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MARJA TUOMAINEN

The present state of and the requirements for indoor climate in the home environment of occupants with respiratory diseases

Doctoral dissertation

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ABSTRACT

Occupants with respiratory diseases (e.g. asthma) are sensitive to factors in indoor climate and therefore preventing exposure to impurities in the home environment is an important element in their treatment and rehabilitation. The overall aims of this thesis were to survey IAQ in residences of occupants with respiratory diseases, and to produce practical information on how to improve IAQ in existing as well as in new residences for people with respiratory diseases.

IAQ was evaluated in 128 residences in which at least one occupant had a respiratory disease. It was found that about 75% of the residences had inadequate or unbalanced ventilation, and in half of the buildings, dampness and microbial growth or too high temperatures were observed. In general, IAQ in the buildings studied corresponded to the IAQ reported earlier in typical Finnish dwellings. Investigations were repeated after remedial action was taken in 27 of the buildings. The follow-up survey showed that no major improvement in IAQ or in the prevalence of symptoms was achieved after repairs. It was thus seen that people with respiratory diseases need individual and detailed guidance to improve their home environment.

In the second part of the thesis, a new block of flats was designed and built especially for occupants with respiratory diseases following the Classification of Indoor Climate, Construction and Finishing Materials (FiSIAQ, 1995). The main changes in the design and construction work compared with conventional practices included the following: a clear target related to IAQ during the whole construction process, a mutual document for the quality certification between the client, the builder and the main building contractors, training in IAQ aspects for construction workers, clean manufacturing, installation and storage of ventilation system components, use of low-emitting building materials and control of cleanliness and moisture on the construction site.

IAQ was measured before the occupants moved in and during the first three years of occupancy. The S1 target levels for room temperature, RH, CO_2, formaldehyde, and the total suspended particles had already been achieved before the occupants moved into the building, and the target levels for CO, TVOC and ammonia were reached five months later. Only the target levels for odour intensity were not achieved. In addition, a seven-day powerful ventilation period after the completion of the building reduced the levels of TVOC by approximately 50%. During the three years of occupancy, indoor climate remained at a high quality level.

Furthermore, the questionnaire indicated that perceived IAQ matched well with the conclusions based on the IAQ measurements in both older residences and the new block of flats. The occupants with respiratory diseases seemed to be more sensitive to indoor air impurities and other defects in the indoor climate than their healthy family members. In addition, they suffered more symptoms and were more dissatisfied. Thus, a high quality indoor domestic climate has a significant role in decreasing symptoms and increasing general comfort, especially among patients with respiratory diseases.

This thesis showed that high IAQ can be achieved by careful design, choice of proper materials and equipment, and high-quality construction work with reasonable additional costs. The Classification of Indoor Climate, Construction and Finishing Materials proved to be a useful tool in the design and construction process. In addition, good IAQ can also be maintained during occupancy, if sufficient information on factors affecting IAQ, and guidance on proper use and care of equipment is available.

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National Library of Medicine Classification: WA 754, WA 770, WF 140
Medical Subject Headings: air pollution, indoor; air pollutants; humidity; temperature; ventilation; respiratory tract diseases; facility design and construction; housing; building codes; construction materials; follow-up studies

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Helsinki, January 2002

Marja Tuomainen

DEFINITIONS

Air-handling unit:
An assembly of air treatment equipment within one handling unit. It may include filters, fans, humidifier, cooler battery and associated controls.

Bake-out procedure:
A procedure in which a building is kept unoccupied and is ventilated at high capacity before occupants or users move in. Besides the high ventilation rate, the room temperature is raised. The terms of "airing out" or "ventilation off" are also used, especially for the process with intensified ventilation.

Classification of Indoor Climate 1995:
A short form for the guideline “Classification of Indoor Climate, Construction and Finishing materials” published by the Finnish Society of Indoor Air Quality and Climate, 1995.

Classification of Indoor Climate 2000:
A short form for the guideline "Classification of Indoor Climate 2000. Target values, design guidance and product requirements" published by the Finnish Society of Indoor Air Quality and Climate, 2001.

Desipol:
A unit for quantifying perceived air quality. One desipol is the pollution level caused by a standard person (one olf) in a space ventilated by 10 l/s of fresh unpolluted air.

Humidification:
A mechanical process of adding water to air to elevate the humidity level in the ambient air.

Indoor air quality:
Attributes of the respirable climate inside a building including gaseous composition, humidity, temperature and contaminants.

Natural ventilation:
The movement of air into and out of a space through intentionally provided openings, such as windows and doors; or through non-powered ventilators; or by infiltration.

Trained odour panel:
A group of people who have trained their olfactory sense to evaluate the level of air pollution/air quality; different chemicals and scales are used for training.

Ventilation:
A process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned. Three main ventilation systems are in use: natural ventilation, mechanical exhaust ventilation, and mechanical supply and exhaust ventilation.

ABBREVIATIONS

A	surface area [m^2]
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
BRI	building related illnesses
C	concentration in air [$\mu g/m^3$]
CEN	European Committee for Standardization
CFU	colony forming unit
CI	confidence interval
DG18	dichloran glycerol agar
ECA	European Collaborative Action
EPA	US Environmental Protection Agency
ETS	environmental tobacco smoke
EU7	efficiency class for a filter with dust spot efficiency of 80-90% according to SFS 5150 (1986)
FIM	Finnish mark
FiSIQ	Finnish Society of Indoor Air Quality and Climate
IAQ	indoor air quality
IOM	Institute of Medicine
IPMVP	International Performance Measurement and Verification Protocol
ISAAC	International study of asthma and allergies in childhood
ISIAQ	International Society of Indoor Air Quality and Climate
MD	median
MEA	malt extract agar
ME	mechanical exhaust
MS	mechanical supply and exhaust
n	number of samples or people
N	air exchange rate [h^{-1}]
NV	natural ventilation
OR	odds ratio
p	probability
PAQ	perceived air quality
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 μm in diameter
PM_{10}	particulate matter less than 10 μm in diameter
ppm	parts per million
RH	relative humidity of air [%]
RR	relative risk
RSP	respirable suspended particles, range 0.1-2.5 μm
SBI	sick building syndrome
SD	standard deviation
SP	suspended particles
SER_a	area specific emission rate [$\mu g/m^2h$]
TSP	total suspended particles
TVOC	total volatile organic compounds
V	volume [m^3]
VOC	volatile organic compounds
WHO	World Health Organization

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on four original publications, referred to in the text by Roman numerals (I-IV). Also some unpublished data were included in the thesis.

I. Tuomainen M., Forss P., Liesivuori J., Pasanen A.-L. Indoor air quality in 128 residences of occupants with respiratory diseases. Submitted.

II. Tuomainen M., Pasanen A.-L., Kalliokoski P.1997. Practical aspects of design and construction of a blocks of flats with good indoor air climate. In Woods J.E., Grimsrud D.T., Boschi N. (eds.) Healthy Buildings/IAQ '97 Global Issues and Regional Solutions. Proceedings volume 3, residences, Bethesda MD, September 27 - October 2, 1997 Washington DC, USA pp. 357-361.

III. Tuomainen M., Pasanen A.-L., Tuomainen A., Liesivuori J., Juvonen P. 2001. Usefulness of the Finnish classification of indoor climate, construction and finishing materials: comparison of indoor climate between two new blocks of flats in Finland, Atmospheric Environment, 35, 305-313.

IV. Tuomainen M., Tuomainen A., Liesivuori J., Pasanen A.-L. The three-year follow-up study in a block of flats - experiences of the use of the Finnish indoor climate classification. Indoor Air, provisionally accepted.

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CONTENTS

1 INTRODUCTION

Today most people, especially children and the elderly, spend approximately, or even more than, 90% of their time in indoor environments, such as at home, the workplace, schools and day-care centres. Indoors, people are exposed to numerous air pollutants and factors that exist in buildings. Many characteristics of the indoor environment may influence comfort, health, satisfaction and productivity of the occupants. (Maroni et al., 1995; Spengler et al., 2001).

The prevalence of allergies and related respiratory illnesses has increased rapidly in the past few decades (ISAAC, 1998). Reasons for this trend are not clearly understood, although several theories have been presented e.g. the improvement in allergy diagnoses and general hygiene, changes in diet, exercise habits, climate conditions (variations in pollen seasons), and exposure to chemicals (e.g. nickel), the increased use of antibiotics and vaccinations, and a role of virus infections (Becher et al., 1996; Bielory and Deener, 1998; Björksten, 1999; Steerenberg et al., 1999; Strannegård and Strannegård, 2001). Besides these, the increased time spent indoors and the increased number of pets have been suggested as having a role in the development of allergic diseases. It is also well known that pollutants from the ambient air, including tobacco smoke, and air pollutants of industry, traffic and combustion, may exacerbate existing allergies (EU-ECA-10, 1991; Pönkä, 1991; WHO, 2000a; Jones, 2000).

As a result of the energy crisis in the 1970's, practices in building technology changed considerably: the air exchange rate decreased and the tightness of buildings increased substantially. This has lead to the accumulation of air pollutants indoors and has caused constrictive problems, such as moisture damage and radon problems. In addition, new building materials were brought quickly onto the market without instructions for proper installation and use. In addition, the overall construction process was shortened and, at the same time, the number of new buildings increased so that there was a greater risk of defects and faults in design and construction.

Achieving good indoor air quality (IAQ) at the completion of a building does not necessarily guarantee good IAQ during the time of occupancy, because improper use and/or maintenance may ruin indoor climate rapidly. Furthermore, over the course of time, living habits have been changed; for example, more water is used in a variety of ways inside buildings and different kinds of chemicals for hygienic and cleaning purposes have become more popular. Compounding these problems is the increasing popularity of different heating and ventilation systems in buildings, coupled with the occupants' potential lack of knowledge of the maintenance and use of these systems. The risk of the deterioration of the structure and materials, accidents (e.g. pipe leaks) and damage rises as the building ages. Therefore, regular maintenance of buildings is necessary to prolong their life span and assure good IAQ.

The World Health Organization (WHO) has recently emphasised that every human being has the right to healthy indoor air and is also encouraged to demand good IAQ (WHO, 2000b). In the USA, the Environmental Protection Agency (EPA) has ranked indoor air pollution as one of the top five environmental risks for public health (US EPA, 2000). In Finland, the annual cost of poor indoor climate (for example, health effects, absenteeism, costs of lower productivity) has been estimated to be approximately EUR 3 billion (FIM 18 billion) (Seppänen and Palonen, 1999). These costs are equal to the annual heating cost of Finnish buildings. In Finland, IAQ and its importance to human health have been taken into consideration in policy through the publication of official guidelines for indoor climate (the Ministry of Social Affairs and Health, 1990, 1997, currently in the process of being updated) and a voluntary Classification of Indoor Climate (FiSIQ, 1995; FiSIQ, 2001). In addition, several large indoor air research programmes, organised and funded by the Finnish Institute of Occupational Health, the Academy of Finland and the National Technology Agency, have been established since 1994 and are still working to increase the knowledge and expertise in this field. In the future, there are some challenging tasks for building technology: how to produce, at a reasonable cost, healthy, safe and comfortable buildings, which are economical and efficient to maintain.

This thesis focuses on the home environment, particularly residences of people with respiratory diseases and allergies. It highlights practical solutions to improve IAQ in existing buildings and describes how to build new healthy, safe and comfortable buildings. Thus, this thesis shows that this target is realistic and possible to achieve in real life.

2 REVIEW OF THE LITERATURE

2.1 Indoor climate and indoor air quality (IAQ) in residences

2.1.1 Composition of indoor climate and sources of indoor pollutants

The indoor climate consists of numerous physical, chemical and biological variables as described in Figure 1. In addition, psychological and social factors have an impact on how indoor climate is experienced and perceived by occupants (Maroni et al., 1995; Spengler et al., 2001).

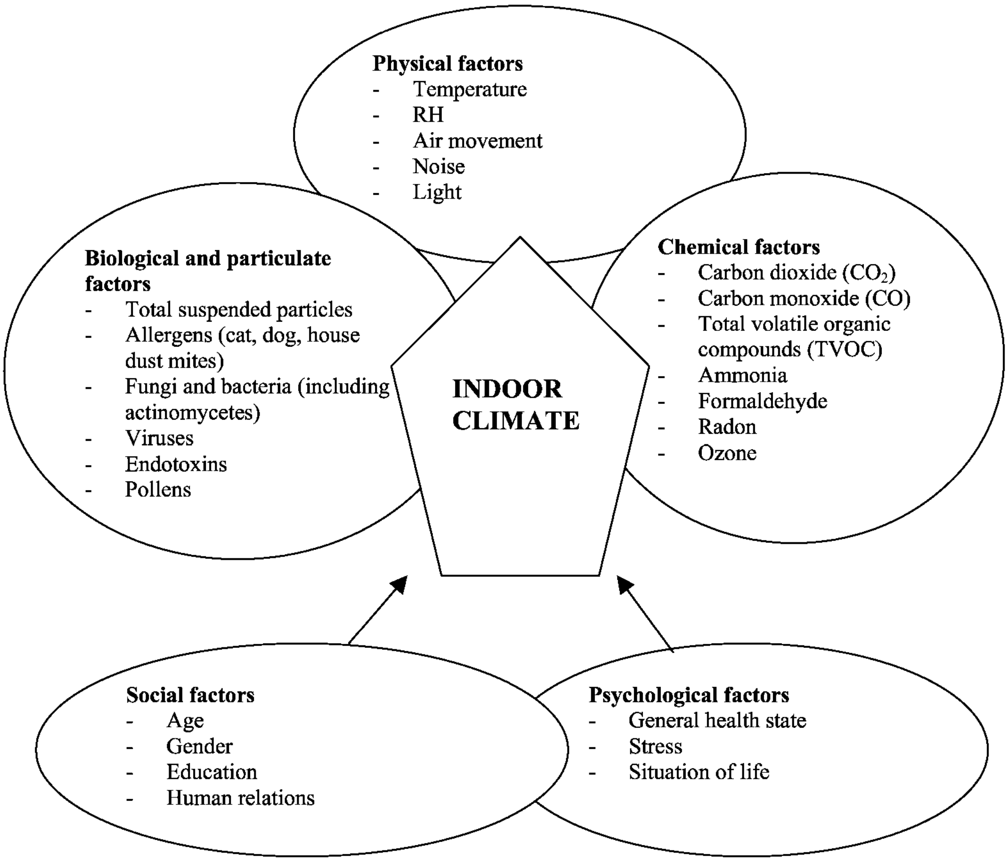


Figure 1. Indoor climate - a complex mixture of physical, chemical, biological, social and psychological factors.

Indoor air pollutants may arise from a number of sources, for example, human activities, household products, various building materials and products including HVAC systems, combustion processes and outdoor air pollution (Maroni et al., 1995; Spengler et al., 2001).

Essential sources of indoor air pollutants are presented in Table 1. Carbon oxide, bacteria, particles and allergens are typical pollutants of human origin and/or derived from human activities, whereas volatile organic compounds (VOC) and ammonia often originate from a building itself, e.g. building materials. Radon, on the other hand, is a pollutant from the soil, while common outdoor pollutants are fungal spores, particles, and carbon monoxide.

Table 1. Typical indoor air pollutants and their sources.

Indoor air pollutant	**Source**
Carbon dioxide, CO_2	Metabolic activity Fuel burning
Carbon monoxide, CO	Fuel burning, e.g. gas and wood stoves Tobacco smoke Outdoor air
Formaldehyde, HCHO	Building materials, e.g. insulating materials Chipboard or plywood furniture Household cleaning agents Tobacco smoke
Volatile organic compounds (VOCs)	Building materials, e.g. paints, carpets, adhesives Household products, e.g. detergents Cosmetics Outdoor air
Ammonia, NH_3	Building materials, e.g. fillers Household products, e.g. detergents People and metabolic activity Pets
Radon, Rn	Soil Water Building materials, e.g. concrete
Total suspended particles, TSP, fine particles PM_{10}, $PM_{2.5}$	Outdoor air People and their activities Tobacco smoke
Fungal spores	Outdoor air Moist constructions and materials Foodstuffs, plants
Bacteria Actinomycetes	People Pets Outdoor air Soil Moist constructions and materials
Allergens	House dust Mites Pets (furred animals, birds) Indoor plants

References: Maroni et al., 1995; WHO, 2000a; Spengler et al., 2001.

Many indoor pollutants are originally derived from outdoors, like from the soil, vegetation, traffic and industry. It has been calculated that indoor air levels of many pollutants may be two to five times, and occasionally, even more than two orders of magnitude higher than outdoor levels (US EPA, 1993). Of course, in areas near busy traffic routes and industry, for example, the quality of outdoor air could be even worse than IAQ. The indoor air concentration of a pollutant depends on the outdoor air concentration, the generation rate of a pollutant indoors, and on the total rate of pollutant removal by ventilation and air cleaning. The interactions of these variables can be illustrated with the formula below (The International Performance Measurement and Verification Protocol, IPMVP, 2000). In addition, indoor concentrations of air pollutants are also subject to geographical, seasonal and diurnal variations, as well as to the building's characteristics, such as the age of a building and type of a building (in particular, the use and structure of a building).

$$\text{Indoor concentration} = \text{Outdoor concentration} + \frac{\text{Generation rate indoors}}{\substack{\text{Sum of the rates of removal processes} \\ \text{(e.g. ventilation rate, air-cleaning frequency)}}}$$

With regard to gaseous pollutants in particular, indoor concentrations of formaldehyde in residences usually varies between 10^1 to 10^2 µg/m^3, but about one order of magnitude higher (up to 7000 µg/m^3) have been reported (Ritchie & Lehnen, 1985; EU-ECA- 7, 1990; Reponen et al., 1991; Stridh et al., 1993; Nordbäck et al., 1995; Salthammer et al., 1995; Wieslander et al., 1997; Villberg et al., 1999; Garrett et al., 1999; Jurvelin et al., 2001). Formaldehyde levels depend on the season and are associated with humidity conditions: higher concentrations are found in spring, summer and autumn compared with winter time in the cold and temperate climates (Reponen et al., 1991; Wolkoff et al., 1991; Salthammer et al., 1995). Also, the levels are usually higher in new flats than in older ones (Reponen et al., 1991; Wolkoff et al., 1991; Salthammer et al., 1995). In general, indoor concentrations of formaldehyde have decreased in recent decades because of active research and development of building materials and products, for example insulation materials and particle boards (Wolkoff et al., 1991; Maroni et al., 1995; Spengler et al., 2001).

A large variation in TVOC levels (usually 10^1- 10^3 µg/m^3, at times even greater than 10000 µg/m^3) can be detected in residences (Harving et al., 1992; Stridh et al., 1993; Kostiainen, 1995; Norbäck et al., 1995; Heavner et al., 1996; Villberg et al., 1999; Hodgson et al., 2000; Wolkoff and Nielsen, 2001). Typically indoor air contains a great number of different compounds, but the mean concentration of each VOC in buildings is generally below 50 µg/m^3 but mostly below 5 µg/m^3 (Brown et al., 1994). The highest TVOC concentrations are usually found in new or recently renovated buildings (Girman, 1989; Mølhave et al., 1990; Rothweiler et al., 1992; Brown et al., 1994; Knöppel and Schlitt, 1995; Brown, 1999; Hodgson et al., 2000).

Radon content in soil depends on the surrounding geography, which also affects radon levels indoors besides basement structures and ventilation of a building. Indoor radon levels usually remain below 100 Bq/m^3 (EU-ECA-15, 1995), but in certain areas, for example in sandy ridges and rocky areas, they may be ten times higher (Kokotti et al., 1989; Ruotsalainen et al., 1992, EU-ECA-15; 1995; WHO, 2000b).

On the other hand, ammonia levels of 10-110 $\mu g/m^3$ (typically below 40 $\mu g/m^3$) have been measured in Finnish residences (Bäck et al., 1997, Villberg et al., 1999). Unfortunately, data on ammonia concentrations in residences is scarcely available from other countries.

Concentrations of CO in residences may temporarily increase to a high, nearly dangerous level (60 mg/m^3), in such cases when fireplaces are not used correctly and/or ventilation in a building is insufficient. In normal circumstances, the levels of CO are low (below 5 mg/m^3). (Maroni et al., 1995; Spengler et al., 2001). Levels of CO_2 can rise to several thousands ppm in occupied spaces if ventilation is insufficient (Fehlmann and Wanner, 1993; Ruotsalainen, 1995; Maroni et al., 1995; Spengler et al., 2001). Generally in residences, the average levels of CO_2 are normally below 1000 ppm, but they show diurnal variation depending on human indoor activity (Ruotsalainen, 1995; Van Winkle and Scheff, 2001).

Dust and particles found indoors have several sources: building materials (e.g. concrete, wood, plaster), furniture (e.g. upholstery, wood dust, old painting), textiles (e.g. carpets and curtains), people (e.g. skin scales, clothes, dirty shoes, and physical activities), and outdoor sources (e.g. soot particles; plant, fungal, pollen, insect, or soil derived particles) (Kildesø and Schneider, 2001). Indoor air concentrations of total suspended particles (TSP) or respirable suspended particle (RSP) can vary across a large scale (9-825 $\mu g/m^3$) (Reponen et al., 1989; Heavner et al. 1996; Ormstad et al., 1997). For the exposure assessment of particles, measurements of different size fractions of particles, like PM_{10} and $PM_{2.5}$ have been recommended (Morawska et al., 2001). Koistinen et al. (2001) showed that the mean indoor concentrations of $PM_{2.5}$ (21 ± 24 $\mu g/m^3$) were approximately 2.5 times higher in dwellings with smokers than those (8 ± 5 $\mu g/m^3$) in non-smoking dwellings. Furthermore, the levels of $PM_{2.5}$ were higher outdoors than indoors in non-smoking dwellings. In general, efficient ventilation with supply air filtration can reduce the exposure to outdoor particles, especially in the size fractions of 1-5 µm depending on a filter type (Partti-Pellinen et al., 2000; Jamriska et al., 2000; Morawska et al., 2001).

Indoor air levels of fungi and actinomycetes are strongly associated with a seasonal variation, at least in the cold and temperate climates where the lowest levels (typically below 100 cfu/m^3) are observed in winter time (Nevalainen, 1989; Reponen et al., 1992; Maroni et al., 1995; Spengler et al., 2001). Although occupants are the main source of bacteria, insufficient ventilation may maintain high bacteria levels indoors (Nevalainen, 1989). In rural areas, indoor air levels of micro-organisms are usually higher than in urban dwellings (Pasanen, 1992).

Keeping pets indoors has become more popular and housecleaning habits have changed; this has been assumed to increase the exposure to indoor allergens. However, data on allergen levels in indoor air in dwellings is scarce so far, and the data available mainly concerns allergen contents in settled house dust. Levels of mite allergens (Der p 1, Der f 1) in house dust are usually rather low (below 2 µg/g) in dry and cold climates such as in Finland, Sweden and Canada. However, they can even be over ten times higher in humid areas and seasonally (e.g. in Australia, Japan, Denmark the Netherlands, the UK, and the USA) (Lau et al., 1989; Sakaguchi et al., 1989; Van Strien et al., 1994; Marks et al., 1995; Custovic et al., 1996; Miyazawa et al., 1996; Luczynska et al., 1998; Raunio et al., 1998; Peterson et al., 1999; Gross et al. 2000; Emenius et al. 2000). High cat and dog allergen levels in settled dust (10^1-10^3 μg/g) are found in the residences where pets are kept inside, but detectable allergen levels (μg/g) also occur in residences and other interior spaces where pets have never visited (Patchett et al., 1997; Raunio et al., 1998; Custovic et al. 1998; Almqvist et al., 1999; Mølhave et al., 2000a). Cat and mite allergen levels of nanograms per m^3 in the indoor air have been reported in a few studies (Peterson et al., 1999, Parvaneh et al., 2000). Cockroach allergens, in humid and warm areas (e.g. Australia, some parts of the USA, Germany), that range up to 10 U/g are found in house dust (De Lucca et al., 1999; Platts-Mills et al., 2000; Hirsch et al., 2000).

2.1.2 Design and control of indoor climate and IAQ

A building is an extremely complex product, and indoor climate in the building is influenced by many factors (Figure 2). All these factors should be considered in both the design and construction phases, and also in the use of the building in order to achieve and control good indoor climate and IAQ.

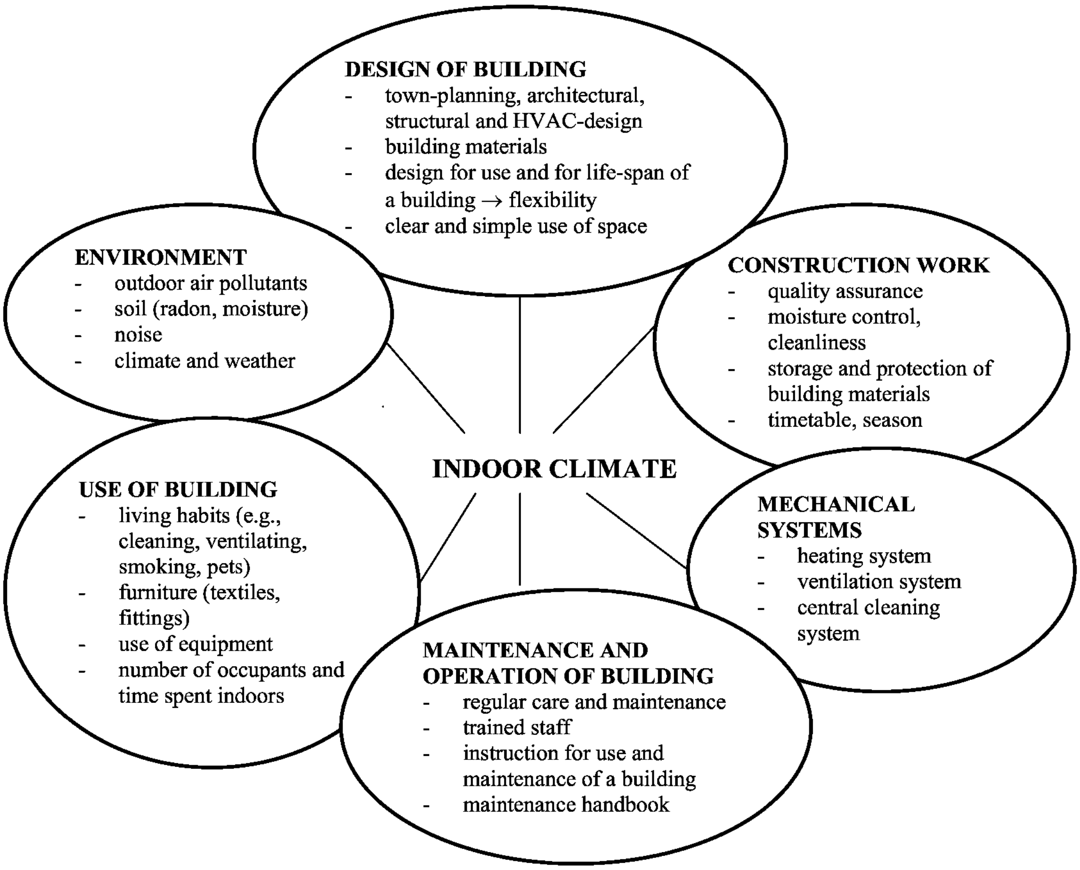


Figure 2. Factors affecting indoor climate in a building.

Control of IAQ can be roughly divided into two parts: the control of the sources and the removal processes of pollutants. One example of source control is use of low-emitting building materials to decrease VOC levels indoors (Saarela et al., 1999; Lundgren et al., 1999; Brown, 1999). It has been estimated that a half of VOCs in indoor air originates from building materials (Mølhave et al., 1996). In new or renovated buildings, so-called bake-out procedure (i.e. airing out or ventilation off procedure) may act as an effective removal process for VOCs. In the airing out or ventilation off procedure, the building is kept unoccupied and ventilated at a high capacity before occupants move into the buildings. In the bake-out procedure, the room temperature is also be raised to speed up the release of impurities from new materials. Another example of source control is radon mitigation. Arvela (1995) has pointed out that radon entry from the soil to indoors can be restricted by good design work with appropriate structures. However, the control of sources is not restricted merely to the design of a building, but important sources of indoor air pollutants (e.g. smoking) can also be controlled during the use of a building.

Ventilation is one of the most important tools in the removal processes to control IAQ (pollutants of human origin, material emissions) over the use of building. Sufficient ventilation also effectively removes humidity caused by occupants and their activities, and thus prevents moisture problems (e.g. condensation) in buildings. The outdoor-air supply of 10 litres per second per person is regarded as sufficient in order to assure fresh indoor air (Godish and Spengler, 1996; Menzies and Bourbeau, 1997; Liddament, 2000). In theory, all types of ventilation systems (natural ventilation, mechanical exhaust ventilation, mechanical supply and exhaust ventilation) could maintain the sufficient air exchange rates if ventilation is correctly designed, used and serviced. However, in practice the best control of IAQ is reached with a mechanical exhaust or a completely balanced mechanical supply and exhaust ventilation system (Fehlmann and Wanner, 1993; Åberg et al., 1996).

Another example of the removal processes includes cleaning procedures, and use of air and vacuum cleaners with which the levels of particles and allergens can be decreased (Franke et al., 1997; Wolkoff et al., 1998; Van der Heide et al., 1999; Rønborg et. al., 1999; Tovey and Marks, 1999; Bellanti et al., 2000; Warner et al., 2000). In the design of buildings, cleaning must be taken into consideration. This includes, for example, choice of finishing materials (Kildesø and Schneider, 2001).

2.1.3 Typical IAQ problems - their reasons and possible health effects

Sometimes indoor climate conditions may worsen and the concentrations of indoor air pollutants rise high enough to lead to IAQ problems in buildings that provoke complaints, discomfort and possible health effects among occupants. IAQ problems are often complex and may be caused by several factors that affect various IAQ parameters.

One common factor is too high room temperature. It may lead to an increase of building material emissions. This can elevate indoor levels of VOC and odours (Van der Wal et al., 1997; Fang et al., 1998). Ruotsalainen et al. (1992) observed that in 46% of Finnish houses and flats studied (n=241), the room temperature exceeded 22 °C. Furthermore, the temperature was significantly higher in flats than in houses. This might be due to different ventilation systems between the building types. Other possible reasons for this are the heating systems (either improper installation and design values or wrong usage) or the proximity of flats and rooms to "warm spaces", for example, boilers or drying rooms. In addition, during a hot spell, the outdoor air temperature heats the indoors via heat radiation. (Ruotsalainen et al., 1997).

Condensation or accumulation of moisture inside a building and increased indoor levels of CO_2, bacteria, allergens, radon and/or odours is also commonly caused by insufficient ventilation or an improperly maintained ventilation system (Ruotsalainen, 1995; Emenius et al., 1998; Emenius et al., 2000, Maroni et al., 1995; Spengler et al., 2001). In buildings with natural ventilation, air exchange rates often remain too low (< 0.5 1/h, Harving et al., 1992; Fehlmann and Wanner, 1993; Ruotsalainen, 1995; Emenius et al., 1998), while in buildings with mechanical ventilation, a common problem is insufficient supply air intake. This results in too high negative pressure indoors that may transfer impurities from structures to the indoor air (Ruotsalainen et al., 1997; Spengler et al., 2001). Typical problems with the mechanical supply and exhaust ventilation system are usually related to defects in the adjustments and neglect of the system maintenance, for example, too long intervals between filter changes and duct cleaning (Pejtersen, 1996; Pasanen, 1998; Spengler et al., 2001).

Dampness, water damage and bio-contamination (microbial growth, proliferation of mites) are also frequent IAQ problems. The reasons for moisture problems in buildings are numerous, such as flaws in design and construction; capillary transfer of water from the ground, insufficient drainage and drying of structures before installation of finishing materials; aging of the building and its materials (for example, pipe or roof leakage); wrong use of building and equipment (for example changed use of basement, temporary use of a ventilation system, too active use of air humidifiers). (ISIAQ, 1996; Lawton et al., 1998; Nevalainen et al., 1998; Maroni et al., 1995; Spengler et al., 2001). In a Finnish survey, signs of current or previous moisture damage were observed in 80% of dwellings regardless of the age of the building in a random sample of 450 houses. In addition, about 55% of the houses, in general, were evaluated to be in need of repair or more thorough inspection (Nevalainen et al., 1998).

The use of poor quality building materials and products or the improper installation of products, for example installation on moist structures, may increase indoor levels of certain pollutants, like ammonia and formaldehyde. In the 1970's at least, formaldehyde containing glues and resins were widely used in chipboards and insulation materials (Salthammer et al., 1995; Maroni et al., 1995; Spengler et al., 2001). Increased concentrations of ammonia have been observed, for example in the buildings where fillers with animal protein have been spread on moist concrete surfaces (Bäck et al., 1997; Puhakka et al., 2000).

The health effects linked with exposure to indoor pollutants may appear soon after exposure or years later. The likelihood of an immediate reaction (e.g. irritation, general symptoms) to indoor air pollutants depends on the occupants, for example their age, gender, general health condition and individual sensitivity. Certain health effects have a long latent period. These include sensitisation and allergy to biological agents, and development of lung cancer. Particular segments of the population may have a greater risk of developing symptoms and diseases. This group includes children, the elderly, those with an earlier history of respiratory diseases and hyper-responders (EU-ECA-10, 1991; WHO, 2000a).

The health effects related to the indoor environment can be divided into five categories caused by different indoor pollutants as shown in Table 2 (Mølhave, 2000b).

Table 2. Categories of health effects and their causes in the indoor environment.

Health effects	**Causative agent**
Immune effects and other hypersensitivity, e.g. asthma	Biological and chemical agents, e.g. micro-organisms, allergens and formaldehyde
Cellular effects including cancer and genotoxic effects, e.g. lung cancer	Asbestos, radon, tobacco smoke
Respiratory effects	NO_2, particulate matter, bioaerosols
Neurogenic and sensory effects	TVOC, formaldehyde, endotoxin
Effects on the cardiovascular system	CO

References: Mølhave, 2000b; Jones, 1999; Maroni et al., 1995; Spengler et al., 2001.

In the connection with indoor environments, especially the office environment, Sick Building Syndrome (SBS) and Building Related Illness (BRI) are often discussed. BRI is caused by exposure to biological (e.g., fungi, bacteria, endotoxin), physical, or chemical agents (e.g., carbon monoxide, formaldehyde, radon) in indoor environments. BRI can be further classified into three groups: airborne infectious diseases (e.g., Legionnaires' disease, Pontiac fever), hypersensitive diseases (e.g., allergic asthma, allergic rhinitis and hypersensitivity pneumonitis), and toxic reactions (e.g., caused by carbon monoxide or pesticides). SBS has no clear aetiology, but is associated with occupancy of a particular building environment. Common symptoms of SBS include eye, nose and throat irritation, sensation of dry mucous membranes and skin, erythema, mental fatigue, headaches, a high frequency of airway infections, cough, hoarseness, wheezing, itching, unspecific hypersensitivity, nausea, and dizziness. In general, the main difference between BRI and SBS is that BRI symptoms do not necessarily cease outside the problem building. (Brightman and Moss, 2001). The WHO has estimated that 30% of new and remodelled buildings worldwide may generate excessive complaints related to IAQ (WHO, 1982).

Reported risks for health effects linked with indoor climate are presented in Table 3. An evident risk for respiratory responses, e.g. asthma (odds ratio >2), has been associated with gas stoves, dampness, moulds and indoor pets. Evidence of the relationship between exposure to chemical compounds and health effects is not as evident.

Table 3. Selected examples of the epidemiological studies on the relationship of health risks and indoor climate in residences.

Study	**Study design**	**Risk factor**	**Health risk**
Dales et al., 1991; Canada	14799 adults (>21 yr) Questionnaire, cross-sectional study	Dampness	Lower respiratory symptoms: OR=1.62, 95% CI=1.48-1.78
Dekker et al., 1991; Canada	17962 schoolchildren Questionnaire, cross- sectional study	Environmental factor: ETS Dampness in home Gas cooking Use of humidifier ETS Dampness in home Use of humidifier	Asthma: OR=1.40, 95% CI=1.13-1.73 OR=1.46, 95% CI=1.28-1.98 OR=1.95, 95% CI=1.41-2.65 OR=1.66, 95% CI=1.36-2.01 Wheezing: OR=1.38, 95% CI=1.17-1.65 OR=1.61, 95% CI=1.39-1.85 OR=1.35, 95% CI=1.15-1.59
Infante-Rivard, 1993; Canada	Cases=457 and controls=457, telephone interview Case-control study	Home environment factor: Mother's heavy smoking Use of a humidifier in the child's room An electric heating system	Asthma: OR=2.77, 95% CI=1.35-5.66 OR=2.27, 95% CI=1.42-3.65 OR=1.82, 95% CI=1.42-3.65
Spengler et al., 1994; USA and Canada	Study population n=15523 Questionnaire study	Housing characteristics: Built before 1970's Homes with smokers Homes with air conditioners Homes with air cleaners Homes with humidifiers Homes with dampness	Lower respiratory symptoms: OR=1.12, 95% CI=1.01-1.24 OR=1.24, 95% CI=1.12-1.37 OR=1.14, 95% CI=1.02-1.28 OR=1.37, 95% CI=1.18-1.60 OR=1.47, 95% CI=1.32-1.63 OR=1.48, 95% CI=1.34-1.64
Andersson et al., 1997; Sweden	Review study, 67 articles	VOC in non-industrial indoor environments	The group concluded that indoor air pollution including VOC is most likely a cause of health effects and comfort problems in indoor environments in non-industrial buildings.

OR=odds ratio; CI=confidence interval; RR=relative risk

Table 3. Continued.

Study	**Study design**	**Risk factor**	**Health risk**
Weislander et al., 1997; Sweden	562 participants, indoor air measurements and questionnaire	Painting: Newly painted indoor surfaces Newly painted wood details Kitchen painting	Asthma: OR=1.5, 95% CI=1.0-2.4 OR=2.3, 95% CI=1.2-4.5 OR=2.2, 95% CI=1.1-4.5
Ahlbom et al., 1998; Sweden	Review study, 89 articles	Pets indoors	The group concluded that all exposure to pets involves a risk of sensitisation. Exposure in infancy involves an increased risk (normally RR=1-1.5) of sensitisation and, to a lesser degree, of the developments of symptoms.
Garrett et al., 1998; Australia	80 households, indoor air measurements and questionnaire	Home environment in general: Gas stove Indoor pets Airborne Aspergillus spores Gas stove	Asthma: OR=3.15, 95% CI=1.28-7.72 OR=2.68, 95% CI=1.07-6.70 Atopy: OR=1.51, 95% CI=1.05-2.18 Respiratory symptoms: OR= 2.32, 95% CI=1.04-5.18
Peat et al., 1998; Australia	Review study, 76 articles	Damp or mould in home	The increased risk of children having symptoms of coughing and wheezing: OR=1.5-3.5
Garrett et al., 1999; Australia	148 children (7-14 yr) Indoor air measurements and questionnaire	Formaldehyde	Atopy: OR=1.40, 95% CI=0.98-2.00
Bornehag et al., 2001; Sweden	Review study, 61 articles	Dampness in general	Increase risk for health effects in the airways, such as coughing, wheezing and asthma: OR=1.4-2.2
Kilpeläinen et al., 2001 Finland	10667 students of university (18-25 yr) Questionnaire study	Visible mold	Asthma: OR=2.21, 95% CI=1.48-3.28 Common cold: OR=1.49, 95% CI=1.18-1.87

OR=odds ratio; CI=confidence interval; RR=relative risk

As a conclusion to this part of the review, Figure 3 shows how IAQ is linked with health responses. The figure shows a sequence that starts from emissions derived from sources through to exposure and dose, ending up with possible health consequences if mitigation strategies cannot prevent the reaction chain.

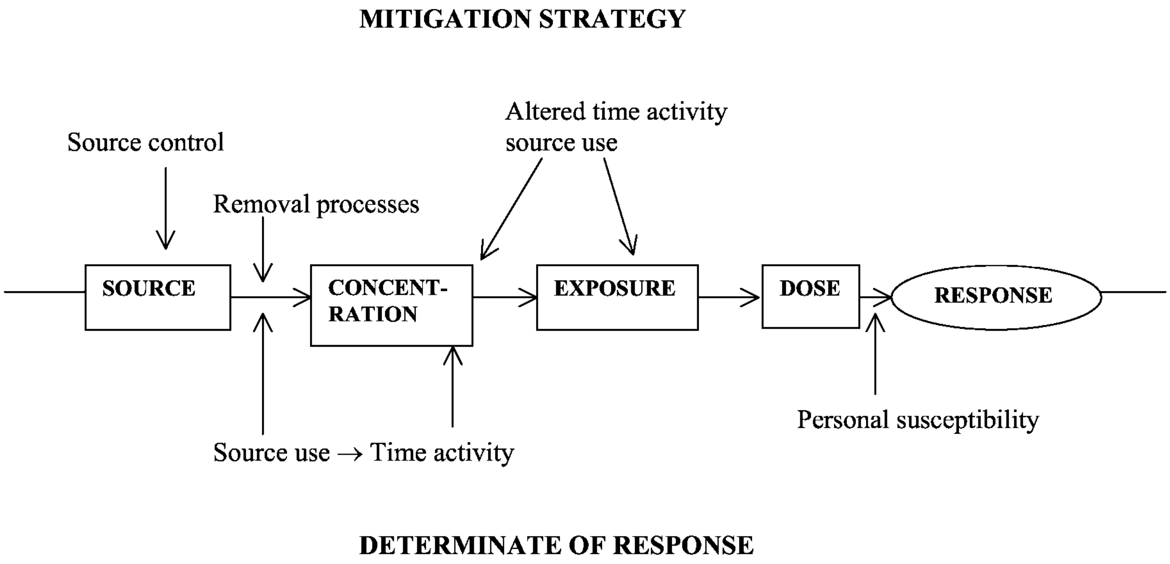


Figure 3. Sequence from indoor air pollution to possible health effects (modified from American Lung Association & American Thoracic Society workshop report, 1997).

2.2 Reference values for indoor climate

Criteria for acceptable air quality have existed for many years for industrial working environments and outdoor air. In Finland, the Ministry of Social Affairs and Health has set the reference values for some indoor climate variables in the Indoor Air Guidelines (Table 4 below). The guidelines have mainly been intended for authorities in order to evaluate health-based acceptability of IAQ in residences, schools and day-care centres. The first guidelines for IAQ were published in 1990, and they were updated in 1997 (including, for example, the reference values for micro-organisms and ammonia) with a supplement of detailed instructions of protocols and methodology for IAQ investigations (Aurola and Välikylä, 1997). Currently, the guidelines are again being updated and a new version will be available in 2002.

The reference values for IAQ given in other Nordic countries, USA and Canada and by the WHO are presented in Table 4 below. The national references values are mainly based on health and comfort aspects, which are rather similar in different countries. The WHO reference values are only based on health effects, and so far, they have been given only for gaseous pollutants. At present, the "Guidelines for Biological Agents in Indoor Environment" is in preparation in the WHO, and they will probably be published in 2002.

Unfortunately, no reference values have been given for indoor allergens in any country. Some epidemiological studies and international workshops have concluded that there is evidence for increased risk for sensitisation if the allergen content in settled dust exceeds 2 or 8 μg/g for cat allergen, Fel d 1, (Call et al., 1992; Gelber et al., 1993), 10 μg/g for dog allergen, Can f 1, (Ingram et al., 1995), 2-4 U/g for cockroach allergen, Bla g 1 (Eggleston et al., 1998), and 2 μg/g for house dust mite allergen, Der p 1, (Platts-Mills et al., 1992). In addition, exposure to greater than 10 μg Fel d 1/g, 10 μg Der p 1/g, or 8 U Bla g 1/g in settled dust has been associated with symptomatic/acute asthma or increased asthma morbidity among children (Pollart et al., 1989; Peat et al., 1996; Rosenstreich et al., 1997). However, these risk factor values have been widely criticized because they are based on the allergen content in settled dust and on relatively little data: they do not describe inhalation exposure to aeroallergens and do not take account of individual susceptibility sufficiently well (Parvaneh et al., 2000).

Table 4. Reference values for indoor climate in different countries and given by various organizations.

Indoor air factor	**Finland (1)**	**Sweden (2)**	**Norway (3)**	**Denmark (4)**	**USA (5)**	**Canada (6)**	**WHO/Europe (7)**
Room temperature	<22 °C	>18 °C	-	-	-	-	-
Relative humidity of air(RH)	<45%	<45%	-	-	-	30-80% in summer 30-55% in winter	-
Air exchange rate	0.5 1/h	0.5 1/h	-	-	-	-	-
Carbon dioxide, CO_2	<2700 mg/m^3	<1800 mg/m^3	<1800 mg/m^3	-	-	$\leq$6300 mg/m^3	-
Carbon monoxide, CO	<8 mg/m^3	-	<10 mg/m^3[8h] <25 mg/m^3[1h]	-	10 mg/m^3 40 mg/m^3 [1h]	$\leq$13 mg/m^3 [8 h] $\leq$29 mg/m^3 [1 h]	100 mg/m^3 [15 min] 60 mg/m^3 [30 min] 30 mg/m^3[1 h] 10 mg/m^3 [8 h]
Nitrogen dioxide, NO_2	-	-	<100 μg/m^3[24h] <200 μg/m^3[1h]	-	93 μg/m^3 [1 year]	$\leq$100 μg/m^3 $\leq$480 μg/m^3[1 h]	200 μg/m^3 [1 h] 40 μg/m^3 [year]
Sulphur dioxide, SO_2	-	-	-	-	79 μg/m^3 [1 year] 368 μg/m^3 [24 h]	$\leq$ 1000 μg/m^3 [5 min] $\leq$50 μg/m^3	500 μg/m^3 [10 min] 125 μg/m^3 [24 h] 50 μg/m^3 [year]
Total suspended particles, TSP	-	-	<40 μg/m^3[RSP]* <90 μg/m^3[SP]**	-	-	$\leq$40 μg/m^3 $\leq$100 μg/m^3[1h]	-
Fungal spores	<100 cfu/m^3	-	-	-	-	-	-
Bacteria	<4500 cfu/m^3	-	-	-	-	-	-
Actinomycetes	<10 cfu/m^3	-	-	-	-	-	-
Ammonia	<40 μg/m^3	-	-	-	-	-	-
Formaldehyde	<150 μg/m^3	<100 μg/m^3	<100 μg/m^3	<150 μg/m^3	-	$\leq$120 μg/m^3	100 μg/m^3 [30 min]
TVOC	<600 μg/m^3	-	<400 μg/m^3	-	-		-
Radon, Rn	<200 Bq/m^3 new houses <400 Bq/m^{3}old houses	<200 Bq/m^3 new houses <400 Bq/m^{3}old houses	<200 Bq/m^3 new houses 200-800 Bq/m^{3}old houses	-	150 Bq/m^3	<800 Bq/m^3	200 Bq/m^3 [1 year]
Ozone	-	-	-	-	-	$\leq$240 μg/m^3 [1 h]	120 μg/m^3 [8 h]

Sources: 1) The Ministry of Social Affairs and Health, 1997; 2) The Boverket, 1999 and the Socialstyrelsen, 1999; 3) The Norwegian Directorate of Health, 1991; 4) The Directorate for the Occupational Environment, 1987; 5) Spengler et al., 2001; 6) The Environmental Health Directorate, 1989; 7) WHO, 2000c.

* RSP = respirable particles, diameter range 0.1 - 2.5 μm, ** SP = suspended particles, diameter range 0.1 - 10 μm

2.3 Classifications and labelling systems for good indoor climate

Since 1995, the Classification of Indoor Climate, Construction and Finishing materials (FiSIQ, 1995) has been available in Finland. Now the Classification has been updated and a new version was released in February 2001 (FiSIQ, 2001). The new classification focuses more accurately on the whole construction process (design, construction time, installation, adjustment, operation and maintenance, as well as, manufacturing of the building materials and products) and takes into account five years of field use with the previous version. The Classification has been well received by the building industry, and currently over 400 tested, low-emitting building materials are available for customers in Finland (Neuvonen, 2000).

The Classification of Indoor Climate 2000 has three parts: (1) The target values for indoor climate (S categories), (2) Guidance for design and construction of buildings (P categories), and (3) Requirements for building products (M categories). In addition, design values for heating, ventilation and air conditioning equipment and systems are given in the first part of the classification. The S categories (target values) include three classes: S1 for individual climate (very good IAQ and comfortable thermal conditions), S2 for good climate, and S3 for satisfactory indoor climate. The S1 target values for indoor climate variables in the previous and current Classifications are presented in Table 5 below. Some changes to the values were made; for example, the requirements for CO_2, radon and ozone were tightened, while the target values for ammonia and odour requirements were loosened. The second part suggests the principles and procedures to be followed in the design of a building and at various stages of the construction process. The procedures presented are intended mainly for construction and contractors, but they also contain requirements for design, equipment manufacturing and maintenance. The requirements for building products presented in Table 6 are intended to promote the development and use of low-emitting building products and clean air-handling equipment and components. The products are required to fulfil the criteria after four weeks from the manufacture.

Table 5. The Finnish target values for individual IAQ (S1 class) given by FiSIAQ in 1995 and 2001.

Indoor air parameter	**Target value for S1 in Classification of Indoor Climate 1995**	**Target value for S1 in the Classification of Indoor Climate 2000**
Room temperature	21-22 °C in winter 22-25 °C in summer	21-22 °C in winter 23-24 °C in summer
Relative humidity of air (RH)	25-45% in winter 30-60% in summer	25-45% in winter not given for summertime
CO_2	<1000 ppm	<700 ppm
CO	<2 mg/m^3	<2 mg/m^3
TSP	<60 µg/m^3	PM_{10} <20 µg/m^3
Ammonia	<20 µg/m^3	<30 µg/m^3
Formaldehyde	<30 µg/m^3	<30 µg/m^3
TVOC	<200 µg/m^3	<200 µg/m^3
Odour intensity	<2 desipol	<3 desipol
Radon	<200 Bq/m^3	<100 Bq/m^3
Ozone	<50 µg/m^3	<20 µg/m^3

Table 6. The requirements for building material emissions in class M1 and M2 (FiSIQ, 2001).

Requirement	**Class M1**	**Class M2**
Emission of TVOC Minimum proportion of identified compounds	<0.2 mg/m^{2}h 70%	<0.4 mg/m^{2}h 70%
Emission of formaldehyde	<0.05 mg/m^{2}h	<0.125 mg/m^{2}h
Emission of ammonia	<0.03 mg/m^{2}h	<0.06 mg/m^{2}h
Emission of carcinogenic compounds belonging to category 1 in the IARC classification (IARC, 1987)	<0.005 mg/m^{2}h	<005 mg/m^{2}h
Proportion of panellists dissatisfied with the odours from the material	<15% The material does not produce odours	<30% The material does not produce distinct odours
Plasters and tiling products, levelling agents, putty, mastics, fillers, screeds and renders shall not be allowed to contain casein.		

Besides Finland, labelling systems have been established in some other countries such as Denmark, Germany, and the United States. All these systems are voluntary and have differences in the criteria and target materials as described below.

The Danish system, the Indoor Climate Labelling (ICL, 2001) is also in use in Norway. The ICL contains testing and labelling criteria for emissions of the following product groups; (1) Carpets, (2) Wall and ceiling systems, (3) Interior doors and folding partitions, (4) Resilient floors, wood based floors and laminated floors, (5) Oils for wood-based floors, (6) Windows and exterior doors, (7). Kitchen, bath and wardrobe cabinets, (8) Interior paint, and (9) Furniture. The basis for the criteria is the so-called indoor-relevant time-value that describes how long a product will emit compounds that may release odours and cause mucous membrane irritation. The estimation of the indoor-relevant time is based on both measurements of chemical emissions from a primary source and sensory evaluation. The chemical testing is generally carried out three times (on days 0, 3, 28) and sensory evaluation once within 28 day after the manufacture. The suppliers are obliged to prepare separate guidelines for storage, transport, installation, cleaning and maintenance of their products in order not to decrease the indoor air properties during the use of the products. For ceiling systems and other fibre-containing products, measurements of particle and fibre emissions are also required (ICL, 2001).

In Germany, there are three different labelling systems; a GuT system for carpets; a GEV-Emicode system for flooring products, such as adhesives, levelling compounds, primers and underplays; and a RAL UZ 38 system for wood and wood-based products. GuT (the Association of Environmentally-Friendly Carpets), established in 1990, has members from nine European countries. The criteria include limitations in use of certain substances in the manufacturing of products, for example carcinogenic, mutagenic or reproduction toxic substances, as well as, testing chemical emissions (e.g. formaldehyde and TVOC) and the sensory evaluation of final products. Emission tests for selected compounds are performed as chamber tests 24 hours after loading. The EMICODE labelling system was established by GEV (Gemeinschaft Emissionskontrollierte Verlegewerkstoffe) for consumer protection to indicate products of very low emissions (EC 1). More than 400 products have been licensed as EMICODE® EC1. The RAL UZ 38 system includes testing of VOC and formaldehyde emissions from wooden products using a chamber method 24h ± 2h after loading and the 28th day after loading. (Plehn et al., 2000; Jann et al., 2000; Winkels, 2000).

The U.S. GREENGUARD™ programme was designed for low-emitting and non-toxic finishing materials. Emissions of VOCs, formaldehyde and total aldehydes are measured for tested products. In addition, other contaminants, such as particles and ozone, are determined from electronic equipment. The products must meet the criteria within a one-week period of installation or usage. (Greenguard™, 2001).

The above-mentioned labelling systems differ from each other mostly regarding the time of testing. As a first step to standardising the testing procedure, the European Commission has given instructions about how to evaluate the VOC emissions from flooring materials (EU-ECA-19, 1997). The standardisation work to harmonize testing of material emissions is still ongoing, however, the first drafts of the methodology for estimation of VOC emissions are available (the chamber tests: CEN, 1999a; the cell method: CEN, 1999b). The standard defines the testing conditions (for example, temperature and RH), the method for sampling and the time of testing.

Guidelines and standards for HVAC systems regarding hygienic aspects have also been developed in Germany (the German guideline VDI 6022, 1998; Funk, 1999) and the USA (ASHRAE, 62-1999). In addition, the European Committee for Standardization has established the CEN/TC 156 work group to develop standards for ventilation in buildings. At present, standards dealing with the design, manufacturing and installation of HVAC systems and components are under development or under an approval process (CEN/TC 156, 2001).

The recommendations for the whole building process have been published in Sweden (Samuelsson, 2000), Canada (Canadian standards Association, 1994) and in Minnesota in the USA (Carmody et al., 2000) in order to reach better IAQ in the public buildings such as offices and schools. In Norway, clean building guidelines have been developed for use at building sites (Johnsen et al., 1996; Johnsen, 1997), and a project to produce and apply the guidelines systematically in real buildings is in progress (Flatheim, 2000).

The main constituents of the indoor climate guidelines and labelling systems discussed above are summarised in Table 7 below. The Finnish Classification of Indoor Climate, as well as the Swedish P-marketing, take into account all main stages of the building process and try to control both the sources and the removal of existing pollutants during the occupancy time, whereas the material labelling systems, described above, only focus on the source control.

Table 7. Properties of the guidelines or labelling systems for indoor climate in different countries.

Guideline/labelling system and country (reference)	**Requirements for design work**	**Requirements for construction work**	**Requirements for HVAC work**	**Requirements for building materials**	**Requirements for furniture**	**Requirements for HVAC components**	**Target value for indoor climate**
Classification of Indoor Climate 2000, Finland (FiSIQ, 2001)	**Yes**	**Yes**	**Yes**	**Yes**	No	**Yes**	**Yes**
Indoor Climate Labelling, Denmark & Norway (ICL, 2001)	No	**Yes/No**	**Yes/No**	**Yes**	**Yes**	No	No
GuT, Germany (GuT, 2001)	No	**Yes**	No	**Yes**	No	No	No
EMICODE EC1$^{®}$, Germany (Winkels, 2000)	No	No	No	**Yes**	No	No	No
RAL, Germany (Plehn et al., 2000; Jann et al., 2000)	No	No	No	**Yes**	No	No	No
GREENGUARD^{TM} program, USA (2001)	No	No	No	**Yes**	**Yes**	No	No
VDI 6022 guideline, Germany (VDI 6022, 1998)	**Yes**	No	**Yes**	No	No	**Yes**	No
Canadian standards Association, Canada (1994)	**Yes**	**Yes**	**Yes**	**Yes**	No	**Yes**	No
ASHRAE guidelines for clean HVAC, USA (ASHRAE 62, 1999)	**Yes**	No	**Yes**	No	No	**Yes**	**Yes**
P-marketing, Sweden (Samuelsson, 2000)	**Yes**	**Yes**	**Yes**	**Yes**	**Yes/No**	No	**Yes**
Clean buildings guidelines, Norway (Johnsen et al.,1996)	No	**Yes**	**Yes**	No	No	No	No

2.4 Healthy residences for people with respiratory allergies

2.4.1 Requirements for indoor climate

An allergen- and irritant-free environment is a key factor for the well being of people with allergies and asthma (Asthma programme in Finland, 1996; Jones, 2000; IOM, 2000; Dahl and Bjermer, 2000). Indoor climate factors may play a role at three levels (Sundell, 2000): activating the immune system to react in unfavourable ways; triggering symptoms in those people already sensitised; and maintaining a sustained inflammatory state in the mucous of the respiratory passages that results in a heightened sensitivity to allergens and other irritants or to provocative conditions, such as oxidant or corrosive pollutants, cold air or physical exertion.

The IOM (Institute of Medicine) has listed typical asthma triggers and the evidence that they cause or associate with the disease (IOM, 2000). Sufficient evidence of a causal relationship between the development of asthma and exposure to house dust mites, cat and cockroach allergens is available. Sufficient evidence has been gathered of an association between asthma and exposure to dog allergens, moulds and high levels of composition pollutants. Limited or suggestive evidence has been obtained on the relationship between asthma and exposure to allergens from domestic birds, ETS, formaldehyde, and fragrances. So far, inadequate or insufficient evidence is present for any link between asthma and exposure to endotoxins, houseplants, pollen exposure in indoor environments, pesticides, plasticizers and VOCs.

Because of clear causal evidence on the relationship between exposure to some indoor air allergens and the development of asthma, detailed instructions on how to deal with furnishings (e.g. carpets, sofas, curtains), houseplants, and cleaning (especially for bedding clothes), and how to control relative humidity of air are given to asthmatic patients in order to reduce exposure (Jones, 2000). Concluding from the literature (Platts-Mills et al., 1997 and 2000; Woodcock and Custovic, 1998; Tovey and Marks, 1999; Jones, 2000; Sundell et al., 2000; Champman et al., 2001), dwellings for people with respiratory allergies should:
1. be easy to clean (in good order, no soft and furry materials, good space for clothes)
2. have adequate ventilation, preferably an adjustable system equipped with supply air filtration
3. have RH of air below 50% and be free from moisture damage both during construction and occupancy. If damage appears, it should be repaired immediately.
4. be as free as possible from air pollutants and allergens (no smoking indoors, control of allergens, e.g. house dust mites, animal dander, houseplants).

2.4.2 Practical examples of building projects

Only a few study buildings for people with respiratory allergies have been reported in the literature, and these were mainly in Sweden. General instructions for dealing with allergy-adapted apartments were published in 1991 (Hult and Persson, 1991). The instructions were divided into five parts: general information about allergens and irritants; requirements for location of a building and its surroundings (e.g. suitable plants and trees for allergenic people); general design instructions for flats; requirements for indoor climate, construction site, building materials and equipment; and some aspects of the quality control.

Blomsterberg and Carlsson (1997) described the building process of a block of flats in 1992 - 1993 in Sweden. In the design, a choice of building materials (low-emitting finishing materials) and ventilation system (mechanical supply and exhaust system with fine supply air filters and the outdoor air ventilation rate of 1 1/h) received special attention. The building envelope and exterior walls were made of concrete, and the air tightness of the building envelope was of 0.5 1/h at 50 Pa. At the construction site, general control and control of moisture in concrete before application of flooring were carried out. In addition, some indoor climate aspects were recommended, for example, continuous heating of bathrooms, a central vacuum cleaner, sufficient daylight, isolated kitchen and clothes closet, at least one bedroom/apartment with a balcony for airing of bedding, and additionally, smoking and furred animals were not allowed in the building. The indoor climate was monitored during the first year after the completion of the building. The target limits for TVOC (<600 $\mu g/m^3$), formaldehyde (<48 $\mu g/m^3$), and CO_2 (<1000 ppm) were achieved, but the requirements for particles, draught and noise from the ventilation system were not fulfilled. The additional costs due to the allergy adaptation were 11%. If the costs for the measures that were not observed to have a noticeable effect on IAQ (exterior walls of concrete, the increased ventilation rate and a central vacuum cleaner) are excluded, the extra costs decreased to a level of 6%.

In the USA, the American Lung Association have prepared instructions and recommendations for healthy buildings (American Lung Association, 2001a, b). The instructions include reduction of indoor allergens, moisture control, avoidance of exposure to indoor impurities from gas cooking and heating, guidance for household furnishings, as well as for use of household products and air filtration.

In Italy, hotels have been developed for sensitive people (Franchi, 2000). The main criteria are the following; (1) floors (or at least rooms) are exclusively reserved for non-smokers and sufficiently large smoke-free areas are available indoors; (2) recommendations for reducing the levels of irritants and allergens, particularly house dust mites; (3) training courses for hotel staff, including kitchen and restaurant staff, about specific groups of people with wood allergy and hyper sensitisation, for example. In Canada, a policy has been established for scent-free hospitals and schools, directed to both the customers and the manufacturers (Fox et al., 1999).

A Swedish building company has developed so-called allergy packages for homes of allergic or hypersensitive people (Björck, 2000). Four separate allergy packages are designed to deal with dust, contact, pollen, and food allergy. In these dwellings, special attention is paid to ventilation (especially supply air and its filtration) and to cleaning (e.g. use of central vacuum cleaner and properties of indoor surfaces).

3 AIMS AND HYPOTHESES OF THE STUDY

This thesis summarises the results of the original articles I-IV and contains some unpublished data. The overall aims of this study were to survey IAQ in residences of people with respiratory diseases and produce practical information on how to improve IAQ in existing, as well as in new residences, for people with respiratory diseases.

The detailed aims of the study were:

1. To survey IAQ in residences of people with respiratory diseases and find out whether it differed from that in other residences in Finland (I).

2. To find out how the home environment is experienced by people with respiratory diseases and how IAQ in residences can be improved (I, IV).

3. To evaluate whether good indoor climate can be achieved in a new block of flats designed and built for people with respiratory diseases (the case building), following the Classification of Indoor Climate, Construction and Finishing Materials (FiSIQ, 1995) and at a reasonable cost (II, III).

4. To study whether a seven-day powerful ventilation period after the completion of the case building, but before occupants move in, is capable of decreasing levels of indoor air pollutants (III).

5. To investigate the effect of three years of occupancy on IAQ in the case building (III, IV).

6. To establish a useful and operative model for the use of building technology and to evaluate the usefulness of Classification of Indoor Climate 1995 in order to build healthy buildings (I-IV).

The hypotheses of the study were:

1. The IAQ in the residences of people with respiratory diseases is better than in Finnish residences in general because patients with respiratory diseases receive information on how to renovate to reduce dust/allergens and the importance of IAQ for their well being after diagnosis.

2. Good indoor climate can be achieved by careful design, choice of proper building materials and equipment, and high quality construction practices. In addition, it was assumed that indoor climate can be maintained at a high level of quality during the time of occupancy.

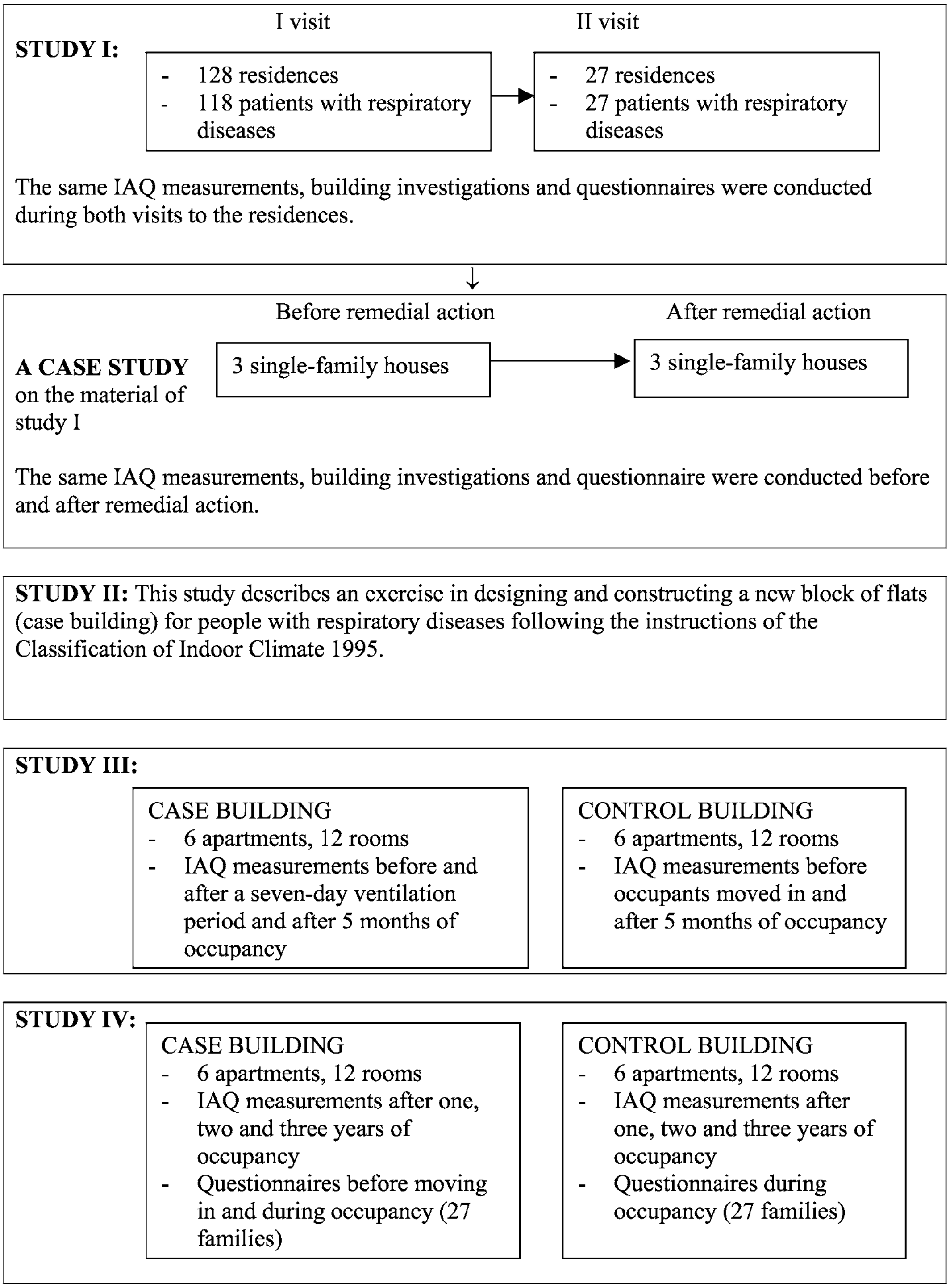
4 MATERIALS AND METHODS

4.1 Study design

This thesis includes two projects. The first project ”Respiratory disease and the home environment” was conducted between May 1995 and December 1998 in North Karelia in eastern Finland (I). The second project, ”Puijonkartano” – good indoor climate for people with respiratory diseases - was carried out between August 1995 and May 2000 in the city of Kuopio (II-IV).

In study I, the home environment of people with respiratory diseases in North Karelia was surveyed by IAQ measurements, building investigations and a questionnaire. Guidance and advice related to matters regarding IAQ and measures to improve IAQ were also given by researchers during the home visits. After about one year from the first visit and after possible remedial action in the residences, a follow-up study was conducted. The IAQ measurements and questionnaire were repeated in order to clarify how remedial action had affected measured and perceived IAQ and the general state of health of the people with respiratory diseases. The follow-up results in three individual cases are also described separately in this thesis (see case study).

In study II, a new block of flats (the case building) was designed and built for people with respiratory diseases following the Classification of Indoor Climate 1995. In studies III and IV, IAQ measurements were performed and a questionnaire given before the occupants moved in. This was done again after five months, one, two, and three years of occupancy of the case building. The results were compared to those from a conventional block of flats (the control building) of the same age located next to the case building. The summary of the study design is illustrated in Figure 4.



STUDY I:

I visit

- 128 residences
- 118 patients with respiratory diseases

II visit

- 27 residences
- 27 patients with respiratory diseases

The same IAQ measurements, building investigations and questionnaires were conducted during both visits to the residences.

A CASE STUDY on the material of study I

Before remedial action

3 single-family houses

After remedial action

3 single-family houses

The same IAQ measurements, building investigations and questionnaire were conducted before and after remedial action.

STUDY II: This study describes an exercise in designing and constructing a new block of flats (case building) for people with respiratory diseases following the instructions of the Classification of Indoor Climate 1995.

STUDY III:

CASE BUILDING
- 6 apartments, 12 rooms
- IAQ measurements before and after a seven-day ventilation period and after 5 months of occupancy

CONTROL BUILDING
- 6 apartments, 12 rooms
- IAQ measurements before occupants moved in and after 5 months of occupancy

STUDY IV:

CASE BUILDING
- 6 apartments, 12 rooms
- IAQ measurements after one, two and three years of occupancy
- Questionnaires before moving in and during occupancy (27 families)

CONTROL BUILDING
- 6 apartments, 12 rooms
- IAQ measurements after one, two and three years of occupancy
- Questionnaires during occupancy (27 families)

Figure 4. Study design of the thesis.

4.2 Study patients

Study I consisted of 118 voluntary patients with respiratory diseases from North Karelia. All the participants had undergone rehabilitation and/or had received treatment for their respiratory disease. The selection of the study patients was neither controlled nor randomised. More detailed background characteristics of the patients are presented in study I, Table 1. Three patients were selected for the case study from the patients of study I. One family member in case house 1, one in house 3, and five members in house 2 had some respiratory disease. All the family members in the case houses were non-smokers; furthermore, they did not have any pets or any wall-to-wall carpets in the houses.

Study IV consisted of 27 patients with respiratory diseases and their families in the case building (= at least one patient/apartment). The control building was an ordinary rental block where the number of asthmatic people ranged from zero to six (up to 22% of the total number of occupants) during the three-year follow-up period. Some background characteristics of the occupants are presented in Table 8. In the case building, furred pets were not allowed, while in the control building, cats or dogs were present in 14-52% (n= 4-12) of the flats during the follow-up period. About 10% of the flats in the case building (n=2-3) and 24% of the flats in the control building (n=4) had aquariums.

Table 8. Background characteristics of the occupants in the case and the control building during the three-year follow-up study (IV). Percentages describe the proportions of all the occupants in the building.

Characteristic	**Case building**		**Control building**
	Asthmatic	**Other occupants**	
	n	**n**	**n**
Number of occupants	25-33	19-35	22-31
Mean age, years (range)	34-38 (2-72)	24-37 (1-74)	30 (12-47)
Woman	14-19 (56-62%)	9-22 (47-63%)	14-16 (52-65%)
Smoking habits:			
At the time of inquiry	0-1 (0-4%)	1-3 (5-17%)	9-12 (38-46%)
Previous to inquiry	9-12 (36-48%)	4-6 (25-33%)	8-21 (50-75%)
Smokes indoors	0 (%)	0 (0%)	0-2 (0-7%)

4.3 Study buildings

Study I included 128 residences, the characteristics of which are summarised in Table 9. The residences were built between the 1940's and the 1990's and had different ventilation and heating systems. Single-family houses were the most common type (58%); most of the buildings were built in 1980's (33%); and, most buildings had natural ventilation (61%) and a central heating system with hot water radiators (54%).

Table 9. Summary of the residences studied (n=128) in study I. The most common types are marked with bold.

Characteristic	Distribution of the type of the building			Total
	Single-family houses n (%)	Terraced houses n (%)	Blocks of flats n (%)	n (%)
Type of building	**74 (58)**	31 (24)	23 (18)	128 (100)
Construction date of the building:				
1940's or earlier	11 (9)	1 (1)	0 (0)	12 (9)
1950's	15 (12)	0 (0)	1 (1)	16 (13)
1960's	11 (9)	4 (3)	2 (2)	17 (13)
1970's	9 (7)	7 (5)	**9 (7)**	25 (20)
1980's	**24 (19)**	**13 (10)**	5 (4)	**42 (33)**
1990's	4 (3)	6 (5)	6 (5)	16 (13)
Type of the heating system:				
Central heating with hot water radiators	26 (20)	**22 (17)**	**21 (16)**	**69 (54)**
Electrical radiators heating	**40 (31)**	7 (5)	2 (2)	49 (38)
Electrical ceiling heating	6 (5)	0 (0)	0 (0)	6 (5)
Air heating	3 (2)	1 (1))	0 (0)	4 (3)
Heating with wood stove	**49 (38)**	2 (2)	0 (0)	51 (40)
Type of the ventilation system:				
Natural ventilation	**54 (42)**	14 (11)	8 (6)	**78 (61)**
Mechanical ventilation	15 (12)	**16 (13)**	**15 (12)**	46 (36)
Mechanical supply and exhaust	3 (2)	1 (1)	0 (0)	4 (3)

In the case study, two of the houses built in 1967-1968 had natural ventilation (house 1 and 2), and the one built in 1985 was equipped with a mechanical exhaust ventilation system (house 3). Houses 1 and 3 had an electrical heating system, and house 2 had central heating with hot water radiators, while supplementary wood heating was used in houses 2 and 3. There were two occupants in house 1, six in house 2 and five in house 3. The floor area was 75, 180 and 145 m^2, respectively.

In studies III and IV, two new blocks of flats were investigated. The case building was designed and built according to the Finnish Classification of Indoor Climate, Construction and Finishing Materials (FiSIQ, 1995). The target values of S1 class were set for IAQ in the case building (II, Table 1). The control building was built with conventional building technology one and half years before the case building. Figure 5 shows that the buildings are almost similar from an architectural perspective. The summary of the essential differences between the case and control building is introduced in study III, Table 1. Many conventional practices were changed in the construction of the case building. The detailed information on the design and construction work of the case building is described in study II.

Figure 5. The case building and control building are situated next to each other in the city of Kuopio.

4.4 IAQ measurements and building investigations

The methods and equipment used in the IAQ measurements and building inspections are presented in Table 10. The building inspections were performed only in study I and a case study was conducted simultaneously with the IAQ measurements. All the IAQ measurements were conducted in the heating period between October and April 1995-1998. The indoor air parameters were always measured in the bedroom of the patient and another room, for example the living room, if possible (I).

In studies III and IV, the IAQ measurements were performed on the same day in all the six flats of the building, in one flat on each floor. The samples were collected and parameters were always measured from the same two rooms in each flat during the follow-up. The flats studied (floor area of 42-92 m^2) were chosen before the occupants moved into the control building. In the case building, the corresponding flats with regard to the location within the building were selected for the study. The same IAQ measurements were conducted in both buildings before the occupants moved in. This was done again after 5 months, and after one, two and three years of occupancy. In addition, in the case building, the investigations were also carried out before the seven-day ventilation period. The first visit to the control building was conducted in November 1995, and to the case building in May 1997.

Table 10. Summary of the methods and equipment used to evaluate IAQ in the study buildings.

Parameter	Method/equipment	Sampling time	Study
Air movements and condition / operation of ventilation system	A traced smoke, operation of exhaust valves were checked by the so called paper test, and visual inspection	-	I, case study
Exhaust air flow	Electrical measuring instrument (TSI VelociCalc Plus 8360)	-	I, case study
Signs of excess moisture and mould growth	Walk-through, a surface moisture detector	-	I, case study
Odour perception / intensity	Researchers' observation (usually 2 researcher/residence) Trained panel of 7 to 10 members	- -	I, case study, III, IV
Temperature	Electrical measuring instrument (TSI Q-trak 8851)	1 h	I, case study, III, IV
Relative humidity (RH)	Electrical measuring instrument (TSI Q-trak 8851)	1 h	I, case study, III, IV
Carbon dioxide (CO_2)	Electrical measuring instrument (TSI Q-trak 8851)	1 h	I, case study, III, IV
Carbon monoxide (CO)	Electrical measuring instrument (TSI Q-trak 8851)	1 h	I, case study, III, IV
Aldehydes (H_xCO) Formaldehyde (H_2CO)	Collected in dinitrophenylhydrazine cartridges and analysed by a high-pressure liquid chromatograph equipped with a diode array detector. Collected in diluted hydrogen sulphurous acid and analysed with a spectrophotometer.	2 - 4 h 1 h	III, IV I, case study
Ammonia (NH_3)	Collected in diluted sulphuric acid and analysed with an ion specific electrode	2 -3 h 2 - 4 h	I, case study III, IV
Total volatile organic compounds (TVOC)	Collected with Tenax TA and analysed with thermal desorption, gas chromatographic separation with a mass selective detector	1.5 h	III, IV
Total suspended particles (TSP)	Electrical measuring instrument (TSI Dust-Trak 8520) Sampled with cellulose acetate membrane filters and determined by a gravimetric method	2 h 4 - 6 h	I, case study III, IV
Size distribution of particles	Optical particles counter HIAC/Royco, model 5000	1.5 - 3 h	IV
Bacteria	Collected on tryptone glucose yeast agar (TGY) by a six-stage impactor (Andersen 10-800), incubated for 14 days at 20-25 °C	15 min	I, case study, IV
Fungal spores	Collected on 2 % malt extract agar (MEA) and dichloran glycerol agar (DG18) by a six-stage impactor (Andersen 10-800), incubated for 7 days at 20-25°C.	15 min	I, case study, IV
Cat, dog and house dust mite allergen levels in house dust	Vacuumed into cellulose acetate/cellulose nitrate filters and analysed with the immunochemical ELISA-method (Raunio et al., 1998)	2 min	IV

4.5 Questionnaire study

The occupants' opinions about their state of health and home environment were surveyed by self- or parent-administered questionnaires in study I, the case study and study IV. The questionnaires were modified from MM40 (Andersson et al., 1993) and the Tuohilampi questionnaires (Susitaival and Husman, 1996). They were always sent before the IAQ measurements were conducted. In study I and the case study, the questionnaires were mailed to the patients twice: before and after remedial action in the residence. In study IV, the questionnaires were conducted five times: before the occupants moved into the case building, after five months, and after one, two and three years of occupancy in both the case and control buildings.

The questionnaire consisted of two parts: one dealt with health data of the patients with respiratory disease and the other with data on the home environment. More details on the questionnaires are described in Table 11.

Table 11. Summary of questionnaires used in study I, the case study and study IV.

Question type	**Study I, case study Number of questions**	**Study IV Number of questions**
Personal and environmental characteristics	30	6
Living habits, e.g. smoking, pets, cleaning, use of ventilation system	29	4
The presence of disturbing factors in the home environment, such as high temperature, odour, noise	17	13
A grade for IAQ, advantages and defects in apartment and living environment	3	3
The occurrence of different symptoms, e.g. headache, fatigue, irritation (nasal, cough, skin)	24	23
The occurrence of allergic symptoms	4	4
Common opinions about the state of health and general satisfaction of life	4	8
Respiratory diseases, their treatment and medication	8	-
Doctors' visits, hospitalisation and sick leaves	3	-
Total number of questions	122	61

- = not asked

4.6 Data analysis

The data were analysed using the SPSS statistical package. The descriptive statistics (mean, median, standard deviation, range) were used to characterize the IAQ data in studies I, III and IV. In studies III and IV, the area-specific emission rates (SER_a, $\mu g/m^2h$) for chemical pollutants were calculated to show the possible effect of low-emitting building materials on the VOC load in indoor air. With the aid of the SER_a, the influence of different ventilation systems and ventilation rates in the case and control buildings could be eliminated. The percentage of observations was used to describe the prevalence of environmental factors and symptoms in the questionnaire data of studies I and IV. The observation was regarded as significant when at least 20% of the occupants reported the symptoms and 40% of them reported disturbing environmental factors (Andersson, 1998; Reijula et al., 1999).

Differences in the indoor air parameters between the patient's bedroom and the other room were tested with the dependent Wilcoxon-test (I). The Wilcoxon-test was also used when testing the IAQ results before and after remedial action (I). In studies III and IV, the differences in SER between the case and control buildings were tested using the independent Mann-Whitney U-test.

5. RESULTS

5.1 IAQ in the houses of people with respiratory diseases

5.1.1 Measured and perceived IAQ

The results of the IAQ measurements in 128 houses of people with respiratory diseases are summarised in study I, Table 2. The IAQ results were interpreted using two references: Finnish Indoor Air Guidelines (Ministry of Social Affairs and Health, 1997) and Classification of Indoor Climate 1995 (class S3). The percentages of the residences exceeding the reference values for indoor parameters are presented in Figure 6. The reference values are listed in Table 3, study I. The reference values were most frequently exceeded with regard to the room temperature (53%), the presence of the fungal genera suggesting moisture damage (56%) and the fungal concentration in indoor air (35%). Based on the building inspections, different kinds of defects in ventilation systems were observed in 75% of the buildings, although the levels of CO_2 exceeded the reference value in only 7% of buildings.

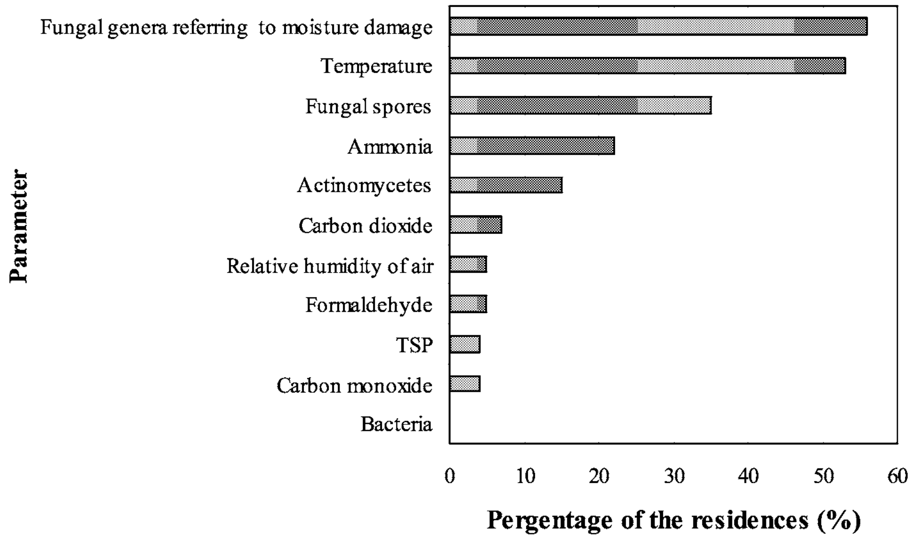


Figure 6. The percentage of the residences in study I exceeding the Finnish reference values for IAQ parameters.

When considering the types of buildings, the information in Table 4 in study I suggests that IAQ problems were more common in buildings with natural ventilation and in those where supplementary wood heating was used. On the other hand, the age of the building was not strongly related to poor IAQ; only problems with ammonia were more frequent in the newer buildings (built after 1980).

In general, the prevalence of allergic symptoms in the patients with respiratory diseases was 57-89%. More details of the perceived home environment and symptoms often reported by the patients are presented in study I, Figure 1. The patients reported most frequently nasal (49%), cough (43%), hoarseness (40%), or fatigue (35%) symptoms in the residences. The most disturbing factors in the home environment included low floor temperature (23%), stuffy air (23%), and unpleasant odour (24%). The patients did not react to too high temperature or dust and dirt in their residences. The findings of perceived IAQ reported by the patients and researchers (Figure 7 and study I, Table 5) were fairly equivalent. The patients more often reported allergen renovation and mouldy odours in the residences than the researchers. On the other hand, the researchers more often observed defects in ventilation. In general, the patients regarded IAQ to be better than evaluated by the researchers.

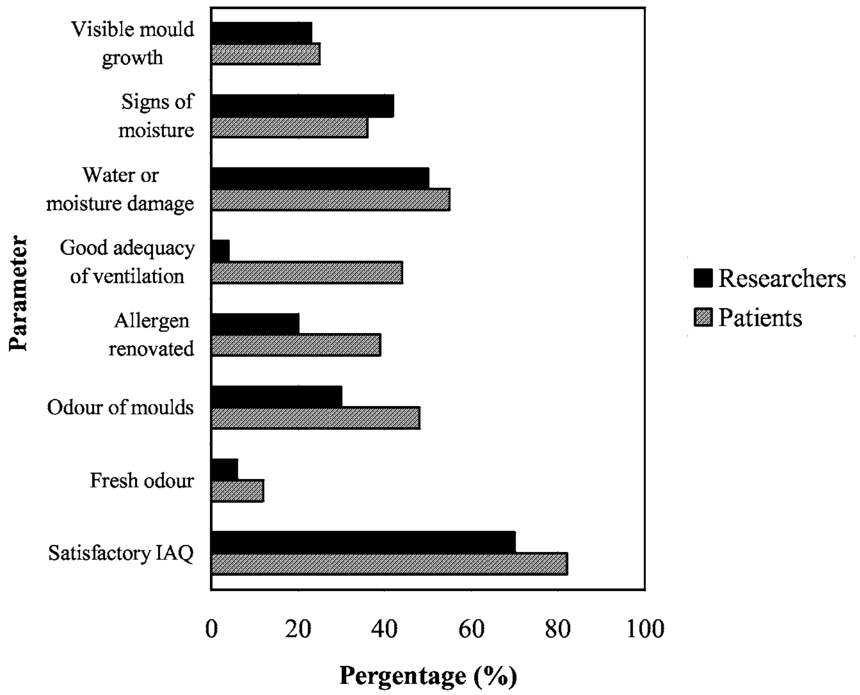


Figure 7. The perceived IAQ in 128 residences reported by the patients and researchers.

5.1.2 Effects of remedial action on IAQ and comfort of patients with respiratory diseases

In 27 of the 128 buildings in study I, improvements to IAQ were attempted through remedial action. In 19 buildings, the measures were completed within one year of the first visit by the researchers, while in eight buildings, repair work was still ongoing during the second visit. In addition, the occupants of some buildings had changed their living habits. For example, they had reduced the room temperature and paid more attention to cleaning and ventilating the residence. Despite these measures, no significant differences or improvements were found between the results of the first and second visits at group level (n=27) (study I). This was true for both IAQ and symptoms. In order to clarify this finding, three typical cases have been selected from the data to be presented here in more detail.

Case 1

This case describes, how important it is to assure careful design and acceptable IAQ in a new residence. The IAQ results in the previous and new residence in case 1 are presented in Table 12. In the previous house, water damage in the bathroom, sauna and another room had been repaired inadequately. This resulted in mould odour and elevated levels of airborne actinomycetes and CO_2, as well as, defects in ventilation. The family decided to tear down the house because seriously decayed structures were found in the basement during the building inspection. It was estimated that reparations would be even more expensive than building a new house. Also, there was uncertainty as to whether all the decayed structures could have been removed from the basement. The new house was built on the same site as the previous one. Limited professional consultation was used in the design and construction of the new building. After one year of occupancy, the IAQ measurements and building inspection again revealed defects in the ventilation system (inadequate supply air intake) and high indoor air levels of actinomycete and fungus due to lack of ventilation in the basement (Table 12). In fact, based on the measurements, IAQ was even worse in the new residence when compared with the previous one. As a result, the asthmatic patient could not live in this new house because he experienced various kinds of irritation symptoms and his asthmatic symptoms worsened.

Case 2

This case demonstrates the importance of an inspection of the home environment by professionals immediately after the diagnosis of the first allergic disease in a family. This is in order to avoid excessive exposure and development of allergic diseases in other family members. In the house studied, there were four children who had lived there all their life. They, as well as their mother, had developed asthma in the seven years of occupancy after 1990 when the first signs of moisture damage were detected. The building investigations revealed several places of severe and long-term moisture damage and microbial growth in the house. These included roof leaks, nearly rotten wooden structures in an unventilated crawl space, and interior spaces with inadequate ventilation resulting in elevated airborne levels of micro-organisms, especially actinomycetes (Table 12). The cost of repairs was high, between EUR 8400-13400 (FIM 50000-80000). According to the IAQ results, the remedial action did not quite succeed in decreasing airborne microbial counts to a satisfactory level (Table 12). The repairs were conducted without professional help and some mouldy materials still remained in the building. The family decided to move to another residence because they all developed symptoms and some of them suffered from infections constantly.

Case 3

This case emphasizes the significance of professional consultation in planning remedial action. In this single family house, there was moisture damage to some parts of a roof and in all window structures, as well as, a lack of thermal insulation in roof structures and ducts. These problems led to microbial contamination in the structure and elevated airborne microbial levels indoors (Table 12). In addition, the occupants used the mechanical ventilation system only occasionally and intake of supply air was inadequate. The family spent approximately EUR 3400 (FIM 20000) on repairs. The remedial action was planned and conducted with a help of construction professionals. After a year from the repairs, decreased indoor air fungal and CO_2 levels were measured (Table 12). The patient mentioned that her state of health had improved, her asthma symptoms had been alleviated, and her medication had been reduced. She was also very satisfied with her rehabilitation.

Table 12. Measured IAQ before and after repairs/removal in three cases. The results exceeding the reference values are marked in bold.

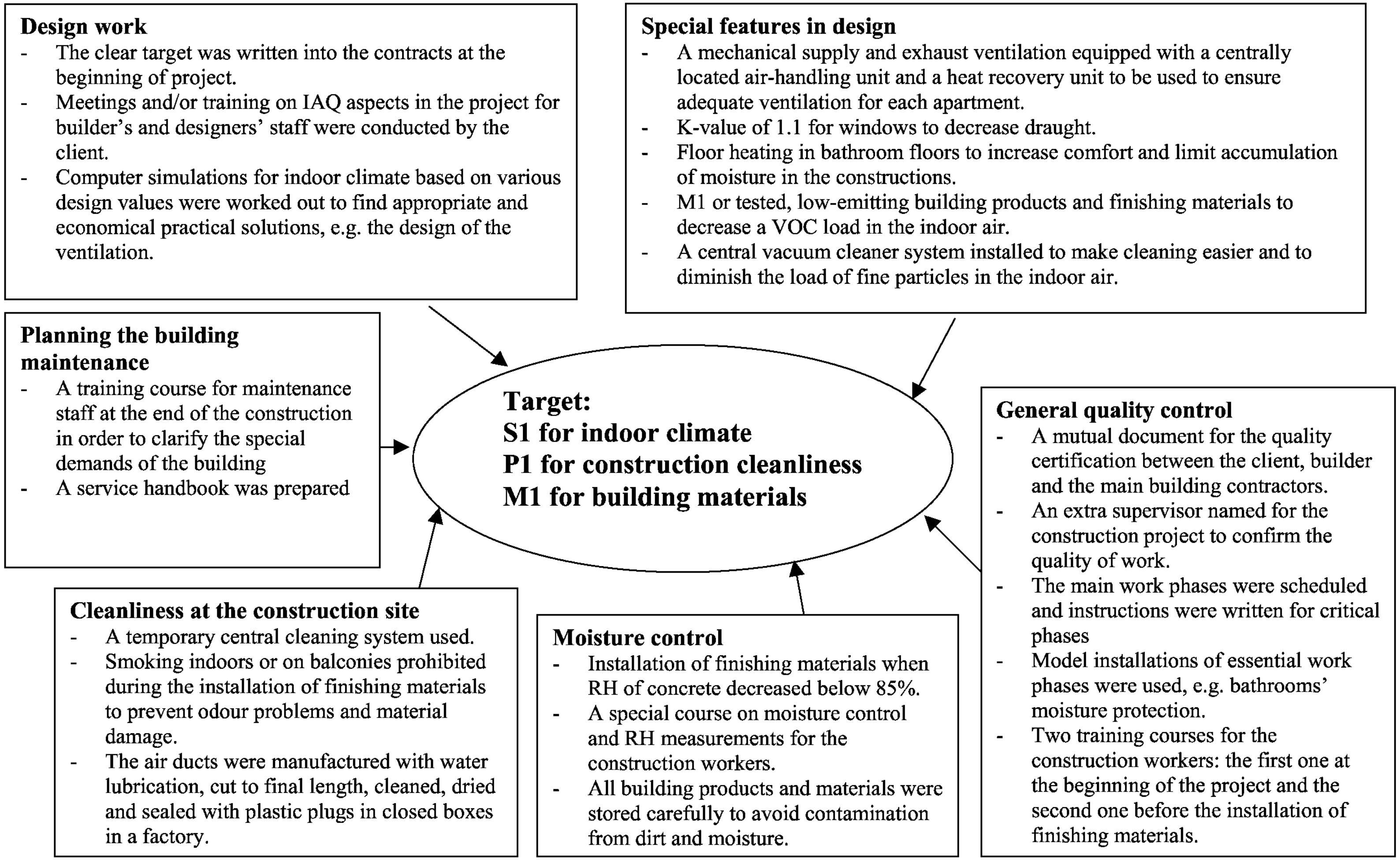
Parameter	**Level of IAQ parameter in case 1**				**Level of IAQ parameter in case 2**				**Level of IAQ parameter in case 3**			
	Previous residence		New residence		Before repairs		After repairs		Before repairs		After repairs	
	Bedroom	Other room	Bedroom	Other room	Bedroom	Other room	Bedroom	Other room	Bedroom	Other room	Bedroom	Other room
Room temperature, °C (outdoor)	**23.6** (-10)	**23.3**	21.4 (9.8)	21.4	**22.4** (-2)	**22.5**	21.9 (2)	20.2	22.0 (2)	20.8	21.7 (0)	21.4
Relative humidity of air, % (outdoor)	23 (-)	23	33 (55)	33	24 (-)	24	35 (72)	36	26 (-)	33	29 (74)	31
Carbon dioxide, ppm	1242	1215	904	848	900	810	691	700	702	846	665	663
Carbon monoxide, mg/m^3	-	-	2.2	2.2	-	-	6.5	4.3	-	-	2.2	2.2
Ammonia, μg/m^3	24	15	16	17	-	-	24	32	-	-	26	22
Formaldehyde, μg/m^3	40	50	14	18	-	-	41	39	-	-	-	-
Fungal spores, cfu/m^3	31	85	**240**	**283**	**125**	**160**	92	**351**	**101**	**141**	7	9
Most common fungal species in sample, % of total fungal counts	Penicillium,61 Aspergillus niger,23 Aspergillus,8 yeast,8	Penicillium, 47 Aspergillus niger, 42	Penicillium,68 Geotrichum,19 Cladosporium,8 Yeast, 3 Aspergillus fumigatus, 1 Aureobasidium,1	Penicillium,85 Geomyces, 9 Acremonium, 3 Cladosporium, 2 Yeast, 1	Trichoderma,25 Penicillium,10 Aspergillus, 2 Phoma, 1	Penicillium,20	Steril, 49 Geotrichum,23 Penicillium, 21 Cladosporium,5 Yeast, 2	Penicillium,96 yeast, 2 Cladosporium, 1 Steril, 1	Aspergillus fumigatus, 67 Penicillium,24 Cladosporium, 5	Aspergillus fumigatus, 46 Penicillium,46 Cladosporium, 8	Penicillium, 67 Yeast, 33	Penicillium, 100
Bacteria, cfu/m^3	365	203	231	309	1368	1766	476	3052	203	193	532	638
Actinomycetes, cfu/m^3	7	**17**	**33**	**19**	**73**	**1368**	**14**	5	≤2	≤2	2	≤2
TSP, μg/m^3	49	19	10	12	14	10	-	-	42	40	14	15

- = not measured

5.2 Measures and practices to achieve good IAQ in the design, construction and completion of the case building

5.2.1 Procedures and measures in the design and construction work

The client (the owner of the building) gave clear targets to the builder and designers at the beginning of the construction project for the case building: the indoor air in the completed building should be as free as possible from irritating, allergenic and odorous pollutants and respirable particles, and interior surfaces of the apartments should be easy to clean. The target values for the indoor climate were set according to S1 class of the Classification of Indoor Climate 1995 and are listed in Table 1, study II. To reach the targets, some additional measures and actions were required in the design and construction work of the case building. The most essential factors and their solutions are presented in Figure 8.



Design work

- The clear target was written into the contracts at the beginning of project.
- Meetings and/or training on IAQ aspects in the project for builder’s and designers’ staff were conducted by the client.
- Computer simulations for indoor climate based on various design values were worked out to find appropriate and economical practical solutions, e.g. the design of the ventilation.

Special features in design

- A mechanical supply and exhaust ventilation equipped with a centrally located air-handling unit and a heat recovery unit to be used to ensure adequate ventilation for each apartment.
- K-value of 1.1 for windows to decrease draught.
- Floor heating in bathroom floors to increase comfort and limit accumulation of moisture in the constructions.
- M1 or tested, low-emitting building products and finishing materials to decrease a VOC load in the indoor air.
- A central vacuum cleaner system installed to make cleaning easier and to diminish the load of fine particles in the indoor air.

Planning the building maintenance

- A training course for maintenance staff at the end of the construction in order to clarify the special demands of the building
- A service handbook was prepared

Target:
S1 for indoor climate
P1 for construction cleanliness
M1 for building materials

General quality control

- A mutual document for the quality certification between the client, builder and the main building contractors.
- An extra supervisor named for the construction project to confirm the quality of work.
- The main work phases were scheduled and instructions were written for critical phases
- Model installations of essential work phases were used, e.g. bathrooms’ moisture protection.
- Two training courses for the construction workers: the first one at the beginning of the project and the second one before the installation of finishing materials.

Cleanliness at the construction site

- A temporary central cleaning system used.
- Smoking indoors or on balconies prohibited during the installation of finishing materials to prevent odour problems and material damage.
- The air ducts were manufactured with water lubrication, cut to final length, cleaned, dried and sealed with plastic plugs in closed boxes in a factory.

Moisture control

- Installation of finishing materials when RH of concrete decreased below 85%.
- A special course on moisture control and RH measurements for the construction workers.
- All building products and materials were stored carefully to avoid contamination from dirt and moisture.

Figure 8. The main measures that deviated from the conventional practices in the design and construction work of the case building (study II).

5.2.2 Design and construction costs

The design and construction costs of the case building were approximately 10% higher than those of the control building (study IV). The distribution of additional costs is described in Figure 9. The delivery prices, design and installation of the versatile ventilation system were responsible for 52% of the extra costs. Moisture control of concrete structures accounted for 18% of the extra costs, special windows for 12%, and the measures regarding cleanliness at the construction site for about 9% of the extra costs. On the other hand, the use of low-emitting building materials did not raise the costs at all.

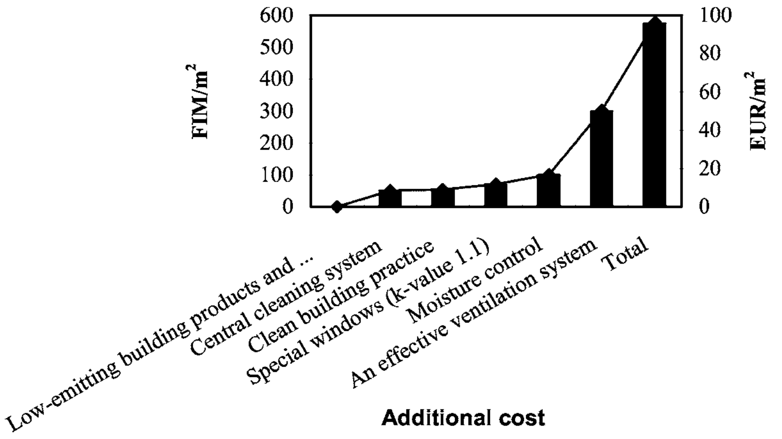


Figure 9. The distribution of the additional costs in the design and construction of the case building.

5.2.3 Effect of the seven-day ventilation period on IAQ after the completion of the case building

The results of IAQ measurements before and after the ventilation period are presented in study III, Table 3. The ventilation period mostly decreased the TVOC-levels: they halved during the ventilation period. In the control building, where the ventilation period was not performed, the mean TVOC concentration of six apartments (4082 $\mu g/m^3$) was one order of magnitude higher than that in the case building (408 $\mu g/m^3$) before occupants moved in (III, Table 3).

5.2.4 Effect of low-building materials and ventilation on IAQ

Because the case and control buildings had different ventilation systems and design values for the ventilation rate, the effect of the emissions from building materials on IAQ was examined by calculating SER_as for some key pollutants from the results of the IAQ measurements in six flats in the buildings. The mean SER_as for TVOC, formaldehyde, acetaldehyde and ammonia in both buildings during the follow-up study are presented in study III: Table 5, in study IV: Table 2, and Figure 10. The results showed the significantly lower SER_as for TVOC in the case building than in the control one during the whole three-year period (Figure 10). On the other hand, the mean SER_a for formaldehyde was lower in the control building than in the case one. For ammonia and acetaldehyde, no clear trends in the SER_as were observed during the follow-up. In addition, the SER_as for TVOC decreased clearly along with occupancy time in both buildings, which was not seen in case of other gaseous pollutants.

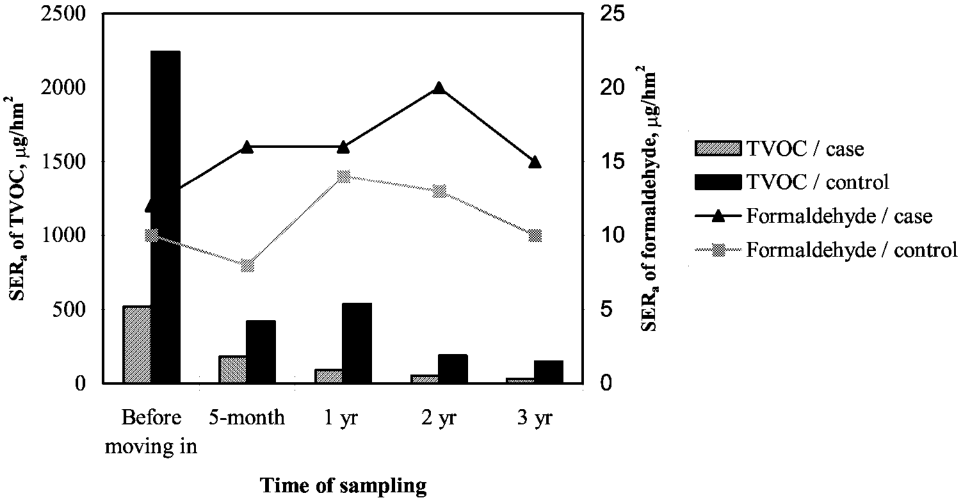


Figure 10. The mean SER_as for TVOC and formaldehyde in the case and the control building during the follow-up (III, IV).

The effect of ventilation on IAQ became more pronounced during occupancy, which can also be seen in the mean levels of CO_2 and bacteria in both buildings (III, IV, Figure 11). During the occupancy time, the mean CO_2 levels in the case building were nearly two times lower than those in the control building. The difference was even larger in the mean concentrations of bacteria: the levels were about 12 times lower in the case building than in the control one during the three-year period.

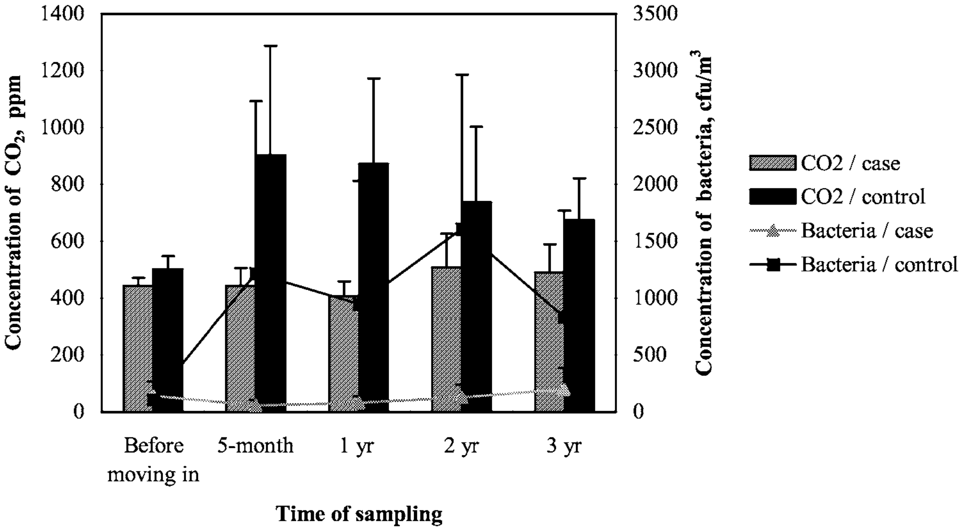


Figure 11. The mean and standard deviations of CO$_2$ and bacteria concentrations in six flats in the case and control buildings during the follow-up period (III, IV).

5.3 IAQ and occupants' perceptions and symptoms during the first three years of occupancy in the case and the control buildings

5.3.1 IAQ detected by measurements

The IAQ results after five months of occupancy are presented in study III and after one, two and three years of occupancy in study IV.

The room temperature varied from 20 to 26 °C during the follow-up in the case building and from 19 to 24 °C in the control building. The RH of air was low in both buildings: 22-40% in the case building and 19-38% in the control building (study III in Table 2, study IV). The S1 target levels were not achieved either for temperature or RH in the case building. The IAQ measurements in the case building were conducted for the first time in October and after that always in May. In addition, there was no mechanical humidification in the building. Thus, the temperature and RH indoors adapted to outdoor conditions.

In the case building, the mean CO_2 levels remained always below 550 ppm on the range of 350-730 ppm, which was clearly within the S1 target level (figure 11). In the control building, differences in the CO_2 levels between the flats were large, the levels ranged from 430 to 1570 ppm and the mean values were always above 650 ppm (study III in Table 2, study IV). CO levels were always low, below 2 ppm, and within the target level in the both buildings studied (III, IV).

In the case building, the S1 target level for TVOC was achieved after five months of occupancy (Figure 12; study III, Table 3). There was a downward trend for the TVOC levels during the occupancy of both buildings. The mean TVOC levels were approximately 5-13 times higher in the case building than in the control one over the follow-up period. Also, the variation in the TVOC levels between the flats in the control building was higher than in the case building.

The concentrations of the most frequent VOC compounds in the buildings, identified by chromatograms, are presented in study III: Table 4 and in study IV: Table 3. The most abundant VOCs in both buildings were terpenes (limonene, α-pinene, 3-carene), toluene, 2-ethyl-1-hexanol, and nonanal during the three years of occupancy.

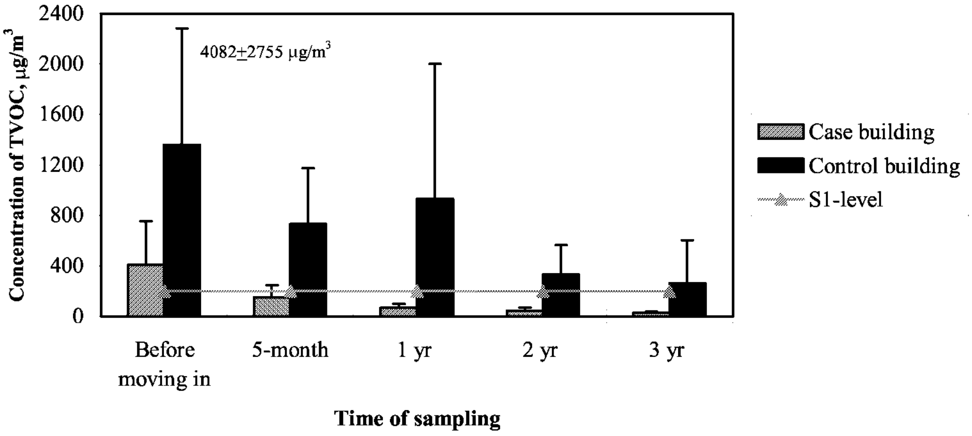


Figure 12. The means and standard deviations of the TVOC-levels in the case and control building during the follow-up (III, IV).

The level of odour intensity did not reach the S1 target value (<2 decipol) in the case building during the follow-up period. The mean values for the level of odour intensity were below 4 decipol in the range of 1.1 – 5.7 during the occupancy time in the case building while in the control building, the odour intensity varied after two and three years of occupancy from 1.8 to 6.6, with an average slightly higher than in the case building (III, IV).

The ammonia levels were approximately two times lower in the case building than those in the control building after completion and 5 months later (Figure 13, III: Table 2). The difference between the buildings was greatest after one year of occupancy: in the case building, the mean level of ammonia was very low 4 µg/m^3, while the corresponding value in the control building was 61 µg/m^3. After that the ammonia levels decreased in the control building, whereas the ammonia levels in the case building after two years were higher than those after completion. It then decreased rapidly and within 6 months reached the S1 target level and remained below the target value to the end of the follow-up period. This temporary increase in the ammonia levels was due to problems of the sewer system (III, IV).

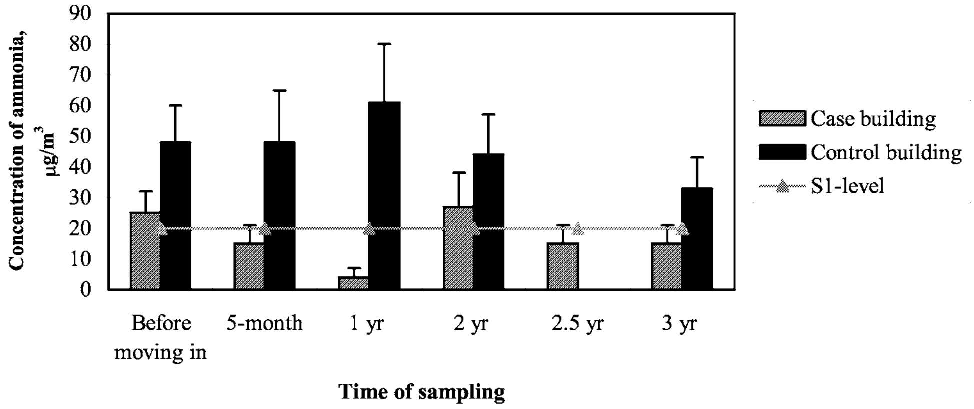


Figure 13. The means and standard deviations of the ammonia concentrations in the case and control building during the follow-up period (III, IV).

The formaldehyde levels in both buildings were low over the follow-up period: in the case building, the concentrations of formaldehyde were always below the S1 target value (30 µg/m^3) and in the control building below 45 µg/m^3. However, in the case building, the formaldehyde levels tended to rise slightly during the first two years of occupancy (Figure 14; III: Table 3; IV: Table 2).

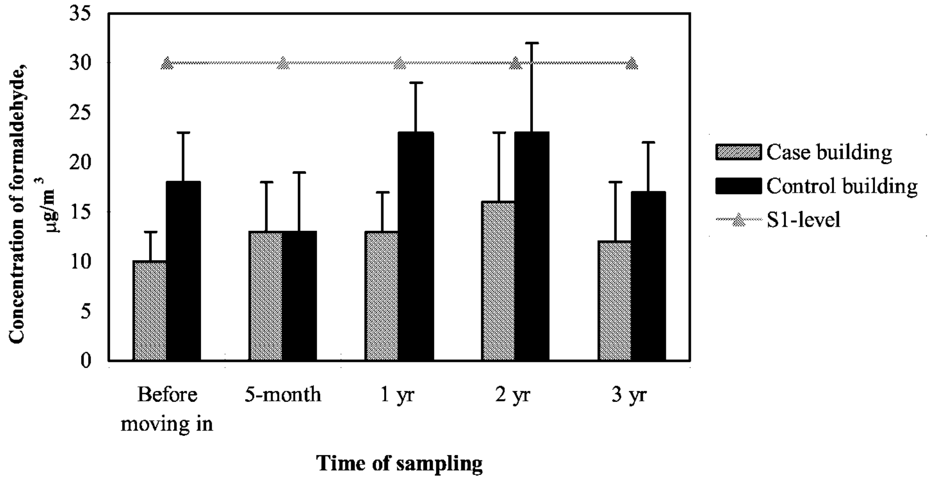


Figure 14. The means and standard deviations of formaldehyde in the case and the control building during the follow-up.

The airborne microbial levels remained low in the case building over the follow-up period: the fungal concentrations were below 80 cfu/m^3 and the bacteria concentration below 570 cfu/m^3 (study IV). The bacteria levels increased slightly with the occupancy time (Figure 11). In the control building, the concentrations varied from 2 to 1000 cfu/m^3 for fungi and from 60 to 3800 cfu/m^3 for bacteria. Consequently, no clear temporal tendency was detected in these counts.

The amount of house dust mite allergen (Der p 1) in the settled dust was very low (<0.02 µg/g) in both buildings. In the case building, where pets were forbidden, the levels of cat allergen (Fel d 1) and dog allergen (Can f 1) also remained low during the first year of occupancy: Fel d 1 in the range of 0.04-0.06 µg/g and Can f 1 in the range of 0.1-6.5 µg/g. In the control building, the Fel d 1 and Can f 1 levels varied from 0.09 to 90 µg/g and from 0.02 to 311 µg/g, respectively during the follow-up period. According to these findings, cat allergens tended to accumulate in the control building. (IV).

The TSP levels (range 1-49 µg/m^3) were clearly within the S1 level (<60 µg/m^3) in the case building during the follow-up period (III, IV). In the control building, TSP levels were always higher (range 4-216 µg/m^3) than in the case building, and they also increased with the occupancy time. However, the same trend was not seen in the case building.

The number distributions of the airborne particles in the case and the control building during the three-year occupancy are presented in study IV, Figure 1. In general, the particle counts were lower in the case building than in the control one in every size fraction over the follow-up period. The highest particle counts were measured in the size fractions of <1 µm and the lowest counts in the fraction of >5 µm in both buildings. In the third year, the particle counts increased for all size fractions in the case building, which might be due to the fact that it was spring (i.e. pollen season) when the measurements were taken. In the control building, the variation in the counts between the particle size fractions and also between the flats was large and, additionally, no temporal trends were seen.

5.3.2 Perceived IAQ and symptoms of the occupants

The perceived IAQ reported by the occupants over the follow-up period in both buildings are presented in study IV, Figure 2. Before the occupants moved into the case building, they experienced stuffy air (nearly 80% of occupants), unpleasant odour (about 60%), dust and dirt (about 60%), noise (35%), and varying temperature (about 35%) in their former residence.

Five months after the occupants moved in, the indoor climate was regarded as good in both buildings; only draught (42%) and low temperature (39%) in the case building and noise (45%) in the control building were reported. During the first two years, no significant disturbing IAQ factors were detected in the case building, whereas about 30-40% of the occupants in the control building reported dry air, draught, passive smoking and stuffy air. In the third year, the asthmatic occupants perceived dry air (35%) and draught (30%) in the case building. In the control building, the most disturbing factors were draught (61%), low temperature (37%), passive smoking (29%) and dry air (26%) (IV).

The score for the IAQ given by the occupants in the case building varied from 4 to 10 and in the control building from 5 to 10. The mean and standard deviations of the scores are presented in Figure 15. The mean score was always higher in the case building than in the control one over the follow-up period (IV).

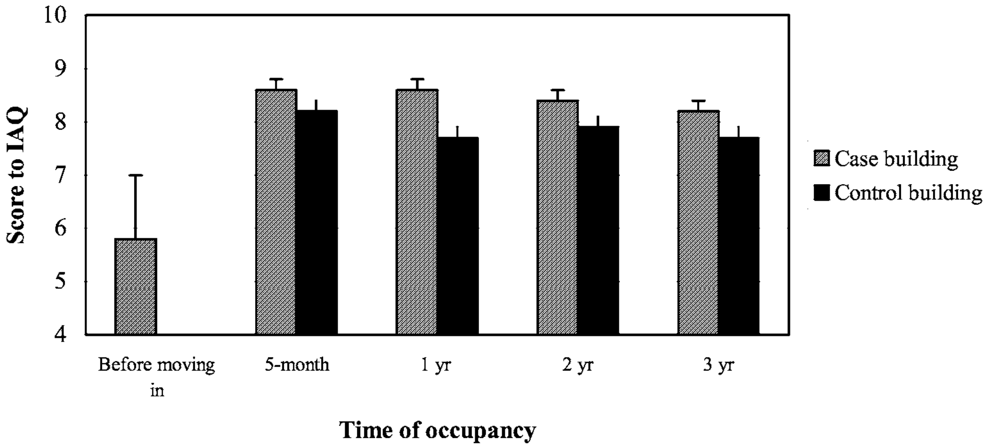


Figure 15. The mean and standard deviations of the score for IAQ given by the occupants in the case and the control buildings (IV).

The prevalence of different symptoms among occupants in the buildings was described in study IV, Figure 3. In their former dwellings, the occupants with asthma had various respiratory, skin and other general symptoms. Over 60% of them reported nasal symptoms, hoarseness, dryness of throat and fatigue. During the first year in the case building, the prevalence of symptoms decreased substantially; asthmatic occupants were the only ones to report fatigue and nasal symptoms, while the other family members had only fatigue symptoms. However, the symptoms of the asthmatic occupants increased in the second and third years: 33-56% of the patients had nasal, cough, fatigue, skin and eye symptoms. This was not observed among the other family members. During the follow-up period, 22-42% of the occupants in the control building reported fatigue, skin and nasal symptoms. However, no significant differences in the prevalence of symptoms were noticed between the different study periods.

6 DISCUSSION

6.1 IAQ in the homes of people with respiratory diseases compared with IAQ in Finnish residences in general and its impact on occupants' comfort

In over 95% of the residences investigated in study I, the levels of RH, CO, TSP, formaldehyde, and bacteria were below the corresponding reference values (I: Table 3; The Ministry of Social Affairs and Health, 1997; FiSIAQ, 1995). For RH of air, this was related to the fact that the monitoring was conducted during the heating season when RH is usually rather low in Finnish buildings. High CO levels in residences are often associated with incomplete combustion, which can be caused by improper use of gas or wood stoves (Maroni et al., 1995; WHO 2000a; Spengler et al., 2001). Among the residences studied, these problems were observed only in two houses. Also, the TSP levels in the studied residences were slightly lower than those usually detected in Finland (Reponen et al., 1989).

Formaldehyde was a common indoor air pollutant in the 1960's and 1970's, when formaldehyde-containing chipboard and insulation foam were widely used. In study I, the formaldehyde levels exceeded 150 $\mu g/m^3$ only in one house built in the 1960's. The results support the findings that the formaldehyde levels in indoor air are currently rather low and have decreased over time (Reponen et al., 1991; Wolkoff et al., 1991; Maroni et al., 1995; Spengler et al., 2001).

The bacteria concentrations in the indoor air were at an acceptable level, even though defects in ventilation were detected in 75% of the residences investigated (study I). A similar finding was also seen in the CO_2 levels: the reference value (1500 ppm) was exceeded only in 7% of the residences. These contradictory results suggest that a short-term sampling of bacteria and/or monitoring of CO_2 does not necessarily sufficiently indicate the adequacy and functioning of ventilation well enough. The results can be significantly affected by whether the occupants are temporarily present or absent at the time of monitoring. Consequently, the monitoring of CO_2 is most useful as a long-term follow-up measure. As an example, Ruotsalainen (1995) measured CO_2 levels in 50 Finnish dwellings with continuous, overnight monitoring and concluded that the Finnish reference value was exceeded in 20% of the buildings studied.

The room temperature exceeded the reference value (22°C) in 53% of the residences investigated in study I. Ruotsalainen et al. (1992) also reported similar findings: the value was exceeded in 45% of 242 buildings studied. In most cases in study I, the reasons for this were occupants' adaptation to higher temperature and/or an incorrectly adjusted heating system and, inadequate or unbalanced ventilation.

Although RH was relatively low in the buildings, 35-56% of the residences had signs of moisture and/or microbial problems based on measurements and building inspections (I). This result agrees with earlier findings in Finland. In a random sample of 450 buildings, Nevalainen et al. (1998) observed signs of current or previous moisture damage in 80% of the residences regardless of the age of the building. Furthermore, they estimated that, in general, about 55% of Finnish dwellings are in need of repair or more thorough inspection (Nevalainen et al., 1998). Also, Koskinen et al. (1999) reported that, in a random sample of 310 buildings, researchers identified moisture problems in 57% of the buildings, and occupants reported visible mould in 24% of the buildings. It should be noted that a Canadian survey showed that moisture sources in buildings were a more significant factor in the presence of mould contamination than relative humidity of the air (Lawton et al., 1998).

The levels of ammonia in study I exceeded Finnish reference values in 22% of the cases. This supports earlier results from Finnish residences; Bäck et al. (1997) and Villberg et al. (1999) found elevated ammonia levels in 21-23% of the residences studied. The elevated levels might be the result of the accumulation of moisture in concrete floors and the negative pressure difference indoors in the residences with mechanical exhaust ventilation. These ventilation systems probably transferred ammonia from structures into the indoor air. Elevated ammonia levels seemed to be most common in new buildings (built in the 1990's).

Although the information in Table 4 in study I suggests that poor IAQ was found especially in the houses with natural ventilation, it should be noted that 61% of all the residences investigated had natural ventilation. This might skew the sample and, therefore, the conclusion. One the other hand, the heating system did not have such a clear impact on IAQ, although there seems to be some connection between too high room temperature and the central heating system with hot water radiators. Additionally, there is some connection between elevated levels of CO, fungi, actinomycetes and TSP and the houses with supplementary wood heating. Lawton et al. (1998) found no association between natural ventilation and elevated levels of moulds, but reported a statistically significant correlation between wood stoves/fireplaces and the amount of fungal biomass in Canadian houses.

According to the results of the questionnaires, perceived IAQ matched well with the conclusions based on the IAQ measurements both in the older residences (study I) and in a new block of flats (IV). Also, the occupants' opinions of IAQ were rather consistent with the researchers' sensory evaluations, especially regarding the signs of moisture and microbial problems (study I). However, the occupants could not link their sensation of stuffy air, odours and draught to defects in ventilation, general cleanliness and too high temperature. In study IV, the higher IAQ in the case building compared with IAQ in the control building was detected both by the IAQ measurements and the occupants' evaluations. On the other hand, it should be bear in mind that in both study I and study IV, the number of study subjects was small and, thus a variation in the results was large. This naturally impairs the generalisation of the results of the questionnaires.

IAQ has a significant impact on the prevalence of various symptoms, and people with respiratory diseases may be more sensitive to the effects of indoor climate than healthy subjects (EU-ECA-10, 1991; Maroni et al., 1995; WHO, 2000a). The results of studies I, IV and the three case studies also support this finding. The prevalence of patients' allergic symptoms was high (57-89%) in study I. About one third of the patients associated their symptoms with the home environment's poor IAQ and moisture/microbial problems. Some of those symptoms, for example fatigue, might be related to too high temperature. It has been shown that too high room temperature increases, for example SBS symptoms (Maroni et al., 1995). Dampness and microbial growth in buildings may provoke lower respiratory symptoms as well as other allergic symptoms (Dekker et al., 1991; Dales et al., 1991; Spengler et al., 1994; Peat et al., 1998; Bornehag et al., 2001). The effects of improved IAQ on the occupants' symptoms were especially clear in study IV, when the occupants moved into the new case building; the prevalence of symptoms decreased considerably (from 15-77%

to 4-42%) during the first five months of occupancy in the case building (IV, Figure 3). In study I, this trend was not as clear after remedial action, because all the remedial action needed had not been done and the follow-up time period might have been too short to show any possible effects. In addition, a small number of cases and a lack of a control group hamper drawing conclusions. The probable higher sensitivity of the patients with respiratory diseases to IAQ compared with the healthy occupants was seen in the higher prevalence of symptoms among the patients during the follow-up period in study IV. For asthmatic people, the prevalence of symptoms during the three years of occupancy was 0-56%, while it was 0-38% for other family members in the case buildings. However, this result should be taken with reservation; the comparison of the groups (people with respiratory diseases versus healthy occupants) is questionable because of the different health status of the subjects.

In conclusion, IAQ in the residences of people with respiratory diseases, as well as the most common IAQ problems and their causes, were somewhat similar to those in Finnish residences in general (I). This finding is opposite to the hypothesis of the study. Thus, the results indicates that general knowledge of the importance of IAQ and factors affecting indoor climate may not necessarily reach occupants at a practical level, even though they are specifically given information on this topic. It is thus seen that more effective measures and individual guidance are needed to improve the IAQ in residences of patients. An ideal solution would be to have a trained home health inspector visit the home of the patient right after a diagnosis. The inspector could then give all the information needed for each individual case. Also, remedial action, when needed in a building, requires special attention. This includes a careful survey of the problems' origins and causes, planning of corrective measures and actions, evaluation of the costs and benefits and, preferably, use of professionals in the design, performance and control of the corrective measures.

6.2 How to achieve and maintain good IAQ in residential buildings

Remedial action in 27 dwellings did not generally improve IAQ or alleviate symptoms of the patients, when the results were examined at group level (study I). Of the three cases described in detail, remedial actions succeeded only in one case. This resulted in a decrease in the levels of some indoor air impurities and a reduction of the patient's symptoms. The other cases showed that even moving to a new building or an inadequately planned and repaired one may not necessary assure acceptable IAQ, and the state of health of patients with respiratory diseases may even deteriorate. Thus, it is of great importance that planning and the performance of repairs is started soon after IAQ problems have been detected, and that professional help is used when needed. (Lindstrom et al., 1995; Shaw et al., 1999; Pejtersen et al., 2001)

In all these three cases, the occupants tried to improve indoor climate conditions after the first visit of the researchers. Some improvement was observed in the follow-up measurements; for example, in every case the room temperature and CO_2 concentration had decreased. Also, the occupants paid more attention to cleaning methods, storage of firewood and common dust reduction in the houses. These findings refer that the behaviour of occupants can be influenced by distributing information and practical guidance on factors and living habits affecting IAQ during home visits of trained inspectors. Though it should be noted that these were only individual cases and no firm conclusions cannot be made based on such a small data.

Studies II and III show that high IAQ can be achieved in a new building by careful design, a choice of low-emitting materials and appropriate equipment, and high-quality construction work with reasonable costs. Study IV indicates that good IAQ can also be maintained during the occupancy if occupants receive sufficient information on factors affecting IAQ and guidance on the proper use and care of equipment. These additional measures caused about a 10% additional cost for the design and construction of the case building. Similar estimates have been presented earlier in a Swedish healthy building project (Blomsterberg and Carlsson, 1997). A part of these investments will be compensated for by the lower running costs of the building over its life span.

There are a number of underlying key factors in the successful final outcome of the design and construction phase of the case building. First of all, the commitment of all partners (clients, builders, contractors, designers) to a clear target is of great importance. This can be ensured by mutual documents for quality certification between a client, builder and the main building contractors. However, the most significant aspect is the fact that each partner, even each worker at a construction site, recognises their own contribution to the whole project and realises the importance of close co-operation with other partners and workers. The client may begin this process by arranging information meetings and training for both partners and workers. The high quality of construction work can be assured by careful planning of timetables, making a moisture control plan for the construction phase, and paying special attention to general cleanliness and storage of building products at a construction site, for example. It is also advisable that aspects regarding the use of a building are taken into consideration as early as possible during the construction phase. This includes items such as the preparation of a service book, training of maintenance staff and occupants to use and service the equipment.

In the case building, the target S1 level was reached for almost all indoor parameters within five months (III). Besides the use of low-emitting building materials, the powerful ventilation period before the occupants moved in had a remarkable impact on achieving the target levels, especially regarding TVOC. The concentration of TVOC decreased as much as by 50% during the ventilation period. These results are consistent with earlier findings. According to some pilot studies, a decrease of 60-90% in the TVOC levels was reached using the bake-out process (Girman et al., 1987; Girman, 1989; Follin, 1997), although the results have not always been as impressive (Bayer 1990; Bayer, 1991; Offerman et al., 1993). In the bake-out procedure, the indoor temperature is raised to a level of 32-40°C, while at the same time outdoor air exchange is increased. However, the elevation of the temperature is problematic, because it may cause material damage, promote the sorption effects and increase the risk of odour and irritation complaints of occupants (Girman et al., 1989; Levin 1989). In addition, it is not always economically feasible, at least in cold climates. Therefore, Valicenti and Wenger (1997) decided to merely improve ventilation by using a continuous supply of fresh air in the study building. They achieved a decrease of 29-33% in the TVOC concentrations. It can be concluded that, based on the results of study III, about a week's ventilation period after the completion of a building or repair measures is an effective way to decrease the VOC load in the indoor air.

The target level for odour intensity was not reached during the whole follow-up period in the case building (III and IV). The results may indicate that a human nose is a more versatile instrument for estimating IAQ than any chemical method. On the other hand, the S1 target level for the odour intensity might be too high to achieve. In addition, some critical opinions have been voiced about the application and usefulness of olfactory responses in the determination of the odour intensity (Spengler et al., 2001). That is, some materials with high emission rates may not be perceived as objectionable.

During the three years of occupancy, IAQ in the case building remained at the S1 level (study IV). As expected, occupancy mostly increased the levels of CO_2 and bacteria; however, sufficient and adjustable ventilation could keep the concentration on an acceptable level. On the other hand, the TVOC levels decreased during occupancy. It has also been reported earlier that TVOC mainly originates from new building materials and finishing products, and therefore, TVOC levels are high in new and renovated buildings (Girman, 1989; Mølhave et al., 1990; Rothweiler et al., 1992; Brown et al., 1994; Knöppel and Schlitt, 1991; Brown, 1999; Hodgson et al., 2000). A slight increase in the formaldehyde levels was observed during occupancy in the case building. Lindström et al. (1995) suggested that living habits, furnishing and furniture may elevate formaldehyde levels indoors (Lindström et al., 1995). Also, the opposite findings on declining levels of formaldehyde during occupancy have been observed in Finnish buildings (Reponen et al., 1991). The levels of cat and dog allergens have been reported to be significantly lower in dwellings where no pets are kept than in those where they are (Raunio et al., 1998). In the case building, the fact that no furred pets were allowed had a direct influence on the low allergen levels in the building. Dust was far below the suggested threshold levels for sensitisation (Call et al. 1992; Gelber et al 1993; Ingram et al., 1995).

Although the S1 level could be maintained well for the first three years of occupancy, there was an episode of a sudden increase in the ammonia levels in the second year. This was caused by problems with the sewer system, and it revealed the sensitivity of indoor climate to ambient disorders. This emphasizes the importance of continuous care and maintenance of a building and its surroundings. In addition, it is necessary to react rapidly if any defects or problems appear. At the beginning of the follow-up period, the impact on IAQ was incontestable for the specific special measures used during the construction time (moisture control, cleanliness at the building site, etc.), for the choice of low-emitting materials, and for the ventilation period after the completion of the case building. However, the significance of a sufficient and balanced ventilation and controlled supply air system with efficient filtration became more important over the course of time. The results of study IV support earlier findings that levels of micro-organisms, VOC, CO_2, and particles can be effectively controlled by ventilation (Reponen, et al., 1989; Reponen et al., 1992; Salthammer, 1999; Seppänen et al., 1999; Liddament, 2000).

The Classification of Indoor Climate 1995 proved to be a good tool to achieve high IAQ in the case building (II, III, IV). It clarified the main target of the project in a concrete way by defining the target values for IAQ and the special requirements for the design and construction phases of the building. In addition, the results of studies III and IV were useful for updating the Classification of Indoor Climate 2000. The new version of the classification (FiSIAQ, 2001) pays more attention to the control of the whole building process. It emphasises the importance of quality certification and moisture control during construction.

Some recommendations in the earlier version were withdrawn because they proved to be troublesome and unpractical. Furthermore, their real benefit remained unclear in field conditions (e.g. how and when it is reasonable to separate clean spaces from dusty ones during construction or how to assure that ventilation works also in isolated clean spaces). In addition, some target values were reconsidered, for example, the S1 values for odour intensity and ammonia were raised, and the value for CO_2 was decreased. Also, some new parameters for the smell of tobacco indoors, for example, were brought out in the updated classification.

In conclusion, the other hypothesis proved true in this study: good indoor climate could be achieved through careful design, choice of proper building materials and equipment, and high quality construction practice in the case building (III). In addition, high quality indoor climate could be maintained at this level during the three-year occupancy (IV). A future challenge is to determine how this practice may become more popular, and how healthy, safe and comfort residences may be produced at a lower cost.

7 CONCLUSIONS

The results of this thesis supports the following conclusions.

Different kinds of IAQ problems related to indoor climate, especially defects in ventilation and moisture/microbial problems, in buildings with people with respiratory diseases seems to be as common as in Finnish residences in general. This is despite efforts to distribute information about factors of the home environment affecting IAQ of patients in connection with treatment and rehabilitation. Thus, more individual and detailed guidance is needed to improve the home environment of patients.

In the residences of the patients with respiratory diseases, the measured IAQ matched relatively well with the perceived IAQ by the researchers and occupants. Occupants seemed to be able to recognise moisture and microbial problems in their residences rather well, but did not necessarily realise the significance of sufficient ventilation and general cleanliness for the IAQ and comfort. These factors are, however, quite easy to improve if practical guidance is available. People with respiratory diseases, such as asthma, seem to be more sensitive to indoor air impurities and other defects in the indoor climate than healthy people. Thus, high quality indoor climate in homes has a significant role in reducing symptoms and increasing general comfort, especially among people with respiratory diseases.

This study showed that it is possible to achieve high IAQ in a new building through careful design, choice of low-emitting materials and appropriate equipment, as well as high-quality construction work. The Classification of Indoor Climate is a good tool when targeting high IAQ. However, additional costs should be calculated in, even though these investments will be partly recompensed by lower running costs during the life span of the building. For a seven-story block of flats (e.g. the case building), the design and construction costs were about 10% higher than the cost for a corresponding building built with conventional practices.

Generally, with respect to the target of high-quality indoor climate, some aspects observed during the design and construction phase of the case building should be pointed out:

1. The commitment of all partners to a clear target is of great importance. This can be verified with mutual documents for quality certification between a client, builder and the main building contractors.

2. Each partner, even each worker at a construction site, recognises their own contribution to the whole project and realises the importance of close co-operation with other partners and workers. The client may start this process by arranging information meetings and training events for partners and workers.

3. Careful planning of time-tables, creating a moisture control plan for the construction phase, and paying attention to general cleanliness and storage of building products at a construction site assure high quality for construction works. In addition, a separate central vacuum cleaner in the construction phase helps to maintain cleanliness at the construction site.

4. The use of a building should be taken into consideration as early as possible in the construction phase. This includes preparation of the service manual and training for the maintenance staff about using and servicing the equipment.

5. A powerful ventilation period, lasting about a week after the completion of a building and before occupants move in, effectively decreases the indoor air levels of volatile organic compounds.

Finally, high-quality indoor climate can be maintained during the time of occupancy by informing the occupants about factors affecting IAQ, and the use and care of the equipment, such as the ventilation system. Sufficient, adjustable ventilation is one of the key factors in assuring that the indoor climate will remain within an acceptable level during occupancy.

REFERENCES

Ahlbom, A., Backman, A., Bakke, J., Foucard, T., Halken, S., Kjellman, N.-L.M., Malm, L., Skerfving, S., Sundell, J. and Zetterström, O. 1998. "NORDPET" Pets indoors - a risk factor for protection against sensitisation/allergy. Indoor Air, 8, 219-235.

Almqvist, C., Larsson, P.H., Egmar, A.-C., Hedren, M., Malmberg, P., Wickman, M. 1999. School as a risk environment for children allergic to cats and a site for transfer of cat allergen to homes. Journal of Allergy and Clinical Immunology, 103, 1012-1017.

American Lung Association & American Thoracic Society workshop. 1997. Achieving healthy indoor air. American Journal of Respiratory and Critical Care Medicine, 156, supplement, 33-64.

American Lung Association. 2001a. Home environment. A guide for creating a healthier home. www.healthhouse.org

American Lung Association. 2001b. A guide for healthier home remodelling. www.healthhouse.org

Andersson, K., Fagerlund, I., Stridh, G., Larsson, B. 1993. The MM-questionnaires - A tool when solving indoor climate problems. Örebro Medical Center Hospital, Department of Occupational and Environmental Medicine.

Andersson, K., Bakke, J.V., Bjøseth, O., Bornehag, C.-G., Clausen, G., Hongslo, J.K., Kjellman, M., Kjergaard, S., Levy, F., Mølhave, L., Skerfving, S., Sundell, J. 1997. TVOC and health in non-industrial indoor environments. Report from a Nordic scientific consensus meeting at Långholmen in Stockholm, 1996. Indoor Air, 7, 78-91.

Andersson, K. 1998. Epidemiological approach to indoor air problems. Indoor Air, supplement 4, 32-39.

Asthma programme in Finland 1994-2004. 1996. Clinical and Experimental Allergy, vol 26, supplement 1.

ASHRAE standard 62-1999. Ventilation for acceptable indoor air quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta, USA.

Arvela, H. 1995. Residential radon in Finland: sources, variation, modelling and dose comparisons. STUK 124, Finnish Centre for Radiation and Nuclear Safety.

Aurola, R. and Välikylä, T. (eds.) 1997. Asumisterveysopas. Asuntojen terveydelliset olosuhteet. Ympäristö ja terveys-lehti, Vammalan Kirjapaino Oy. (in Finnish).

Bayer, C.W. 1990. An investigation into the effect of "building bake-out" conditions on building materials and furnishings. In Proceedings 5th International Conference of Indoor Air Quality and Climate, Vol. 3, pp. 581-586. Canada Mortgage and Housing Corporation, Ottawa.

Bayer, C.W. 1991. The effect of building bake out conditions on volatile organic compound emissions. In . J.G. Kay, G.E. Keller, and J.F. Miller, (eds.) Indoor air pollution: radon, bioaerosols, and VOCs. pp. 101-113. Lewis Publishers, Inc., Chelsea, Michigan.

Becher, R., Hongslo, J.K., Jantunen, M.J., Dybing, E. 1996. Environmental chemicals relevant for respiratory hypersensitivity: the indoor environment. Toxicology Letters, 86, 155-162.

Bellanti, J.A., Zeligs, B.J., Mac Dowell-Carneiro, A.L., Abaci, A.S., Genuardi, J.A. 2000. Study of the effect of vacuuming on the concentration of dust mite antigen and endotoxin. Annals of Allergy and Asthma Immunology, 84, 249-54.

Bielory, L., Deener A. 1998. Seasonal variation in the effects of major indoor and outdoor environmental variables on asthma. Journal of Asthma, 35, 7-48.

Björck, M. 2000. Skanska is offering allergy-adapted homes in Sweden. In Seppänen O. and Säteri J (eds.) proceedings of Healthy Buildings 2000, Espoo Finland, vol 4, 479-484.

Björksten, B. 1999. The environmental influence on childhood asthma. Allergy, 54, 17-23.

Blomsterberg, Å. and Carlsson, T. 1997. Evaluation of apartment building for allergenic persons. In Woods J., Grimsrud D., Boschi N. (eds.) Proceedings of Healthy Buildings'97. Healthy Buildings/IAQ'97, Washington, USA, vol 1, 431-436.

Bornehag, C.-G., Blomquist, G., Gyntelberg, F., Järvholm, B., Malmberg, P., Nordvall, L., Nielsen, A., Pershagen, G., Sundell, J. 2001. Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP). Indoor Air, 11, 72-86.

Boverket. 1999. Boverkets Byggregler. Karlskrona, Sweden (in Swedish).

Brightman, H.S. and Moss, N. 2001. Sick building syndrome studies and the compilations of normative and comparative values. In Spengler J.D, Samet J.M. and McCarthy J.F. (eds) Indoor air quality handbook, McGraw-Hill, New York, pp. 3.1-3.32.

Brown, S. K., Sim, M. R., Abramson, M. J. and Gray C. N. 1994. Concentrations of volatile organic compounds in indoor air - a review. Indoor Air, 4, 123-134.

Brown, S.K. 1999. Occurrence of volatile organic compounds in indoor air. In Salthammer T. (ed.) Organic Indoor Air Pollutants. Occurrence, Measurement, Evaluation, Wiley-VCH, Weinheim, pp. 171-184.

Bäck, B., Reijula, K., Puhakka, E. 1997. Measurement of ammonia in indoor air samples. In Woods J., Grimsrud D., Boschi N. (eds.) Proceedings of Healthy Buildings'97. Healthy Buildings/IAQ'97, Washington, USA, vol 3, 321-323.

Call, R.S., Smith, T.F., Morris, E., Chapman. M., Platts-Mills, T.A.E. 1992. Risk factors for asthma in inner city children. Journal of Pediatrics, 121, 862-866.

Canadian Standards Association. 1994. (Canadian Standards Z204-1994). Guideline of Managing Indoor Air Quality in Office Buildings, Occupational health and safety, Toronto, Ontario, Canada.

Carmody, J., Guzowski, M., Grimsrud, D. 2000. Development and applications of the "Minnesota sustainable design guide". In Seppänen O. and Säteri J. (eds.) Proceedings of Healthy Buildings 2000 Espoo, Finland, vol 3, 563-567.

Chan-Yeung, M., Manfreda, J., Dimich-Ward, H., Lam, J., Ferguson, A., Warren, P., Simons, E., Broder, I., Chapman, M., Platts-Mills, T., Becker, A. 1995. Mite and cat allergen levels in homes and severity of asthma. American Journal of Respiratory Critical Care Medicine, 152, 1805-1811.

Champman, M.D., Tsay, A., Vailes, L.D. 2001. Home allergen monitoring and control - improving practice and patient benefits. Allergy, 56, 604-610.

CEN (European Committee for Standardization). 1999a. Building products - determination of the emission of volatile organic compounds - Part 1: Emission test chamber. PrENV 13419.1.

CEN (European Committee for Standardization). 1999b. Building products - determination of the emission of volatile organic compounds - Part 2: Emission test cell method. PrENV 13419-2

CEN (European Committee for Standardization). 2001. CEN/TC Work programme. Ventilation for buildings. www.cenorm.be/standardization

Custovic, A., Taggart S., Francis H., Chapman M., Woodcock A. 1996. Exposure to house dust mite allergens and the clinical activity of asthma. Journal of Allergy and Clinical Immunology, 98, 64-72.

Custovic, A., Fletcher, A., Pickering, C.A.C., Francis, H.C., Green, R., Smith, A., Chapman, M., Woodcock, A. 1998. Domestic allergens in public places III: house dust mite, cat, dog and cockroach allergens in British hospitals. Clinical and Experimental Allergy, 28, 53-59.

Dahl, R. and Bjermer, L. (eds.). 2000. Nordic consensus report on asthma management. Respiratory Medicine, 94, 299-327.

Dales, R.E., Burned, R., Zwanenburg, H. 1991. Adverse health effects among adults exposed to home dampness and molds. American Reviews of Respiratory Diseases, 143, 505-509.

De Lucca, S., Taylor, D.J.M., O'Meare, T.J., Jones A.S., Tovey E.R. 1999. Measurement and characterization of cockroach allergens detected during normal domestic activity. Journal of Allergy and Clinical Immunology, 104, 672-680.

Dekker, C., Dales, R., Bartlett, S., Brunekreef, B., Zwanenburg, H. 1991. Childhood asthma and the indoor environment. Chest, 10, 922-926.

The Directorate for the Occupational Environment. 1985. (Arbejdstilsynet). Ventilation guideline.(Vejledning om ventilation). At-meddelelse no 1.01.8, Denmark.

Eggleston, P.A., Rosenstreich, D., Lynn, H., Gergen, P., Baker, D., Kattan, M., et al. 1998. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. Journal of Allergy and Clinical Immunology, 102, 563-570.

Emenius, G., Egman, A.-C., Wickman, M. 1998. Mechanical ventilation protects one-storey single-dwelling houses against increased air humidity, domestic mite allergens and indoor pollutants in a cold climatic region. Clinical and Experimental Allergy, 28, 1389-1396.

Emenius, G., Korsgaard, J., Wickman, M. 2000. Window pane condensation and high indoor vapour contribution - a markers of an unhealthy indoor climate. Clinical and Experimental Allergy, 30, 418-425.

Environmental Health Directorate. 1987. Exposure guidelines for residential indoor air quality. A Report of the federal-provincial advisory committee on environmental and occupational health. Health Canada, Ottawa.

EU-ECA-7. 1990. Indoor air pollution by formaldehyde in European countries. European Concerted Action on indoor air quality & its impact on man. Report no 7. Office for Official Publications of the European Communities, Luxembourg.

EU-ECA-10. 1991. Effects of indoor air pollution on human health. European Concerted Action on indoor air quality & its impact on man. Report no 10. Office for Official Publications of the European Communities, Luxembourg.

EU-ECA-15. 1995. Radon in indoor air. European Concerted Action on indoor air quality & its impact on man. Report no 15. Office for Official Publications of the European Communities, Luxembourg.

EU-ECA-17. 1996. Indoor air quality and the use of energy in buildings. European Concerted Action on indoor air quality & its impact on man. Report no 17. Office for Official Publications of the European Communities, Luxembourg.

EU-ECA-18. 1997. Evaluation of VOC emissions from building products. Solid flooring materials. European Concerted Action on indoor air quality & its impact on man. Report no 18. Office for Official Publications of the European Communities, Luxembourg.

EU-ECA-19. 1997. Total volatile Organic Compounds (TVOC) in indoor air quality investigations. European Concerted Action on indoor air quality & its impact on man. Report no 19. Office for Official Publications of the European Communities, Luxembourg.

Fang, L., Clausen, G., Fanger, P.O. 1998. Impact of temperature and humidity on the perception of indoor air quality. Indoor Air, 8, 80-90.

Fehlmann, J. and Wanner, H.U. 1993. Indoor climate and indoor air quality in residential buildings. Indoor Air, 3, 41-50.

FiSIAQ. 1995. Classification of indoor climate, construction, and finishing materials. Finnish Society of Indoor Air Quality and Climate, Monila Oy, Helsinki.

FiSIAQ. 2001. Classification of Indoor Climate 2000. Target values, design guidance and product requirements. Finnish Society of Indoor Air Quality and Climate, Kirjapaino Verbi, Espoo.

Flatheim, G. 2000. Non complaint buildings in Rigg 2000. In Seppänen O. and Säteri J. (eds.) Proceedings of Healthy Buildings 2000 Espoo, Finland, vol 4, 451-456.

Follin, T. 1997. Airing out pollutions. In Woods, J.E., Grimsrud, D.T., Boschi, N. (eds.) Proceedings of Healthy Buildings/IAQ'97, Healthy Buildings/IAQ'97 Washington DC, Vol. 3, pp. 353-356.

Fox, R., Joffres, M., Barrett, R., Williams, T. 1999. "No scents policy " in the province of Nova Scotia. In Raw G., Aizlewood C. Warren P. (eds.) Proceedings of 8th International Conference on Indoor Air Quality and Climate, Indoor Air '99, Edinburgh, vol 1, 511-515.

Franchi, M. 2000. Jubilee project: Are Italian hotels ready to receive pilgrims? In Seppänen O. and Säteri J (eds.) Proceedings of Healthy Buildings 2000, Espoo, Finland, vol 4, 485-487.

Franke, D.L., Cole, E.C., Leese, K.E., Foarde, K.K., Berry M.A. 1997. Cleaning for improved indoor air quality: an initial assessment of effectiveness. Indoor Air, 7, 41-54.

Funk, L. 1999. New guideline VDI 6022: Hygienic standards for ventilation and air-conditioning systems. In Raw G., Aizlewood C. Warren P. (eds.) Proceedings of 8th International Conference on Indoor Air Quality and Climate, Indoor Air'99, Edinburgh, vol 3, 49-53.

Garrett, M.H., Hooper, M.A., Hooper, B.M., Rayment, P.R., Abramson, M.J. 1999. Increased risk of allergy in children due to formaldehyde exposure in homes. Allergy, 54, 330-337.

Garrett, M.H., Abramson, M.J., Hooper, B.M., Rayment, P.R., Strasser, R.P. Hooper, M.A. 1998. Indoor environmental risk factors for respiratory health in children. Indoor Air, 8, 236-243.

Gelber, L.E., Selzer, L.H., Bouzoukis, J.K, Pollart, S.M., Chapman, D., Platts-Mills, T.A.W. 1993. Sensitization and exposure to indoor allergens as risk factors for asthma among patients presenting to hospitals. American Reviews of Respiratory Diseases, 147, 573-578.

Girman, J., Alevantis, L., Kulasingam, G., Petreas, M., and Webber, L. 1987. Bake-out of an office building. In Proceedings of 4th Int. Conf. Indoor Air Quality and Climate, Vol. 1, pp. 22-26. Institute for Water, Soil, and Air Hygiene, Berlin.

Girman, J. R. 1989. Volatile organic compounds and building bake-out. In Cone, J. E. and Hodgson, M. J. (eds.) Problem buildings: building-associated illness and the sick building syndrome, pp. 695-712. Hanley & Belfus, Inc., Philadelphia, PA.

Godish, T. and Spengler, J. 1996. Relationships between ventilation and indoor air quality: a review. Indoor Air, 6, 135-145.

Greenguard^{TM} 2001. Health through indoor air quality. www.greenguard.org/iaq

Gross, I., Heinrich, J., Fahlbusch, B., Jäger, L., Bischof, W., Wichmann, H.E. 2000. Indoor determinants of Der p 1 and Der f 1 concentration in house dust are different. Clinical and Experimental Allergy, 30, 376-382.

GuT. 2001. Carpets tested for a better living environment. www.gut-ev.de.

Harving, H., Dahl, R., Korsgaar, D.J., Linde, S.A. 1992. The indoor environment in dwellings: a study of air-exchange, humidity and pollutants in 115 Danish residences. Indoor Air, 2, 121-126.

Heavner, D.L., Morgan, W.T., Ogden, M.W. 1996. Determination of volatile organic compounds and respirable suspended particulate matter in New Jersey and Pennsylvania homes and workplaces. Environmental International, 22, 159-183.

Hirsch, T., Stappenbeck, C., Neumeister, V., Weiland, S.K., von Mutius, E., Keil, U., Leupold, W. 2000. Exposure and allergic sensation to cockroach allergen in East Germany. Clinical and Experimental Allergy, 30, 529-537.

Hodgson, A.T., Rudd, A.F., Beal, D., Chandra, S. 2000. Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. Indoor Air, 10, 178-192.

Hult, M. and Persson, R. 1991. Allergikeranpassade bostäder - Generellt planeringsunderlag. Byggforskningsrådet, report R1. (in Swedish).

The Indoor Climate Labelling. 2001. Taastrup, Denmark.

Ingram, J.M., Sporik, R., Rose, G.R., Honsinger, R., Chapman, M.D., Platts-Mills, T.A.E. 1995. Quantitative assessment of exposure to dog (Can f 1) and cat (Fel d 1) allergens: relationship to sensitization and asthma among children living in Los Alamos, New Mexico. Journal of Allergy and Clinical Immunology, 96, 449-456.

Infante-Rivard, C. 1993. Childhood asthma and indoor environmental risk factors. American Journal of Epidemiology, 137, 834-844.

Institute of Medicine (IOM), Committee of the assessment of asthma and indoor air. 2000. Clearing the air: Asthma and indoor air exposures. National Academy Press, Washington D.C.

The International Performance Measurement and Verification Protocol (IPMVP). 2000. Concepts and practices for improved indoor environmental quality, volume II, Office of Energy Efficiency and renewable energy, USA.

The International study of asthma and allergies in childhood (ISAAC) steering committee. 1998. Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. Lancet, 351, 1225-1232.

International Society of Indoor Air Quality and Climate, ISIAQ. 1996. Control of Moisture Problems Affecting Biological Indoor Air Quality, TFI-1996, Ottawa, Canada.

Jamriska, M., Thomas, S., Morawska, L., Clark, H. 1999. Relation between indoor and outdoor exposure to fine particles near a busy arterial road. Indoor Air, 9, 75-84.

Jamriska, M., Morawska, L., and Clark, B.A. 2000. Effect of ventilation and filtration on submicrometer particles in an indoor environment. Indoor Air, 10, 19-26.

Jann, O., Wilke, O., Brödner, D., Plehn, W. 2000. Eco-label emission wood products and wood base products (RAL-UZ 38) – Part 2: test procedure and results. In Seppänen O. and Säteri J (eds.) proceedings of Healthy Buildings 2000, Espoo Finland, vol 4, 525-530.

Johnsen, L.G.W., Prytz, E., Rustan, A. 1996. Clean Building Guidelines. The National Institute of Technology, Oslo.

Johnsen, L.G.W. 1997. The clean building concept – working methods. In Woods J.E., Grimsrud D., Boschi N. (eds.) Proceedings of Healthy Buildings'97. Healthy Buildings/IAQ'97, Washington DC, USA, vol 2, 341-346.

Jones, A.P. 1999. Indoor air quality and health. Atmospheric Environment, 33, 4535-4564.

Jones, A.P. 2000. Asthma and the home environment. Journal of Asthma, 37, 103-124.

Jurvelin, J., Vartiainen, M., Jantunen, M., Pasanen, P. 2001. Personal exposure levels and microenvironmental concentrations of formaldehyde and acetaldehyde in the Helsinki metropolitan area, Finland. Journal of the Air & Waste Management Association, 51, 17-24.

Kildesø, J. and Schneider, T. 2001. Prevention with cleaning. In Spengler, J.D., Samet, J.M., McCarthy, J.F. (eds). Indoor air quality handbook. McGraw-Hill, New York, Charter 64.

Kilpeläinen, M., Terho, E.O., Helenius, H., Koskenvuo, M. 2001. Home dampness, current allergic diseases, and respiratory infections among young adults. Thorax, 56, 462-467.

Kokotti, H., Savolainen, T., Raunemaa, T., Kalliokoski, P. 1989. Indoor radon in three similar two-story houses with different ventilation systems. Environmental International, 15, 289-292.

Koistinen, K.J., Hänninen, O., Rotko, T., Edwards, R.D., Moschandreas, D., Jantunen, M.J. 2001. Behavioral and environmental determinants of personal exposures to $PM_{2.5}$ in EXPOLIS - Helsinki, Finland. Atmospheric Environment, 35, 2473-2481.

Kostiainen, R. 1995. Volatile organic compounds in the indoor air of normal and sick houses. Atmospheric Environment, 29, 693-702.

Knöppel, H., and Schlitt, C. 1995. Nature, sources and toxicity of pollutants on indoor air. In Indoor Air Quality. A Comprehensive reference book. M. Maroni, B. Seifert, and T. Lindwall (eds). Elsevier, Amsterdam, pp. 29-57.

Lau, S. Falkenhorst, G., Weber A. et al. 1989. High mite allergen exposure increases the risk of sensitization in atopic children and young adults. Journal of Allergy and Clinical Immunology, 84; 718-725.

Lawton, M.D., Dales, R.E., White, J. 1998. The influence of house characteristics in a Canadian community on microbiological contamination. Indoor Air, 1998; 8: 2-11.

Levin, H. 1989. Building materials and indoor air quality. In Cone, J. E. and Hodgson, M. J. (eds), Problem buildings: building-associated illness and the sick building syndrome. Hanley & Belfus, Inc., Philadelphia, PA, pp. 667-669.

Liddament, M.W. 2000. A review of ventilation and the quality of ventilation air. Indoor Air, 10, 193-199.

Lindstrom, A.B., Proffitt, D., Fortune, C.R. 1995. Effects of modified residential construction on indoor air quality. Indoor Air, 5, 258-269.

Lundgren, B., Jonsson, B., Ek-Olasussen, B. 1999. Materials emission of chemicals - PVC flooring materials, Indoor Air, 9; 202-208.

Lyczynska, C., Sterne, J., Bond, J., Azima, H., Burney P. 1998. Indoor factors associated with concentrations of house dust mite allergen, Der p 1, in a random sample of houses in Norwich, UK. Clinical and Experimental Allergy, 28, 1201-1209.

Marks, G., Tovey, E., Toelle, B., Wachinger, S., Peat, J., Woodcock, A. 1995. Mite allergen (Der p 1) concentration in houses and its relation to the presence and severity of asthma in a population of Sydney schoolchildren. Journal of Allergy and Clinical Immunology, 96, 441-448.

Maroni, M., Seifert, B., Lindwall, T. (eds.) 1995. Indoor air quality. A comprehensive reference book. Elsevier, Amsterdam.

Menzies, D. and Bourbeau, J. 1997. Building-related illnesses. The New England Journal of Medicine, 337, 1524-1531.

The Ministry of Social Affairs and Health. 1997. Finnish Indoor Air Guideline, guidebook 1. (in Finnish).

Miyazawa, H., Sakaguchi, M., Inouye, S., Ikeda, K., Honbo, Y., Yasueda, H., Shida, T. 1996. Seasonal changes in mite allergen (Der I and Der II) concentrations in Japanise homes. Annals of Allergy, Asthma and Immunology, 76, 170-4.

Morawska, L., He, C., Hitchins, J., Gilbert, D., Parappukkaran, S. 2001. The relationship between indoor and outdoor airborne particles in the residential environment. Atmospheric Environment, 35, 3463-3473.

Mølhave, L. 1990. Volatile organic compounds, indoor air quality, and health. In Proc. 5th Int. Conf. Indoor Air Quality and Climate, Vol. 5, pp. 15-33. Canada Mortgage and Housing Corporation, Ottawa.

Mølhave, L., Sparks, L.E., Wolkoff, P., Clausen, P.A. Nielsen, P.A., Brergsø, N.C. 1996. The Danish twin apartment study- Part II. Mathematical modelling of the relative strength of sources of indoor air pollution. Indoor Air, 6, 18-30.

Mølhave, L., Schneider, T., Kjorgaard, S.K., Larsen, L., Norn, S., Jørgensen, O. 2000a. House dust in seven Danish offices. Atmospheric Environment, 34, 4767-4779.

Mølhave, L. 2000b. Indoor air quality and health. In Seppänen O. and Säteri J. (eds.) Proceedings of Healthy Buildings 2000 Espoo, Finland, vol 1, 3-14.

Nevalainen, A. 1989. Bacterial aerosols in indoor air. Publications of the National Public Health Institute A3.

Nevalainen, A., Pasanen, A.-L., Niininen, M., Reponen, T., Kalliokoski, P., Jantunen, M.J. 1991. The indoor air quality in Finnish homes with mold problems. Environment International, 17, 299-302.

Nevalainen, A., Partanen, P., Jääskeläinen, E., Hyvärinen, A., Koskinen, O., Meklin, T., Vahteristo, M., Koivisto, J., Husman, T. 1998. Prevalence of moisture problems in Finnish homes. Indoor Air, supplement 4, 45-49.

Neuvonen, P. 2000. The classification of Finishing Materials. In: Seppänen O and Säteri J. (eds). Proceedings of Healthy Buildings 2000, Espoo, Vol 4, pp. 537-538.

Nielsen, A. 1999. Planning of rooms for better cleaning. In Raw G., Aizlewood C. Warren P. (eds.) Proceedings of 8th International Conference on Indoor Air Quality and Climate, Indoor air'99, Edinburgh, vol 3, 68-73.

Norbäck, D., Björnsson, E., Janson, C., Widström, J., Boman G. 1995. Asthmatic symptoms and volatile organic compounds, formaldehyde, and carbon dioxide in dwellings. Occupational and Environmental Medicine, 52, 388-395.

The Norwegian Directorate of Health. 1991. Guidelines for indoor air quality in Norway.

Offerman, F. J., Loiselle, S. A., Ander, G., and Lau H. 1993. Before and after a building bake out. In Proceedings of the ASHRAE Conference IAQ'93. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Philadelphia, PA.

Ormstad, H., Gaarder, P.I., Johansen, B.V. 1997. Quantification and characterisation of suspended particle matter in indoor air. The Science of the Total Environment, 193, 185-196.

Pasanen, A.-L. 1992. Airborne mesophilic fungal spores in various residential environments. Atmospheric Environment, 26A, 2861-2868.

Pasanen, P. 1998. Emissions from filters and hygiene of air ducts in the ventilation systems of office buildings. Kuopio University Publications C. Natural and environmental sciences 80, Kuopio.

Parvaneh, S., Ahlf, .E, Elfman, L.H.M., van Hage-Hamsten, M., Elfman, l., Nybom, R. 2000. A new method for collecting airborne allergens. Allergy, 55, 1148-1154.

Patchett, K., Lewis, S., Crane, J., Fitzharris, P. 1997. Cat allergen (Fel d 1) levels on school children's clothing and in primary school classrooms in Wellington, New Zealand. Journal of Allergy and Clinical Immunology, 100, 755-759.

Peat, J.K., Tovey, E., Toelle, B.G., Haby, M.M., Gray, E.J., Mahmic, A. et al. 1996. House dust mite allergens. A major risk factor for childhood asthma in Australia. American Journal of Respiratory and Critical Care Medicine, 153, 141-146.

Peat, J.K., Dickerson, J., Li, J. 1998. Effects of damp and mould in the home on respiratory health: a review of the literature. Allergy, 53, 120-128.

Pejtersen, J. 1996. Sensory pollution and microbial contamination of ventilation filters. Indoor Air, 6, 239-248.

Pejtersen, J., Brohus, H., Hydgaard, C.E., Nielsen, J.B., Valbjorn, O., Hauschildt, P., Kjaergaard, S., Wolkoff, P. 2001. Effect of renovating an office building on occupants' comfort and health. Indoor Air, 11, 10-25.

Peterson, E.L., Ownby, D.R., Kallenbach, L., Johnson C.C. 1999. Evaluation of air and dust sampling schemes for Fel d 1, Der f 1, and Der p 1 allergens in homes in the Detroit area. Journal of Allergy and Clinical Immunology, 104, 348-355.

Pertti-Pellinen, K., Marttila, O., Ahonen, A., Suominen, O., Haahtela, T. 2000. Penetration of nitrogen oxides and particles from outdoor into indoor air and removal of the pollutants through filtration of incoming air. Indoor Air, 10, 126-132.

Plehn, W., Jann, O., Wilke, O. Brödner, D. 2000. Eco-label for wood products and woodbase products (RAL-UZ 38) – Part 1: criteria and requirements for labeling. In Seppänen O. and Säteri J (eds.) Proceedings of Healthy Buildings 2000, Espoo Finland, vol 4, 519-524

Platts-Mills, T.A.E., Thomas, W.R., Aalberse, R.C., Vervloet D., Chapman, M.D. 1992. Dust mite allergens and asthma: report of a second international workshop. Journal of Allergy and Clinical Immunology, 89, 1046-1060.

Platts-Mills, T.A.E., Vervloet, D., Thomas, W.R., Aalberse, R., Chapman M. 1997. Indoor allergens and asthma: report of the third international workshop. Journal of Allergy and Clinical Immunology, 100, supplement 6, 1-24.

Platts-Mills, T.A.E., Vaughan, J.N., Carter, M.C., Woodfolk, J.A. 2000. The role of intervention in established allergy: avoidance of indoor allergens in the treatment of chronic allergic disease. Journal of Allergy and Clinical Immunology, 106, 787-804.

Pollart, S.M., Chapman, M.D., Fiocco, G.P. Rose, G., Platts-Mills, T.A.E. 1989. Epidemiology of acute asthma: IgE antibodies to common inhalant allergens as a risk factor for emergency room visits. Journal of Allergy and Clinical Immunology, 83, 875-882.

Puhakka, E., Joutsiniemi, J., Kärkkäinen, J. 2000. Remedial measures against high concentrations of ammonia in buildings. In Seppänen O. and Säteri J. (eds.) Proceedings of Healthy Buildings 2000 Espoo, Finland, vol 3, 451-456.

Pönkä, A. 1991. Asthma and low level air pollution in Helsinki. Archives of Environmental Health, 46(5), 262-270.

Raunio, P., Pasanen, A.-L., Reiman, M., Virtanen, T. 1998. Cat, dog, and house-dust-mite allergen levels of house dust in Finnish apartments. Allergy, 53, 195-199.

Reijula, K., Kallas, T., Kähkönen, E., Lahtinen, M., Loikkanen, P., Palomäki, E., Saarinen, L. 1999. Kosteus ja homevaurio-ongelmat työpaikoilla. Opas työterveyshuoltoa varten. Työterveyslaitos, Helsinki. (in Finnish)

Reponen, T., Nevalainen, A., Raunemaa, T. 1989. Bioaerosol and particle mass levels and ventilation in Finnish homes. Environmental International, 15, 203-208.

Reponen, T., Raunemaa, T., Savolainen, T., Kalliokoski, P. 1991. The effect of material ageing and season on formaldehyde levels in different ventilation systems. Environment International, 17, 349-355.

Reponen, T., Nevalainen, A., Jantunen, M., Pellikka, M., Kalliokoski P. 1992. Normal range criteria for indoor air bacteria and fungal spores in a subarctic climate. Indoor Air, 2, 26-31.

Ritchie, I.M. and Lehnen, R.G. 1985. An analysis of formaldehyde concentrations in mobile and conventional homes. Journal of Environmental Health, 47, 300-305.

Rosenstreich, D.L., Eggleston, P., Kattan, M., Baker, D., Slavin, R.D., Gergen, P, et al. 1997. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. New England Health Medicine, 336, 1356-1363.

Rønborg, SM, Poulsen, LK, Skov, PS, Mosbech, H. 1999. Effect of two different types of vacuum cleaners on airborne Fel d 1 levels. Annals of Allergy, Asthma and Immunology, 82, 307-10.

Rothweiler, H., Wäger, P. A., Schlatter, C. 1992. Volatile organic compounds and some very volatile organic compounds in new and recently renovated buildings in Switzerland. Atmospheric Environment, 26A, 2219-2225.

Ruotsalainen, R., Rönnberg, R., Säteri, J., Majanen, A., Seppänen, O., Jaakkola, J.J.K. 1992. Indoor climate and the performance of ventilation in Finnish residences. Indoor Air, 2, 137-145.

Ruotsalainen, R. 1995. Ventilation, indoor air quality and human health and comfort in dwellings and day-care centers. Helsinki University of Technology. Report A1.

Ruotsalainen, R., Palonen, J., Jokiranta, K., Seppänen, O. 1997. The guide for diagnosing Indoor Air Quality (Sisäilmaston kuntotukimus). SuLVI 4, Cosmoprint Oy, Helsinki. (in Finnish)

Saarela, K., Laine-Ylijoki, J., Lukkarinen, T., Kettunen, A.-V., Ruotsalainen, R. 1999. Emissions of floor structures during building phase and the indoor air quality of a new office building. In Raw G., Aizlewood C. Warren P. (eds.) Proceedings of 8th International Conference on Indoor Air Quality and Climate, Indoor air'99, Edinburgh, vol 1, 564-569.

Sakaguchi, M., Inouye, S., Yasueda, H., Irie, T., Yoshizawa, S., Shida T. 1989. Measurements of allergens associated with dust mite allergy. II. Concentrations of airborne mite allergens (Der I and Der II) in the house. Int. Arch. Allergy Appl. Immunol. 90, 190-193.

Salthammer, T., Fuhrmann, F., Kaufhold, S., Meyer, B., Schwarz, A. 1995. Effects of climatic parameters on formaldehyde concentrations in indoor air. Indoor Air, 5, 120-128.

Salthammer, T. (ed.) 1999. Organic Indoor Air Pollutants. Occurrence, measurement, evaluation. Wiley-VCH, Weinheim.

Samuelsson, I. 2000. Quality assurance of the indoor environments in schools, offices and dwellings through P-marking. In Seppänen O. and Säteri J. (eds.) Proceedings of Healthy Buildings 2000 Espoo, Finland, vol 4, 555-559.

Schou, C., Hansen, G., Lintner, T., Lowenstein, H. 1991. Assay for major dog allergen, Can f 1: investigation of house dust samples and commercial dog extracts. Journal of Allergy and Clinical Immunology, 88, 847-853.

Seppänen, O.A., Fisk, W.J. and Mendell, M.J. 1999. Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institution buildings. Indoor Air, 9, 226-252.

Seppänen, O. and Palonen, J. 1999. The effects of indoor climate on national economy. FiSIAQ report 10, Monila Oy, Helsinki.

Shaw, C.H., Salares, V., Magee, R.J., Kanabus-Kaminska, M. 1999. Improvement of indoor air quality in four problem homes. Building and Environment, 34, 57-69.

Socialstyrelsen. 1999. Socialstyrelsens författningssamling, 21. Stockholm, Sweden (in Swedish).

Spengler, J., Neas, L., Nakai, S., Dockery, D., Speizer, F., Ware, J. Raizenne, M. 1994. Respiratory symptoms and housing characteristics. Indoor Air, 4, 72-82.

Spengler, J.D., Samet, J.M., McCarthy, J.F. 2001. Indoor air quality handbook. McGraw-Hill, New York.

Stannegård, Ö. and Strannegård, I.-L. 2001. The causes of increasing prevalence of allergy: is atopy a microbial deprivation disorder. Allergy, 56, 91-102.

Steerenberg, P.A., Van Amsterdam, G.C., Vandebriel, R.J., Vos J.G., Van Bree L., Van Loveren H. 1999. Environmental and lifestyle factors may act in concert to increase the prevalence of respiratory allergy including asthma. Clinical and Experimental Allergy, 29, 1304-1308.

Stridh, G., Fredikson, R., Jansson, L., Bobertson, S., Viklund, L. 1993. Levels of volatile compounds (VOC) and formaldehyde in the Swedish housing stock. In Saarela K., Kalliokoski P. and Seppänen O. (eds.) Proceedings of 6th International Conference on Indoor Air Quality and Climate, Indoor air'93, Helsinki, vol 2, 159-163.

Stridh, G. And Andersson, K. 1995. The effect of different restoring measures in a domestic area with severe indoor climate problems. In Morawska L., Bofinger N.D. Maroni M. (eds.) Proceedings of Indoor Air: An integrated approach, Amsterdam, Elsevier, pp. 247-250.

Sundell, J., Wickman, M., Pershagen, G., Nordvall, S.L. 1996. Ventilation in homes infested by house-dust mites. Allergy, 50, 106-112.

Sundell, J. 2000. Building related factors and health. In Seppänen O. and Säteri J (eds.) Proceedings of Healthy Buildings 2000, Espoo Finland, vol 1, 23-33.

Sundell, J. Malindzak, G., Holcatova, I., Boschi, N., Tuomainen, M. 2000. Healthy building concepts to reduce allergies and asthma. In Seppänen O., Tuomainen M. Säteri J. (eds.) Workshop summaries: of Healthy Buildings 2000, Espoo Finland, 25- 28.

Susitaival, P. and Husman, T. (eds.). 1996. Tuohilampi - a set of questionnaires for population studies of hypersensitivity diseases of respiratory tract, skin and eyes. Hakapaino Oy, Kuopio. (in Finnish).

Tovey, E. and Marks, G. 1999. Methods and effectiveness of environmental control. Journal of Allergy and Clinical Immunology, 103, 179-191.

US EPA (United States Environmental Protection Agency). 1993. Targeting indoor air pollution. EPA's approach and progress. http://www.epa.gov.iaq/pubs/targetng.html.

US EPA (United States Environmental Protection Agency). 2000. Why should you be concerned about the quality of air that you breathe? http://www.epa.gov/iaq/index.html.

Valicenti, J.A. and Wenger, J. 1997. Air quality monitoring during construction and initial occupation of a new building. Journal of Air & Waste Management Association, 47, 890-897.

Van der Heide, S, Van Aalderen, W.M.C., Kauffman H.F., Dubois, A.E.J., de Monchy J.G.R.. 1999. Clinical effects of air cleaners in homes of asthmatic children sensitised to pet allergens. Journal of Allergy Clinical Immunology, 104, 447-51.

Van der Wal, J.F., Hoogenveen, W., Wouda, P. 1997. The influence of temperature on the emission of volatile organic compounds from PVC flooring, carpet, and paint, Indoor Air, 7, 215-221.

Van Strien, R., Verhoeff, A., Brunekreef, B., Van Wijnen, J. M. 1994. Mite antigen in house dust: relationship with different housing characteristics in the Netherlands. Clinical and Experimental Allergy, 24, 843.852.

Van Winkle, M.R. and Scheff, P.A. 2001. Volatile organic compounds, polycyclic aromatic hydrocarbons and elements in the air of ten urban homes. Indoor Air, 11, 49-64.

VDI 6022, 1998. Hygienic standards for ventilation and air-conditioning systems offices and assembly rooms. Germany.

Villberg, K., Saarinen, A., Saarela, K., Lukkarinen, T. Mussalo-Rauhamaa, H., Pasanen A.-L. (eds.).1999. Finnish research programme on environmental health SYTTY. Project: Indoor air quality control. Progress report , Technical Research Center of Finland.

Warner, J.A., Frederick, J.M., Bryant, T.N., Weich, C., Raw, G.J., Hunter, C., Stephen, F.R., McIntyre, D.A., Warner, J.O. 2000. Mechanical ventilation and high-efficiency vacuum-cleaning: A combined strategy of mite and mite allergen reduction in the control of mite-sensitive asthma. Journal of Allergy and Clinical Immunology, 105, 75-82.

WHO. 1982. Indoor air pollutants: exposure and effects. Euro reports and studies 78. Copenhagen.

WHO. 2000a. Guidelines of air quality. Geneva. http://www.who.int/peh/

WHO. 2000b. The right to healthy indoor air. Report on a WHO Meeting, Bilthoven, the Netherlands 15-17 May 2000.

WHO, 2000c. Air quality guidelines for Europe. Second edition. European series No.91, Denmark.

Wieslander, G., Norbäck, D., Björnsson, E., Janson, C. Boman, G. 1997. Asthma and the indoor environment: the significance of emission of formaldehyde and volatile organic compounds from newly painted indoor surfaces. International Archives of Occupational and Environmental Health, 69, 155-124.

Winkels, K. 2000. EMICODE® labeling system of GEV for flooring installation products – new developments. In Seppänen O. and Säteri J (eds.) Proceedings of Healthy Buildings 2000, Espoo Finland, vol 4, 513-518.

Wolkoff, P., Clausen P.A., Nielsen P.A. Mølhave L. 1991. The Danish twin apartment study; Part I: formaldehyde and long-term VOC measurements. Indoor Air, 4, 478-490.

Wolkoff, P., Schneider, T., Kildesø, J., Degerth R., Jaroszewski, M., Schunk H. 1998. Risk in cleaning: chemical and physical exposure. The Science of the Total Environment, 215, 135-156.

Wolkoff, P., Nielsen G.D. 2001. Organic compounds in indoor air - their relevance for perceived indoor air quality. Atmospheric Environments, 35, 4407-4417.

Woodcock, A. and Custovic, A. 1998. ABC of allergies. Avoiding exposure to indoor allergens. British Medical Journal (BMJ), 316, 1075-1078.

Wood, R., Chapman, M., Adkinson, N., Eggleston P.A. 1989. The effect of cat removal on allergen content in household dust samples. Journal of Allergy and Clinical Immunology, 83, 730-734.

Yu, C. and Crump, D. 1998. A review of the emission of VOCs from polymeric materials used in buildings. Building and Environment, 33, 357-374.

Åberg, N., Sundell, J., Eriksson, B., Hesselmar, B., Åberg, B. 1996. Prevalence of allergic diseases in schoolchildren in relation to family history, upper respiratory infections, and residential characteristics. Allergy, 51, 232-237.