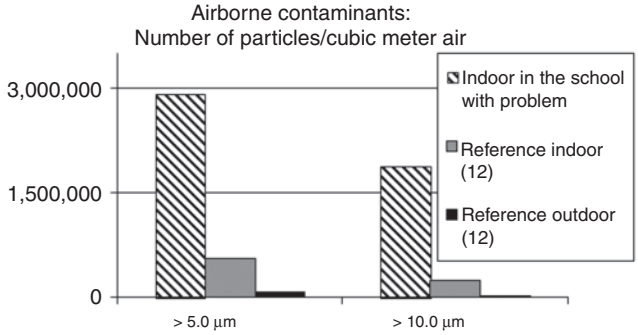

Fig. 3. Airborne contaminants in a school where health problems are reported.

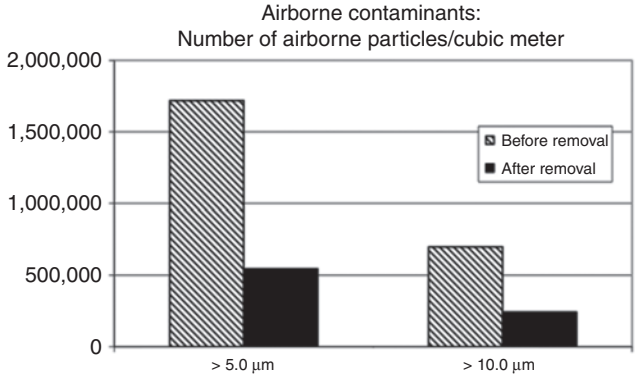

Fig. 4. Differences in particle concentration, average value from three schools [14].

may be dispensed with, thereby diminishing the burden on the indoor environment [14].

An important philosophy for the type of activities in a school is to create flexible, comfortable, and durable furnishings that inspire and provide an enjoyable working atmosphere. Parameters for the development of a school

environment are:

- Pleasant environment that draws the pupils to school and stimulates teaching activities.
- Improved hygiene at school, decreased amount of airborne pollutants.
- Improving, in the best way possible, day-to-day working conditions for school personnel.

Measurements, after actions have been taken to decrease load on indoor environment, show large improvements of air quality, see Figure 5. Measurements of thermal conditions showed levels considered normal. Similarly, a representative selection of environmental parameters from one of the classrooms were not unreasonable (see Figure 6 for carbon dioxide levels and Figure 7 for results on air humidity and temperature). A possible exception was air humidity which was periodically very low. Below 10% relative humidity was measured during very cold weather when the temperature was down to −25°C. In such an environment it is difficult to regulate low air humidity levels to bring them within normal limits using technical equipment.

The problems at the school could be solved within the framework of this project. This was shown with illuminating results on improved air quality (Figure 5). Interviews with school personnel and pupils indicated that health problems had decreased and that the school environment was found aesthetically more pleasant, cleaner, and less dusty. Further, it was now easier to keep order in the school, teaching activities were made easier and the change created a calmer environment, not least due to fewer visual distractions. Additionally, both pupils and personnel state that the noise level has decreased. The cost of these improvements was not high, and may fit into the budget of a normal nonprivate school [18].

Survey Addressed to Swedish Local Authorities to Gain Insight Concerning the Problems of Indoor Climate

The results from direct contact with 81 local authorities showed that all have had these problems. Assessments performed lacked necessary validation and generally focussed on the buildings themselves. For five of the local authorities questioned the problems reached such magnitude that buildings have been demolished and replaced by new since the causes of the problems could not be found. This meant that within the span of a single year, 6.2% of the local authorities in the present survey have been affected by quite severe and resource-demanding problems; recalculation to encompass the whole country implies 18 local authorities [17].

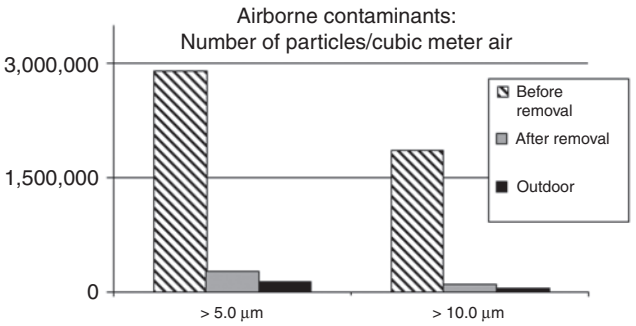

Fig. 5. Airborne contaminants in a school where health problems were reported, before and after action has been taken.

Discussion

It is understood that people who stayed regularly in the school building, investigated in this project, have been affected by health problems since there were serious emission problems indoors (Figure 3). To get rid of these emissions it was important to take the sources of the problems into account. The hypothesis of this project is that factors other than the building itself are decisive, this may be illustrated by the results shown in Figure 5. The actions taken have decreased emissions by more than 90%. A literature survey showed that reports often do not work according to this hypothesis. The focus is concentrated on the building as a static unit and the question asked is whether technical modifications could solve the problems described in this project. A literature study shows that assessments often lack calibration against known common health hazards and this limits the chances of locating sources of hygiene problems in the indoor environment [19–23]. This is evident in the school study in which results showed that earlier reports were inadequate, since important parameters were not taken into account. The technical modifications previously made in the building did not eliminate the problem, the source of pollutants and bad hygiene still persisted. After a more comprehensive analysis that identified the emission sources, the problem could be resolved. The results indicated that exposure to poor environments decreased as monitored in the school environment, where interperson contacts regularly occur. An example is the transport of allergens and other contaminants brought in by people who, outside the school, regularly come into contact with poor environments including pets and smokers.

Currently there are no threshold values or reference values for school environments concerning the amount of airborne particles $>5.0\,\mu m$. To provide background information three monitoring instruments were

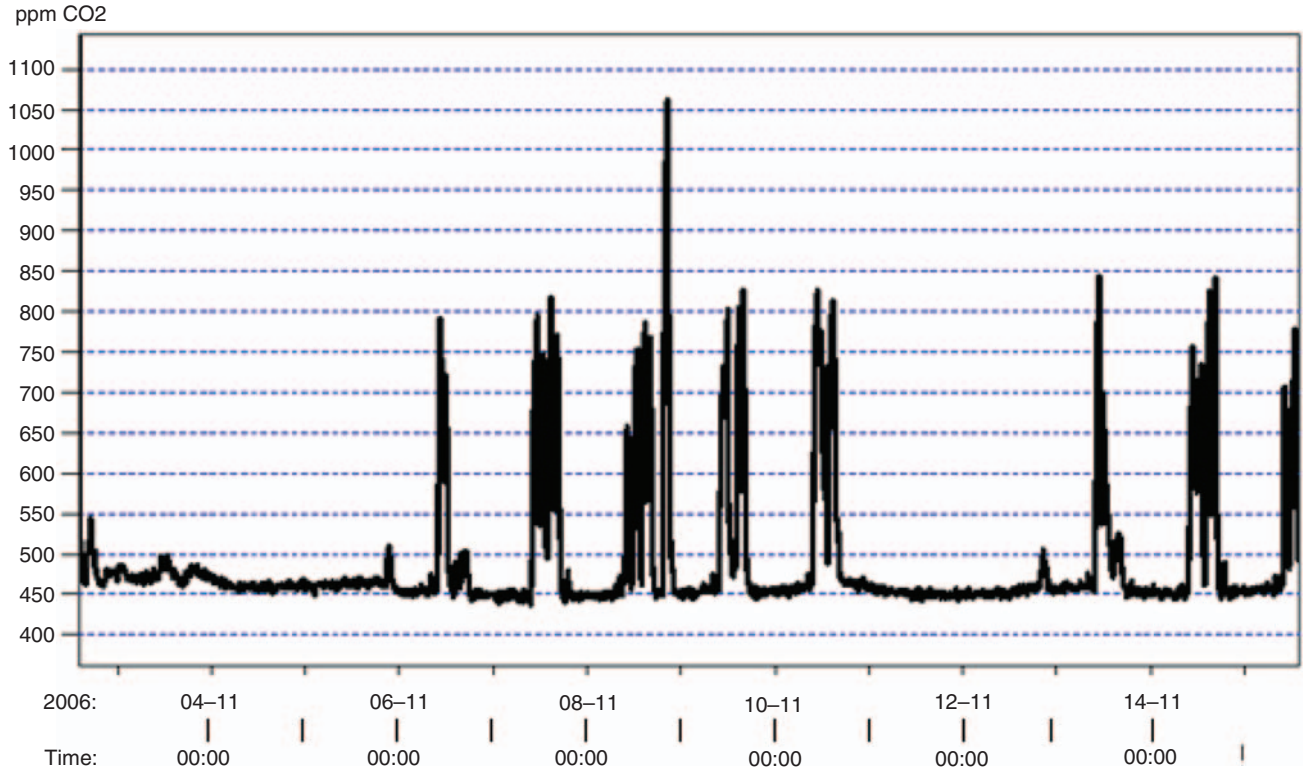

Fig. 6. Carbon dioxide (CO_2), ppm, in a school where health problems were reported, a representative selection from one of the classrooms. The figure shows a measuring period of 14 days, from 2 November to 15 November 2006.

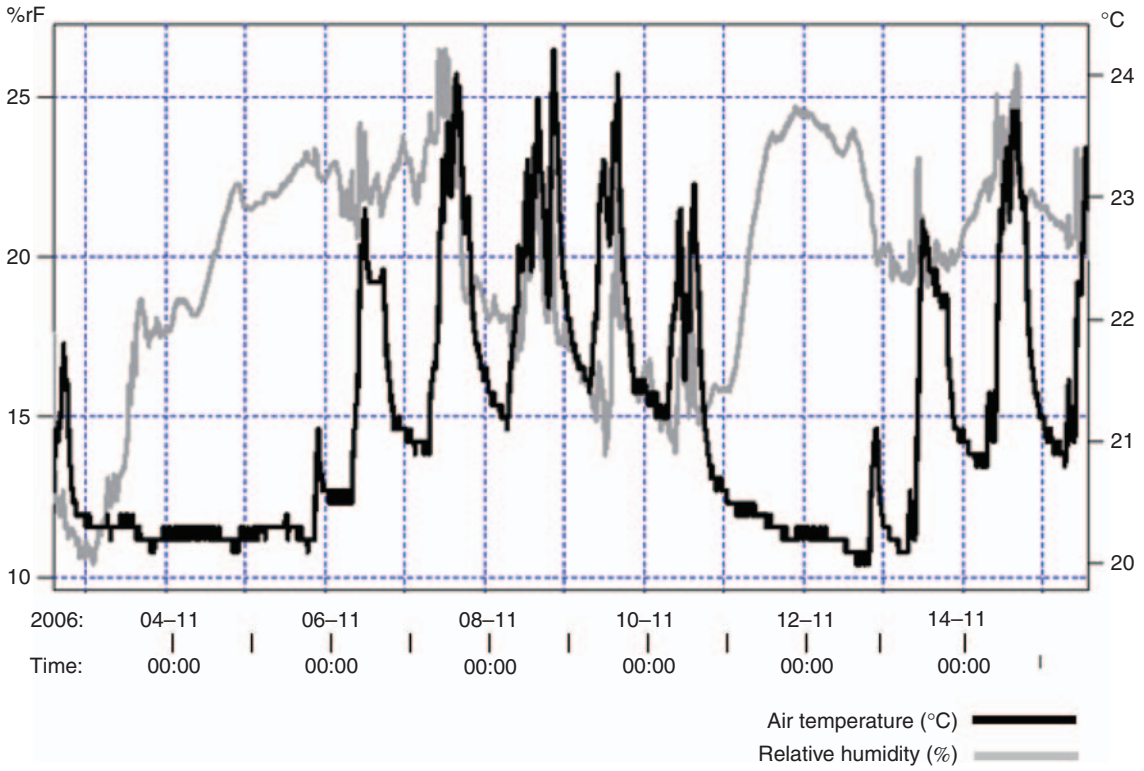

Fig. 7. Air temperature (°C) and relative humidity (%) in a school where problems were reported, a representative selection from one of the classrooms. The figure shows a measuring period of 14 days, from 2 November to 15 November 2006.

compared. Results from these were comparable and to a first approximation it was shown that the air outside buildings may as well be used as an indicator of problems as the indoor air (Figure 2), and that this may be used as basis for the development of methods which have greater validation. The need for calibrated methods is large within this field, since survey results show that the problem is common in Sweden today. Within the scope of a single year 6.2% of all municipal authorities have had serious environmental problems, solution of which can be expensive with costs sometimes amounting to 10 million Euro (€) for modifications carried out based on assessments without necessary validation [25]. Such an outcome is unnecessary involving suffering for many people as well as large-scale waste of resources.

References

1 Asplund K, Pershagen P, Svartengren M: The Environmental Health Report, ISBN 91-7201-931-X (Miljöhälsorapporten), The National Board of Health and Welfare, Stockholm (in Swedish), 2005.
2 Nilsson PE: Achieving the Desired Indoor Climate, Gothenburg, Chalmers University of Technology, 2003.
3 The National Board of Health and Welfare: Message to Boards of Environment and Health Protection, County Administrations and units for Environmental Medicine of the County Councils, Health risks with moisture problems in buildings (Hälsorisker vid fuktproblem i byggnader), 2006 (in Swedish).
4 Swedish Work Environment Authority: Plan of Action for Dealing with Sick-Building Problems, Available at: http://www.av.se/teman/sjuka_hus/Startintro_sjukahus.aspx, (Handlingsplan för att hantera sjuka-hus-problem) (accessed September 2008) (in Swedish).
5 Swedish Radio programme 4 (2007), Higher Amounts of Poison in Houses with Mould, Available at: http://www.sr.se/cgi-bin/ekot/artikel.asp?artikel=1772132, (Högre halter gift i mögelangripna hus) (accessed September 2008) (in Swedish).
6 Stridh G: Should we measure the chemistry beneath the floor coverage and, if so, how do we interpret the results? (Skall vi mäta kemin under golvbeläggningar och hur tolkar vi i så fall mätresultaten?) Indoor Climate Örebro, Örebro University Hospital 2003, pp. 102–108 (in Swedish).
7 Grinbergs L: Mould Resistance of Surfaces in Wet Rooms (Mögelresistens hos beklädnader i våtrum). Stockholm, Department of Building Technology, KTH – Royal Institute of Technology, 1992 (in Swedish).
8 Alsmo T: A Study with Surveys and Particle Measurements (En studie med enkäter och partikelmätningar), Stockholm, Department of Buildings and Construction, KTH – Royal Institute of Technology, 1994 (in Swedish).
9 Sundell J, Kjellman M: The Indoor Air We Breathe (Luften vi andas inomhus), Stockholm, Swedish National Institute of Public Health, 1995 (in Swedish).
10 Wikipedia (2008), Available at: http://sv.wikipedia.org/wiki/Sensibilisering (accessed September 2008) (in Swedish).
11 Månsson L: The Invisible Enemy of High-Tech (Högteknologins osynlige fiende), Malmö, TIMAB AB, 1992 (in Swedish).
12 Ramtorp M: Clean Technology and Clean Rooms – An Introduction (Renhetsteknik och rena rum – en introduktion), Malmö, BioTeknisk Processdesign AB, 1999 (in Swedish).
13 Einberg G: Air diffusion and solid contaminant behaviour in room ventilation – a CFD based integrated approach, PhD Thesis, Stockholm, Technology and Health, KTH – Royal Institute of Technology (2005).
14 Alsmo T, Holmberg S: Sick Buildings or Not: Indoor Air Quality and Health Problems in Schools: Indoor Built Environ 2007;16(6):548–555.
15 The National Board of Housing, Building and Planning: Law on Technical Requirements for Construction Work (Regelsamling för funktionskontroll av ventilationssystem, OVK), 2008 (in Swedish).
16 Radosavljevic M, Semir P: Air Environment Indoors, Problems in School Environments (Luftmiljö inomhus, problem i skolmiljön), Stockholm, Technology and Health, KTH – Royal Institute of Technology, 2006 (in Swedish).
17 Alsmo T: List of Municipalities, Summary of Municipalities Included in Survey (Kommunlista sammanställning kommuner som ingår i enkät), Stockholm, Technology and Health, KTH – Royal Institute of Technology, 2008 (in Swedish).
18 Alsmo T: Case Study Indoors, Volgsjö School – Vilhelmina Municipality (Fallstudie inomhus, Volgsjö skola – Vilhelmina kommun), Swedish Association of Local Authorities and Regions 2007 (in Swedish).
19 Bornehag CG, Blomquist G, Gyntelberg F, Järvholm B, Malmberg P, Nordvall L, Nielsen A, Pershagen G, Sundell J: Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on association between exposure to "dampness" and health effects, (NORDDAMP): Indoor Air 2001;11(2):72–86.
20 Bornehag CG, Sudell J, Bonini S, Custovic A, Malmberg P, Skerfving S, Sigsgaard T, Verhoeff A: Dampness in building as a risk factor for health effects, EUROEXPO. A multidisciplinary review of the literature (1998–2000) on dampness and mite exposure in buildings and health effects: Indoor Air 2004;14(4):243–257.
21 Emenius G, Svartengren M, Korsgaard J, Nordvall L, Pershagen G, Wickman M: Indoor exposures and recurrent wheezing in infants; A study in the BAMSE cohort: Acta Paediatrica 2004;93:899–905.
22 Wargocki P, Sundell J, Bischof W, Brundrett G, Fanger PO, Gyntelberg F, Hanssen SO, Harrison P, Pickering A, Sepponen O, Wouters P: Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN): Indoor Air 2002;12:113–128.
23 MM surveys, indoor climate (MM-enkäter, inneklimat) Available at: http://www.orebroll.se/uso/pagewide____16288.aspx (accessed September 2008) (in Swedish).
24 Estenberg S: Investigation on Kyrkbyskolan, Älvdalen municipality (utredningsmaterial Kyrkbyskolan, Älvdalens kommun, 2008 (in Swedish).