INDOOR AIR PROBLEMS IN FINNISH HOSPITALS – FROM THE OCCUPATIONAL HEALTH PERSPECTIVE

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ACADEMIC DISSERTATION

To be publicly discussed with the permission of the Medical Faculty of the University of Helsinki, in Auditorium XIII, University Main building, Unioninkatu 34, Helsinki, on Friday 23rd November, at 12 noon.

Helsinki 2012
The demands for indoor air quality are higher in hospital buildings than in other premises because patients are often more sensitive to impurities than the general population is. At the same time, there are more infectious agents, some of which are contagious and spread through the indoor air.

In hospitals, indoor air problems can be related to both the processes and the facilities. The ventilation systems are usually large, complex, and difficult to maintain properly. Hospital buildings can suffer from moisture damage due to some typical building structures and because of the amounts of water used in patient care. Investigating hospital buildings is demanding, and finding solutions to the problems encountered is even more challenging.

Many Finnish hospital buildings are in need of renovation not only because of their age but also because of changes in space requirements and processes. Carrying out renovations is complicated in hospital surroundings in that the processes cannot be disrupted, there is not enough evasive space, and, during some phases, microbes can spread throughout the indoor air.

The purpose of this study was to assess the indoor air quality and indoor-air-related symptoms perceived by hospital staff, as well as to determine the relationship between these factors and the condition of hospital buildings and their ventilation systems. Investigating and finding solutions to indoor air problems requires multi-professional collaboration. One objective of the present study was to determine how the problem solution process functions in hospitals, especially from the occupational health perspective. In order to develop new tools for use in occupational health care in the examination of persons exposed to indoor air impurities, the usability of nasal lavage was tested among employees in water-damaged buildings.

The Indoor Air Questionnaire of the Finnish Institute of Occupational Health was used in the survey to collect information on the complaints and indoor-air-related symptoms of hospital employees. Altogether 5598 forms were sent out, and 3811 employees returned the questionnaire. At the same time, a group of professionals on construction and ventilation examined the hospital buildings and their ventilation systems. Semi-structured interviews concerning the processes aimed at resolving indoor air problems were carried out amongst personnel working in hospital occupational health, occupational safety, and infection control. Nasal lavage was performed as a part of the examinations of 28 employees working in a moisture-damaged hospital ward.

Hospital employees experienced poor indoor air quality and symptoms related to indoor air more often than office workers did. The workers in moisture-damaged
departments more often had complaints and symptoms than did the workers in departments that were in good condition. In hospitals where, for the most part, the ventilation systems were in need of repair, the workers experienced more inconvenience and symptoms than did those in hospitals in which the ventilation systems were mostly in good condition. Workers in moisture-damaged departments showed signs of immuno-suppression in their nasal lavage samples, and their inflammatory cell counts and cytokine levels were lower than in controls.

All of the interviewed persons considered the indoor air problems difficult to tackle. The roles and responsibilities of occupational health professionals, the technical department, and the employer in solving the problems were not clear. There was a definite need to improve the flow of information between the different parties. An “indoor air group” had been appointed in only three of the seven hospitals in which the interviews were carried out. These groups were considered good, especially in regard to the flow of information.

In conclusion, “an indoor air group” should be established in every hospital. The Indoor Air Questionnaire should be used as a part of occupational health activities in all hospitals. Indoor air quality should be monitored with regular questionnaire surveys, as well as with regular walk-throughs of the buildings and evaluations of the ventilation systems. A plan for this purpose is presented. Moisture damage should be repaired as soon as possible, and the ventilation systems should undergo necessary service and renovation before poor indoor air quality leads to complaints and symptoms.

The nasal lavage findings of moisture- and mould-exposed persons can show immuno-suppression or immuno-activation. Further studies are needed to better understand the role of immune reactions before these methods can be applied in occupational health activities.
LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original papers, referred to in the text by their Roman numerals. In addition, some previously unpublished data are presented.


The publications are referred to in the text by their roman numerals.
ACKNOWLEDGEMENTS

This work was carried out at the Finnish Institute of Occupational Health, Helsinki. I wish to express my gratitude to my supervisor and former superior Professor Kari Reijula for providing the idea and possibilities for this work, as well as for his encouragement and scientific advice throughout the entire period. I am also deeply indebted to my other supervisor Helena Mussalo-Rauhamaa, MD, PhD, for her guidance and support. Without my excellent and profound reviewers Professor emeritus Gustav Wickström and Markku Seuri, MD, PhD, the result would not be what it is now. I am very grateful for their involvement and constructive criticism.

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I am very grateful to my friends, especially Elisa, Eija, Tuula and Soila, for their support and encouragement. I am also grateful to my parents Viljo and Rauni, who encouraged me and made it possible for me to study. Finally, I owe my warmest thanks to my sons Roy-Peter and Paul; the happiness and love you have brought to my life has helped me cope not only with this work but also with other challenges of life as well.

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<tr>
<td>BSI&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Building symptom index (5 symptoms)</td>
</tr>
<tr>
<td>BSI&lt;sub&gt;8&lt;/sub&gt;</td>
<td>Building symptom index (8 symptoms)</td>
</tr>
<tr>
<td>BRS</td>
<td>Building-related symptoms</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>DEPH</td>
<td>Di(2-ethyl-hexyl)phthalate</td>
</tr>
<tr>
<td>ECP</td>
<td>Eosinophilic cationic protein</td>
</tr>
<tr>
<td>FEV&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Forced expiratory volume in 1 second</td>
</tr>
<tr>
<td>FIOH</td>
<td>Finnish Institute of Occupational Health</td>
</tr>
<tr>
<td>FVC</td>
<td>Forced vital capacity</td>
</tr>
<tr>
<td>HAI</td>
<td>Hospital-acquired infection</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, ventilation, and air-conditioning</td>
</tr>
<tr>
<td>IAQ</td>
<td>Indoor air quality</td>
</tr>
<tr>
<td>IgE</td>
<td>Immunoglobulin E</td>
</tr>
<tr>
<td>IgG</td>
<td>Immunoglobulin G</td>
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<tr>
<td>IL</td>
<td>Interleukin</td>
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<tr>
<td>MM questionnaire</td>
<td>Miljö Medicin questionnaire</td>
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<td>MPO</td>
<td>Myeloperoxidase</td>
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<tr>
<td>MTM</td>
<td>Macroyclic trichothecene mycotoxin</td>
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<tr>
<td>NAL</td>
<td>Nasal lavage</td>
</tr>
<tr>
<td>ODTS</td>
<td>Organic dust toxic syndrome</td>
</tr>
<tr>
<td>OH</td>
<td>Occupational health</td>
</tr>
<tr>
<td>OR</td>
<td>Odds ratio</td>
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<tr>
<td>OS</td>
<td>Occupational safety</td>
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<tr>
<td>PEF</td>
<td>Peak expiratory flow</td>
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<tr>
<td>PSI&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Person symptom index (5 symptoms)</td>
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<tr>
<td>PSI&lt;sub&gt;8&lt;/sub&gt;</td>
<td>Person symptom index (8 symptoms)</td>
</tr>
<tr>
<td>RR</td>
<td>Risk ratio</td>
</tr>
<tr>
<td>RSH</td>
<td>Royal Society of Health</td>
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<tr>
<td>SBS</td>
<td>Sick-building syndrome</td>
</tr>
<tr>
<td>SCHER</td>
<td>Scientific Committee on Health and Environmental Risks</td>
</tr>
<tr>
<td>TNF-α</td>
<td>Tumour necrosis factor α</td>
</tr>
<tr>
<td>US EPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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1 INTRODUCTION

Hospitals are an essential part of any modern health service system. They have traditionally been buildings in which to be cured, shelters in which to suffer and be sick, to be born, and to die. As with respect to security, in most people’s set of values, the hospital is second after the home. As a challenge of the 2000s, a new attitude has been adopted, in which hospitals are not distinguished from other buildings but are, instead, only places for taking care of patients’ diseases. They should also provide a healthy work environment for hospital personnel (Hancock 1999). Health services are, in many ways, moving out of hospitals and into homes and out-patient clinics. At the same time, hospitals are becoming a better part of society and turning into a cosy healing environment, which accelerates recovery.

Various health-care facilities and departments are associated with hospitals, such as in-patient wards, operating theatres, intensive care units, delivery rooms, outpatient departments, pharmacies, radiology departments, and laboratories. Each facility has its own functions, and the day-to-day running of each of them can differ greatly from that of the others. There are three main groups of occupants in a hospital: patients, health-care workers, and visitors. The groups differ in terms of their health status and their susceptibility to airborne impurities, such as chemicals and microbes. The diversity of facilities and occupants makes the complex hospital environment unlike any commercial or industrial buildings.

The central hospital buildings of the 20 Finnish hospital districts were built, for the most part, between the 1950s and 1970s. Now, many of them are at the end of their life cycle and need refurbishment. The building and ventilation techniques used in the 1950s do not meet current demands. Furthermore, hospital work has become more effective and diverse since that time. Renovations in hospital environments are challenging and expensive. Construction dust in renovated hospitals almost always contains substances that may cause a health risk. Mould spores, especially Aspergillus spores, can be life threatening to immuno-compromised patients (Vonberg and Gastmeier 2006; Haiduven 2009) and may also cause adverse health effects amongst otherwise healthy employees (Stark et al. 2005).

It is difficult to find enough evasive space for hospital activities during the renovation of hospital buildings, and renovations may have been postponed for this reason. Mistakes during the design, construction, and use of hospitals have led to significant moisture damage in some buildings and have caused mould problems in the building structures. Exposure to moulds in these buildings may cause symptoms and, at its worst, work-related disease amongst the employees.
In a survey called *Work and Health in Finland*, which was carried out by the Finnish Institute of Occupational Health (FIOH), a total of 20% of hospital employees reported the smell of mould in their workplace (Kauppinen et al. 2004). According to the Finnish Register of Occupational Diseases, which contains both recognised and suspected occupational diseases in Finland, microbes related to moisture damage caused most of the occupational diseases that occurred amongst health-care and social workers in 2005–2009 (Laakkonen et al. 2007; Karjalainen et al. 2008, 2009; Oksa et al. 2010; Oksa et al. 2011). About two thirds of all occupational diseases related to moisture damage had occurred in the social and health-care or education sector; this figure demonstrates the extent of the problem in these two fields of public activity.

Indoor air problems have become a considerable challenge to occupational health (OH), causing significant impairment to employees’ health, welfare, and productivity. In recognising and solving indoor air problems, the OH sector has an important role. Hospital work involves some processes from which impurities may be spread to the indoor air, such as anaesthetic gases, pharmaceutical products, laboratory chemicals, sterilising agents, and plaster dust. In addition, problems involving the building and its ventilation may cause employees to suffer adverse health effects. Moisture and mould problems are common in hospital buildings for several reasons, such as flat roofs and architecture that includes many protruding segments. In addition, a large amount of water is used in hospital care.
2 REVIEW OF THE LITERATURE

2.1 INDOOR AIR AND FACTORS AFFECTING ITS QUALITY

In industrialised countries most of a person’s time is spent indoors (Leech et al. 2002; Brasche and Bischof 2005). Thus it is important that the indoor air quality (IAQ) be good. The IAQ is good enough if most of the occupants of the space in question are satisfied with the indoor air, and it does not cause adverse health effects (Reijula and Haahtela 1998). This definition emphasises the experience of the occupant. Generally, occupants are satisfied with indoor air if it is considered fresh and pleasant, it has no negative impact on their health, and, in addition, it is stimulating and work-promoting (Ole Fanger 2006). Current ventilation standards and guidelines are based on the modest requirement that the indoor air be “acceptable” (i.e., only the most sensitive part of a population, usually 20%, perceives the air to be unacceptable) (ASHRAE 2004). According to Ole Fanger (2006), there is an enormous potential for improving IAQ through the utilisation of new, emerging technologies that would enable the provision of IAQ that is acceptable for even the most sensitive persons. He claims that already modest improvements, compared with the current minimum standards and typical conditions in practice, could significantly decrease the risk of asthma and allergy in homes, improve learning in schools, and increase productivity, while maintaining or even decreasing energy use.

According to Bluyssen (2009), there are four basic environmental factors that influence the perception of the environment and affect comfort and health: thermal comfort, visual or lighting quality, IAQ, and acoustical quality. Thermal comfort includes temperature, air velocity, and humidity. Indoor air contaminants consist of particles, such as dust and fibres, bioaerosols, and gases or vapours. Their levels are influenced both by outdoor air concentrations and indoor emissions. Indoor emissions may come from the inside structures, like wall coverings and devices, including furniture, as well as from the people and activities being carried out. The concentrations of air pollutants are important with respect to well-being and health.

2.1.1 MICROBIAL GROWTH IN DAMP BUILDINGS

The prevalence of dampness in homes is estimated to be on the order of 10%–50% in the most affluent countries; in less affluent countries the prevalence may some-
times exceed 50% (Heseltine and Rosen 2009). Indicators of dampness and microbial growth include, among others, the presence of condensation on surfaces or in structures, the peeling of furnishing material, leakage or penetration, visible mould, perceived mould or stuffy odour, and a history of water damage.

There are some genera of fungi that are especially related to dampness in buildings, for example, *Acremonium*, *Aspergillus*, *Chaetomium*, *Fusarium*, *Stachybotrys* and *Trichoderma*, *Eurotium*, *Exophiala*, *Phialophora*, *Tritirachium*, *Ulocladium*, *Wallemia*, and yeasts (Heseltine and Rosen 2009).

Bacteria grow in the same areas as fungi (Heseltine and Rosen). They require higher humidity than most fungi. Actinobacteria, spore-formating soil bacteria, imitate moulds in buildings. In particular, *Streptomyces*, gram-positive, spore-forming bacteria, may grow on damp or wet building materials. They are probably the cause of the typical “smell of cellar” in water-damaged buildings. The smell, however, depends on the stage of microbial growth and is not always present.

Protozoa such as amoebae may also appear in microbial growth in damp indoor environments (Yli-Pirilä et al. 2004). Amoebae survive on many wet building materials, and they can alter the survival and growth of some microbes and enhance the pro-inflammatory properties of certain microbes (Yli-Pirilä et al. 2006, 2007, 2009). Dust mites survive better in damp environments (Korsgaard 1998). They may co-exist with moulds and cause allergies (Pennanen et al. 2007).

Microbial growth in damp buildings may release many substances into indoor air, such as mould spores, mycotoxins, endotoxins, fungal and house-dust mite allergens, as well as cell wall fragments such as β-glucans in indoor air (Heseltine and Rosen 2009). There can also be microbial and other volatile organic compounds in the air (Korpi et al. 2009).

Moulds that are frequently found in wet buildings can produce metabolites that are toxic to other microbes. Dearborn et al. (1999) precipitated the concern with “toxic” moulds in the mid-1990s by reporting an unusual cluster of bleeding in the lungs (idiopathic pulmonary haemosiderosis) of infants in Cleveland, Ohio. Bloom et al. (2009) found that 66% of the analysed samples of building materials, 51% of the cultured dust samples, and 11% of the settled dust samples were positive for at least one of the studied mycotoxins. *Stachybotrys chartarum* is often discussed when individual moulds known to produce mycotoxins are under consideration. It may produce a variety of mycotoxins, the most potent of which are the macrocyclic trichotheccenes, such as satratoxin G and H. In his review, Straus (2009) showed that the macrocyclic trichotheccene mycotoxins (MTMs) of *S. chartarum* were easily dissociated from the surface of the organism as it grows and could therefore consequently spread in buildings. He also showed that MTMs remain toxic over extended periods of time. In a laboratory study, he showed that MTMs can become airborne and may be attached to spores or particulates smaller than spores. He was also able to demonstrate the presence of MTMs in the sera of persons who had been exposed
to *S. chartarum* in indoor environments. *Stachybotrys* fungi are often regarded as the major danger in water-damaged houses.

Endotoxins are integral components of the outer membrane of gram-negative bacteria and are composed of proteins, lipids, and lipopolysaccharides. Täubel et al. (2011) has shown their co-occurrence with mycotoxins in indoor samples from mouldy buildings. They also showed the presence of toxins of gram+ bacteria, such as *Streptomyces*, in mouldy buildings.

### 2.1.2 VENTILATION

Ventilation is one of the most important factors contributing to IAQ. It supplies fresh air for human beings, and it removes or dilutes pollutants generated indoors (pollutants from people, building materials, furniture, cleaning products, and the ingress of soil gasses such as radon). It is also important in humidity control aimed at preventing the growth of dust mites, as well as microbial growth in building structures. In addition, it is used to control the pressure levels in buildings in order to prevent pollutants from spreading. It is also often used to control temperature. On the other hand, moisture-related heating, ventilation, and air-conditioning (HVAC) components, when poorly maintained, may be sources of indoor air contaminants (Mendell et al. 2008).

### 2.1.3 OTHER FACTORS

Particulate matter from outdoor air, room dust including dandruff from humans, and fibres, such as asbestos and man-made vitreous fibres, may also deteriorate indoor air, as does discharges from building and surface materials and equipment and furniture (Bluyssen 2009). The number of indoor particles is related to the number of people inside the building space and the effect of ventilation. Good filters in supply-air terminals can reduce the number of fine particles from outdoors. Only some of the biggest particles settle on the surfaces and can be removed by cleaning.

Several sources of man-made vitreous fibres, such as heat insulations, acoustic boards and silencers of ventilation noise, may exist in an indoor environment (Bluyssen 2009). Salonen et al. (2009a) found that more than 60% of the surface dust and almost 90% of the samples collected from supply air ducts contained man-made vitreous fibres.

Damp concrete floors are known to increase the chemical degradation of plasticisers in polyvinyl chloride floor coatings and glues, with emissions of ammonia and volatile organic compounds (VOCs) into the indoor air (Gustafsson and Lundgren 1997; Wiglusz et al. 1998). Di(2-ethylhexyl)phthalate (DEPH) is the commonest
phthalate found indoors, and it is widely used as a plasticiser in the polyvinyl chloride included in common consumer products, such as building materials, cleaning products, and cosmetics (Schettler 2006). Its degradation product, 2-ethyl-1-hexanol, in indoor air is an indicator of the dampness-related alkaline degradation of DEPH (Gustafsson and Lundgren 1997).

Environmental tobacco smoke used to be a significant contaminant in indoor air, but it is no longer a big problem in Finnish workplaces due to legislation forbidding smoking at work (Heloma and Jaakkola 2003a).

Formaldehyde is a tangy, colourless gas. Its indoor sources are urea-formaldehyde resin, which is used as adhesive in furniture fibreboards, and chipboard and phenol-formaldehyde resin, used as a binder in mineral wool. Structures or non-real estate property getting wet causes degradation of binding resin, which then frees formaldehyde (Salthammer et al. 2010).

The indoor sources of VOCs are building materials, furniture, textiles, office supplies and cosmetics, among others. The odour thresholds of some compounds are low (Salonen et al. 2009b, 2009c).

Indoor ozone comes from laser printers and copying machines (Bluyssen 2009). It can react with building materials and unsaturated organic compounds, the result being other adverse reaction products, for example, formaldehyde and fine particles (Weschler 2011).

Radon gas is released from the soil, earth fillings, rocky concrete, or light concrete structures; the concentrations in some parts of Finland are high when compared with concentrations found in other European countries (Bochicchio et al. 1995).

### 2.2 SYMPTOMS AND DISEASES RELATED TO INDOOR AIR

Human reactions to the indoor environment can be divided into the following three main categories: 1) comfort inconvenience, such as thermal discomfort, complaints of stuffy air, dry air or malodours; 2) nonspecific symptoms with an unclear cause, called the “sick building syndrome” (SBS) or “building-related symptoms” (BRS); and 3) building-related illness, such as hypersensitivity pneumonitis, building-related asthma and legionellosis (Norback 2009). Table 1 presents some of the common sources of indoor-air-related complaints and the health effects associated with them.
Table 1. Common sources or agents of indoor-air-related complaints and the health effects associated with them.

<table>
<thead>
<tr>
<th>Source/Agent</th>
<th>Health effect</th>
<th>Remarks</th>
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<tr>
<td><strong>Physical factors</strong></td>
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<tr>
<td>Temperature</td>
<td>Extreme indoor temperatures are a serious health hazard (e.g., for elderly, sick people).</td>
<td>Too high a temperature exacerbates the effects of insufficient humidity. Lowering the temperature alleviates nasal and skin symptoms. Females are more sensitive to ambient air temperature, especially to cold.</td>
<td>Reinikainen and Jaakkola 2001; Healy 2003; Kosatsky 2005; Karjalainen 2011</td>
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<tr>
<td>Relative humidity (RH)</td>
<td>Skin symptoms (dryness, rash), nasal dryness and congestion are associated with low relative humidity. Stuffiness seems to be increased by artificial steam humidification. In computer work with sensory irritants present, low RH (&lt;40%) conditions may exacerbate the development of eye irritation symptoms.</td>
<td>In excess humidity, water condenses onto cold surfaces and may cause mould growth. High humidity also favours the growth of dust mites. Odour perception increases with high RH.</td>
<td>Reinikainen and Jaakkola 2003; Wolkoff et al. 2006</td>
</tr>
<tr>
<td>Radon</td>
<td>Lung cancer.</td>
<td>High radon concentration causes no symptoms as such.</td>
<td>Al-Zoughool and Krewski 2009</td>
</tr>
<tr>
<td><strong>Chemical factors</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Man-made mineral (vitreous) fibres</td>
<td>Irritation of eyes, skin, and respiratory tract.</td>
<td>Due to the heat insulation of ventilation ducts and acoustic boards.</td>
<td>Tuomainen et al. 2003</td>
</tr>
<tr>
<td>Environmental tobacco smoke</td>
<td>Chronic obstructive, pulmonary disease, asthma, stroke, cancer.</td>
<td>Primary source of more than 4000 chemicals, of which 50 are carcinogens (e.g., benzene, fine and ultra-fine particles indoors).</td>
<td>Husgafvel-Pursiainen 2004; Dhala et al. 2006; Reardon 2007</td>
</tr>
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### Chemical factors

<table>
<thead>
<tr>
<th>Chemical factors</th>
<th>Odour. Sensory irritation. Associated with asthma symptoms and bronchial hyper-reactivity.</th>
<th>Mostly used as an indicator of an unusual indoor source of impurities.</th>
<th>Venn et al. 2003; Dales and Raizenne 2004; Rumchev et al. 2004; Rumchev et al. 2007</th>
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</thead>
<tbody>
<tr>
<td><strong>Volatile organic compounds (VOCs)</strong></td>
<td>Volatile organic compounds (VOCs)</td>
<td>Effects well-known from exposure in industry.</td>
<td>Salonen et al. 2009b; Salthammer et al. 2010</td>
</tr>
<tr>
<td><strong>Formaldehyde</strong></td>
<td>Sensory irritation of eyes and mucous membranes of upper respiratory tract. Asthma- and allergy-related health effects? Nasopharyngeal cancer?</td>
<td>Effects are still uncertain.</td>
<td>Bornehag et al. 2004a; Bornehag and Nanberg 2010; Kimber and Dearman 2010</td>
</tr>
<tr>
<td><strong>Plasticisers/phthalates</strong></td>
<td>Allergic disease in children? Immune and allergic responses, asthma?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Biological factors

<table>
<thead>
<tr>
<th>Biological factors</th>
<th>Symptoms in allergic persons, sensibilisation.</th>
<th>Pets, but also noxious insects (e.g., cockroaches)</th>
<th>Instanes et al. 2005; Tranter 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Animal allergens</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biological hazards associated with damp indoor environments</strong></td>
<td>Different allergic, infectious, irritant or toxic effects.</td>
<td>Associated with several health effects, but causal mechanisms are unclear. Few follow-up studies are available.</td>
<td>Bruneckreef et al. 1989; Dales et al. 1991; Bornehag et al. 2001, 2004b; Institute of Medicine 2004; Fisk et al. 2004b; Hirvonen et al. 2005</td>
</tr>
<tr>
<td><strong>Bacteria, viruses, and other microorganisms</strong></td>
<td>Acute inflammatory responses, infection.</td>
<td>Impact of HVAC on distribution.</td>
<td>Li et al. 2005a, 2005b</td>
</tr>
</tbody>
</table>

In a Finnish survey from 2004, the commonest inconvenience complaints amongst office workers were dry air (35%), stuffy air (34%), dust or dirt in the indoor environment (25%), and draught (22%) (Reijula and Sundman-Digert 2004). In a random sampling of office workers in the United States, 24% said there were air quality problems in their work environments, and 20% believed these problems affected their work performance (Kreiss 1990).
2.2.1 BUILDING-RELATED SYMPTOMS

The term “sick-building syndrome” (SBS) emerged when office workers in North America and Europe reported symptoms and other health problems that they attributed to their work environment (Hodgson 1995; Redlich et al. 1997; Burge 2004). The recognition of this syndrome coincided with a period of time when the importance of saving energy was being emphasised. According to a World Health Organization (WHO) working group, SBS is characterised by eye, nose, and throat irritation; a sensation of dry mucous membranes and skin; erythema; mental fatigue; headache; a high frequency of airway infections and cough; hoarseness; wheezing, itching and non-specific hypersensitivity; as well as nausea and dizziness (WHO 1983). All, except skin symptoms, should improve within a few hours after an affected person leaves a problem building; dryness of the skin may take a few days to improve.

The term SBS has been justly criticised (Thorn 1998). It has limited clinical utility because the symptoms are non-specific. In the medical literature “syndrome” refers to certain specific symptoms of a person when the disease or cause behind the symptoms is not known. SBS is a group phenomenon, and therefore the term cannot be used for a single person. When it comes to the building itself, the reason behind the building-related symptoms must be determined. Otherwise, the situation cannot be improved. No single environmental factor or group of factors has been established as the single cause of SBS (Mendell 1993; Brauer et al. 2006). Thus it is best viewed as multifactorial in origin, related to various factors and exposures, the two main features being contaminants in the indoor air and the ventilation system used to remove them. Different people in the same room or building may have different symptoms, and even a single person may have different symptoms at different times. Therefore, the term “building-related symptoms” (BRS) is used in this study.

In a Finnish study from 2004, the commonest work-related symptoms were irritated, stuffy or runny nose (20%), itching, burning or irritation of the eyes (17%), and fatigue (16%). The United States Environmental Protection Agency conducted a systematic survey of 100 randomly selected office buildings in the 1990s (the Building Assessment Survey Evaluation = BASE study): 45% of the workforce reported at least one work-related health symptom, and 20% reported at least three symptoms (Brightman et al. 2008). Female gender and self-reported allergy have been found to be associated with a higher prevalence of BRS (Stenberg and Wall 1995; Brasche et al. 2001; Reijula and Sundman-Digert 2004), while no consistent association between age and BRS has been found (Reijula and Sundman-Digert 2004). Neuroticism and subjectively estimated physical health, as well as the type of building ventilation, explained 15% of the variance in the SBS index (Gomzi et al. 2007).
Most studies on BRS are cross-sectional in design and have dealt with symptoms amongst office workers. A longitudinal study amongst office workers concluded that health problems may lead to increased complaints about the indoor environment and thus to a reversed effect between health and the environment (Brauer et al. 2008). Sahlberg et al. (2009) showed an increased risk for the onset of mucosal symptoms (risk ratio [RR] 3.17), any skin symptoms (RR 2.32), or general symptoms (RR 2.18) for those who had experienced dampness or moulds in their dwelling during a 10-year follow-up period. Only a few studies have been carried out on the association between indoor particulate matter in the air and BRS. Two studies of Allermann et al (2003, 2007) showed an association between the inflammatory potential of indoor settled dust and BRS symptoms. Edvardsson et al. (2008) showed that BRS was long-lasting in that nearly half of the patients claimed that the symptoms were more or less unchanged after 7 years or more, despite actions taken to reduce them, 25% were on a sick-list, and 20% drew a disability pension due to persistent symptoms at follow-up.

BRS may also include a syndrome called multiple-chemical sensitivity or idiopathic environmental intolerance, a condition in which people have acute hypersensitivity reactivity to low levels of chemicals found in everyday substances. These symptoms are also nonspecific, such as fatigue, nausea, headache, dyspnoea, and eye irritation. Patients with multiple-chemical sensitivity do not experience or differentiate between smells better than controls do, but they do not adjust to the smell the way that controls do (Graveling et al. 1999).

According to Seppänen and Fisk (2002), most studies indicate that, in comparison with natural ventilation, air conditioning, with or without humidification, is consistently associated with a statistically significant increase in the prevalence of one or more BRS symptoms. Deficiencies in HVAC system design, construction, operation, or maintenance may contribute to increases in symptom prevalences. There can be also microbial contamination in the air handling units (Straus 2011).

### 2.2.2 BUILDING-RELATED ILLNESS

Building-related illness applies to a well-defined medical condition for which a specific cause can be found (Horvath 1997). Building-related illnesses are much less common than BRS. Mechanisms of this illness fall into the three main categories of allergic and immunological disease, infections, and exposure to chemicals and other substances (Horvath 1997). They include infectious diseases spread from building services, such as Legionnaires’ disease, or from person to person within a building, as well as toxic reactions to chemicals used within a building or derived from fungi growing within a building (Burge 2004).
Legionella is a gram-negative bacterium found in freshwater environments, especially in warm potable water systems, and in the moistening systems and cooling towers of ventilation systems. It can cause two different forms of disease in humans. Legionnaires’ disease has an incubation period of 2–10 days, and is a multi-system illness that involves the lungs, causing pneumonia, and possibly neurological symptoms, and diarrhoea; the mortality rate may be up to 50%. Pontiac fever, with an incubation period of only 1–2 days, is an acute, self-limited, influenza-like disease that does not cause pneumonia. Legionella pneumophila is responsible for more than 90% of Legionella infections (Fields et al. 2002).

The prevalence of plastic additives in indoor air has been found to be related to newly diagnosed asthma. Villberg et al. (2008) have found increased concentrations of 2,2,4-trimethyl-1,3-pentanediol diisobutyrate, a compound widely used as a plastic additive in indoor materials, to be associated with new cases of asthma (odds ratio [OR] 2.84, 95% confidence interval [CI] 1.04–7.81). The role of this compound in asthma development is not known for sure.

Ventilation reduces the prevalence of airborne infectious diseases and thus the number of sick leave days amongst employees (Seppanen and Fisk 2004). The RR for respiratory illnesses is 1.5–2 for low, compared with high, ventilation rates (Seppänen et al. 1999).

When not adequately functioning and maintained, ventilation can spread airborne pathogens or impurities originating from ventilation systems. Tuberculosis is the most well-known disease found to be related to inadequately functioning ventilation systems (Menzies et al. 2000).

### 2.2.3 DAMPNESS-RELATED ILLNESS

Dampness-related moulds may adversely affect human health through the following three processes: allergy, infection, and toxicity. Type I allergic reactions are mediated by immunoglobulin E (IgE), but they explain only a fraction all immunological reactions to moulds. The main diseases of IgE-mediated responses are allergic rhinitis, conjunctivitis, and asthma. It is estimated that about 10% of the population has allergic antibodies to fungal antigens. Half of the persons with antibodies show clinical symptoms related to these antibodies; thus about 5% of the population is predicted to have allergic symptoms due to exposure to moulds (Hardin et al. 2003).

Respiratory diseases and symptoms that may be produced by exposure to indoor fungi in damp buildings include asthma development, exacerbation of asthma, hypersensitivity pneumonitis, cough, wheeze, dyspnoea (shortness of breath), nasal and throat symptoms, and respiratory infections (Park and Cox-Ganser 2011). In addition to these illnesses, the occurrence of rhinosinusitis and sarcoidosis in oc-
cupants of water-damaged building are also drawing increasing scientific attention (Laney et al. 2009).

### 2.2.3.1 Asthma and asthma-related symptoms

There is sufficient epidemiological evidence indicating an association between indoor dampness and the exacerbation of asthma, the development of asthma, and current asthma according to many expert groups (Bornehag et al. 2001, 2004; Institute of Medicine 2004; Heseltine and Rosen 2009; Park and Cox-Ganser 2011). The epidemiological evidence also shows that indoor dampness and moulds are associated with asthma-related symptoms such as cough, wheeze, and dyspnoea (Bornehag et al. 2001, 2004; Institute of Medicine 2004; Heseltine and Rosen 2009). Dampness may be associated with dust mites and bacterial growth, but the connection between dampness and mould and asthma exists even after these exposures have been taken into account (Bornehag et al. 2001). In 2007, Fisk et al. (2007) reported the results of a quantitative meta-analysis on residential, dampness-related risks for adverse health effects. They concluded that “building dampness and mould are associated with approximately 30–50% increases in a variety of respiratory and asthma-related health outcomes”. For asthma, they found a summary OR of 1.3 (95% CI 0.9–2.1) for development and dampness factors. For current asthma and dampness factors, they reported an OR of 1.6 (95% CI 1.3–1.9). In a companion paper, Mudarri and Fisk (2007) estimated that, if the reported associations were causal, 21% of the cases of asthma in the United States (US) could be attributable to dampness and mould in housing, leading to a total annual cost of USD 3.5 billion. Associations between dampness, mould, and asthma-related illness have been observed in many studies conducted in various geographical regions (Andriessen et al. 1998; Na斯塔d et al. 1998; Peat et al. 1998; Norbäck et al. 1999; Bornehag et al. 2001; Kilpeläinen et al. 2001; Jaakkola et al. 2005). Positive associations have been found for infants (Nafstad et al. 1998), children (Andriessen et al. 1998), and adults (Nafstad et al. 1998; Engvall et al. 2001; Kilpeläinen et al. 2001; Pekkanen et al. 2007), and some evidence has been found for dose–response relationships (Nafstad et al. 1998; Engvall et al. 2001; Kilpeläinen et al. 2001; Pekkanen et al. 2007). A retrospective case–control study of asthma incidence showed that dampness or mould in the main living area of a house was related in a dose–response fashion to asthma development in infants and children (Pekkanen et al. 2007). The multivariate-adjusted ORs for asthma incidence in association with three levels of moisture damage assessed by civil engineers were 1.0, 2.8 (95% CI 1.4–5.4), and 4.0 (95% CI 1.6–10.2).

Mendell et al. (2011) found that there are consistent positive associations between evident dampness or mould and multiple allergic and respiratory effects in
their recent review of epidemiological evidence for respiratory and allergic health effects of dampness, mould, and dampness-related agents. Measured microbiological agents in dust been found to have limited suggestive associations, including both positive and negative associations for some agents. Thus they concluded that the prevention and remediation of indoor dampness and mould are likely to reduce health risks, but current evidence does not support measuring specific indoor microbiological agents as a means of guiding health-protective actions. They found some evidence for measured microbiological factors, such as higher concentrations of ergosterol in dust, being associated with increases in current asthma and higher concentrations of endotoxin in dust being associated with increases in wheeze. Medium concentrations of (1→3)-β-D-glucans were associated with increases in wheeze, while the highest concentrations were associated with decreases in wheeze (Mendell et al. 2011). These associations were considered to be only suggestive.

Norbäck et al. (2000) have shown asthma symptoms to be related to increased humidity in concrete-floored constructions and to emissions of 2-ethyl-1-hexanol, an indicator of dampness-related alkaline degradation of the plasticiser DEPH. Wieslander et al. (1999) found the same emissions to be related to nasal symptoms. Bornehag et al. (2004a) showed that DEHP in floor dust is significantly associated with medically diagnosed asthma amongst Swedish children.

### 2.2.3.2 Other dampness-related illness

The Institute of Medicine (2004) found sufficient evidence to exist for an association between dampness-related agents and hypersensitivity pneumonitis in susceptible persons. This disease is an immunologically mediated lung disease in which the repeated inhalation of certain antigens (bacteria, fungi, animal proteins, and chemicals) provokes a hypersensitivity reaction with granulomatous inflammation and fibrosis in the gas-exchanging portion of the lung (Mazur and Kim 2006).

Allergic bronchopulmonary aspergillosis is an immunologically mediated lung disease that occurs primarily in patients with asthma and cystic fibrosis (Greenberger 2002). Aspergillus fumigatus represents its commonest etiological agent. It has been estimated that 1%–2% of all asthmatics will also have this disease before long (Greenberger 2002; Hodgson 2010). Typically, patients with this disease have had difficult-to-manage asthma for years, as well as allergic diathesis. Allergic fungal sinusitis is a combination of nasal polyposis, crust formation, and sinus cultures that yield a fungal agent (Mazur and Kim 2006). It is estimated that approximately 5%–10% of all patients with chronic rhinosinusitis have allergic fungal sinusitis. Indoor mould has not been suggested as a particular risk factor in the aetiology of either (Hardin et al. 2003).
Humidifier fever is a flu-like illness that occurs a few hours after exposure to aerosols generated from forced air-conditioning and humidifier systems (Mazur and Kim 2006). The onset occurs after intense exposure in a single day, and it usually subsides within 24 hours without residual effects. Tachyphylaxis occurs after frequent repeated exposures. Organic dust toxic syndrome (ODTS) is also a self-limited flu-like syndrome that occurs after exposure to organic dusts from mouldy or damp silage, hay, other agricultural dusts, or contaminated wood chips from mulching. ODTS is also sometimes found in damp buildings (Wolff 2011). Humidifier fever and ODTS are assumed to result from endotoxin-like reactions to high doses of microbial by-products (Mazur and Kim 2006).

2.2.3.3 Possible pathogenesis of damp building-related illness

The possible mechanisms or pathogenesis of symptoms and diseases caused by inhaled microbial particles have been under investigation for many years, but still nothing can be said for sure. In vitro and in vivo studies have found diverse inflammatory, cytotoxic, and immune-suppressive responses after exposure to the spores, metabolites, and components of specific microbial species found in damp buildings. Microbes present in the indoor air of moisture- and mould-damaged buildings have been shown to be able to trigger inflammatory responses in human (Roponen et al. 2001, 2003b) and mouse cell lines and in mouse lungs (Huttunen et al. 2001; Jussila et al. 2001, 2002a, 2002b, 2003).

The recent advances in innate immunity and its relationship with specific immunity suggest many mechanisms to explain the phenomena seen in illnesses caused by inhaled microbial particles (Wolff 2011). The roles of inflammasomes, a family of cytosolic multi-protein complexes, the Nod-like receptor protein family, and pro-inflammatory cytokines, most importantly interleukin-1β (IL-1β) and IL-18, seem to be central (Bauernfeind et al. 2010). Activation of IL-1β production requires two distinct signals for activation (Wolff 2011). Microbial components have the ability to activate an inflammasome and IL-1β (Franchi et al. 2010). It has also been shown that MTMs of S. chartarum can activate an inflammasome and that β-glucans can provide both signals for the activation of IL-1β production (Kankkunen et al. 2009, 2010).

Neither the immunological mechanisms of exacerbation nor the development of dampness-related asthma is currently fully understood. Repeated immune activation and prolonged inflammation from microbiological exposures may contribute to inflammation-related diseases such as asthma.

For atopic asthma patients with mould exposure, the T helper cell 2 type of inflammatory response may be an important mechanism. Fungal spores have long been known to cause allergy (Levetin and Van de Water 2001). However, most
asthma cases amongst mould-exposed people may be non-allergenic; of possible occupational asthma patients, only 20% have shown mould sensitisation (Karvala et al. 2010). In a mixed exposure, such as in a damp building, the effects and mechanisms are difficult to understand, as some factors may act as allergens and others as adjuvants (Park and Cox-Ganser 2011). One hypothesis is that exposure to environmental fungi may modulate the effect of chitinases in individuals with asthma (Wu et al. 2010). Chitinases are enzymes that cleave chitin, which is present in fungal cells; two types of human chitinases seem to play an important role in asthma.

There are two theories as to how mould components may increase susceptibility to respiratory infections: either by suppressing the immune system or by causing membrane inflammation, which in turn can lead to increased permeability to infective organisms (Park and Cox-Ganser 2011).

2.2.3 RISK ASSESSMENT FOR INDOOR AIR PROBLEMS

The indoor environment is a complex issue with respect to health risk assessment (Scientific Committee on Health and Environmental Risks [SCHER] 2007). There are many types of pollutants that may give rise to combined effects. Chemicals present in indoor air can react with one another, either in the gas phase or on surfaces, altering significantly the types of chemicals and their concentrations. Such chemical reactions are often the major source of free radicals and other short-lived reactive species in indoor environments (Weschler et al. 2006). Secondary pollutants are often of greater concern than primary pollutants. Indoor chemical activity varies with the time of day and season, as well as with the geographic location and the nature of the building itself. The skin, hair, and clothing of occupants affect the indoor chemistry. Surface chemistry often has a larger overall impact on indoor environments than gas-phase chemistry (Weschler 2011). For most pollutants, the data available are yet limited in regard to their risk assessment. Thus far, the combined effects of indoor air pollutants have rarely been assessed.

However, SCHER believes that the health risk assessment of pollutants in indoor air should be done according to the principles used in the European Union for the risk assessment of chemicals, for which an evidence-based approach is required. SCHER recommends the development of health-based guideline values for key pollutants to aid risk management. It also recommends that practical experiences should be collected and systematised to establish approaches using evidence-based risk assessment (SCHER 2007).

Moisture and mould damage is an exception and a special case in the risk assessment of indoor air problems because the exact causes of the health effects are not known. The risk of adverse health effects seems to grow as the extent and number
of damaged areas grow (Haverinen et al. 2001; Park et al. 2004). The importance of the damage is assessed on the basis of the extent and number of areas, the pressure ratios of the air, and the already observed health effects.

A working group established by the Ministry of Social affairs and Health in Finland compiled national guidelines for the risk assessment of mould problems on this basis (Working Group on Moisture Damage 2009). According to the Working Group, there are no foundations for setting health-based occupational limits or threshold limit values at the moment. Occupation safety (OS) authorities are the main supervisory administrators in matters related to moisture and mould damage in workplaces, but health protection authorities or building supervision authorities may also carry out enforcement. Table 2 presents the assessment of exposure in damp buildings according to the Working Group.

### Table 2. Exposure assessment in damp buildings according to the Ministry of Social Affairs and Health in Finland (Working Group on Moisture Damage 2009).

<table>
<thead>
<tr>
<th>Assessment rating</th>
<th>Assessment criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmful exposure improbable</td>
<td>No dampness damage, no risk structures, spaces not strongly under pressured, no leakage of airflow rates (e.g., through inlets or shafts to unusual indoor microbe sources)</td>
</tr>
<tr>
<td>Harmful exposure possible</td>
<td>Signs of dampness (no visible microbial growth), repaired water damage, spaces occasionally under pressured and/or possible leakage of airflow rates to indoor unusual microbe sources</td>
</tr>
<tr>
<td>Harmful exposure probable</td>
<td>Visible damage of interior surfaces, microbial growth in materials or surrounding structures, exceptional microbial exposure agents discovered (air or dust sample), spaces strongly under pressured, or air connection from damaged spaces to work space</td>
</tr>
</tbody>
</table>

### 2.3 INDOOR AIR IN HOSPITAL ENVIRONMENTS

IAQ is more critical in hospitals than in most other indoor environments because of the many infectious microbial agents present and the number of patients with increased susceptibility. Hospitals are complex environments that consist of many kinds of spaces with different hygiene demands. For patients, personnel and visitors, it is very important that the performance of the ventilation system provides comfort and controls hazardous emissions. Health-care personnel remain subject to several occupational exposure risks, however (Kalliokoski et al. 2003). SBS episodes amongst hospital workers have been reported by Kelland (1992), Nordström et al. (1995, 1999). According to the WHO Report *Working Together for Health,*
health-care systems worldwide are plagued by difficulties with the recruitment and retention of staff, work absenteeism, occupational musculoskeletal injuries, violence, and stress, as well as with exposure to biological, chemical, and physical hazards (WHO 2006).

Water damage is common in Finnish hospital buildings, partially due to the architecture (Reijula 2005). In addition, much water is handled in hospitals, especially in patient wards. Many of the 20 Finnish central hospitals were built in the 1950s and 1960s, and the buildings are in need of renovation. This need, together with operational changes, makes hospitals targets for continuous alteration and repair work. Renovation work significantly contaminates the environment with microbes (Overberger et al. 1995; Abdel Hameed et al. 2004). Although exposure to fungi does not usually cause infections in healthy people, fungal infections constitute a special danger for immune-compromised patients because efficient medication to handle this problem has not yet been developed. *A. fumigatus* is currently a major airborne fungal pathogen, causing different kinds of disease (e.g., invasive or non-invasive pulmonary infections and allergic bronchopulmonary aspergillosis) depending on the immune status of the host (McCormick et al. 2010). Virtually all outbreaks of nosocomial aspergillosis have been attributed to airborne sources, usually construction work (Vonberg and Gastmeier 2006).

In the international literature, only a few cases of water damage in hospitals have been reported. Brownson (1999, 2000) highlighted poor hospital IAQ with in a case study. A few cases have been reported in Sweden (Nordstrom et al. 1995, 1999; Wieslander et al. 1999). In Finland, an outbreak of respiratory diseases amongst employees in a military hospital building with severe, repeated, and enduring water and mould damage has been described (Seuri et al. 2000). Asthma and respiratory symptoms in hospital workers have been reported relation to dampness in the United States (Cox-Ganser et al. 2009). Smedbold et al. (2002) discovered decreased nasal patency in nursing personnel in hospitals; this problem was evidently due to the contamination of the ventilation ducts with *A. fumigatus*.

### 2.3.1 Indoor Air Impurities Originating from Hospital Activities

#### 2.3.1.1 Chemical impurities

Exposure to chemical impurities due to hospital activities include anaesthetic gases, disinfectants and sterilising agents, cytotoxic agents and anti-neoplastic agents, latex, isocyanates, and methyl methacrylate. Table 3 presents chemical indoor air impurities originating from hospital activities and their possible health effects.
<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Target groups</th>
<th>Health effect(s) or health-related characteristic(s)</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaesthetic gases (sevoflurane, nitrous oxide)</td>
<td>Pregnant workers in operating theatres, recovery rooms, delivery rooms</td>
<td>Increased risk of miscarriages, foetal malformations, liver and kidneys diseases, mutations, cancer</td>
<td>Amanatidis 1997</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>Central sterile processing workers</td>
<td>Interacting mutagen, suspected carcinogen, allergen (asthma, eczemas)</td>
<td>Sobaszek et al. 1999</td>
</tr>
<tr>
<td>Glutaraldehyde</td>
<td>Staff cleaning endoscopes and endoscopic equipment</td>
<td>Irritant to skin, respiratory tract, eyes; skin sensitiser</td>
<td>Di Stefano et al. 1998; Shaffer and Belsito 2000; Waters et al. 2003</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Staff in pathology laboratories</td>
<td>Mutagen, teratogen, human carcinogen (nasopharyngeal cancer), contact dermatitis, allergic reactions</td>
<td>IARC 2006</td>
</tr>
<tr>
<td>Chloramine-T</td>
<td>Cleaners, nurses</td>
<td>Sensitiser of respiratory tract and skin</td>
<td>Wrangsjo and Meding 1997; Palczynski et al. 2003</td>
</tr>
<tr>
<td>Cytotoxic and anti-neoplastic agents</td>
<td>Nurses, pharmacists</td>
<td>Mutagen, teratogen, carcinogen</td>
<td>Jakab et al. 2001; Tompa et al. 2006</td>
</tr>
<tr>
<td>Latex</td>
<td>Staff using rubber gloves</td>
<td>Sensitiser of skin and respiratory tract, asthma</td>
<td>Toraason et al. 2000; Nettis et al. 2002; Amr and Bollinger 2004</td>
</tr>
<tr>
<td>Methyl diphenyl isocyanate</td>
<td>Staff working with synthetic plasters cast, e.g. staff in emergency departments</td>
<td>Asthma, asthmatic reaction</td>
<td>Tarlo and Liss 2002; Donnelly et al. 2004; Suojalehto et al. 2011</td>
</tr>
<tr>
<td>Methyl methacrylate</td>
<td>Staff in orthopaedic surgery</td>
<td>Mild skin irritant, potential skin sensitiser in susceptible persons, toxic to cardiovascular system, hypersensitivity, asthmatic reactions, local neurological symptoms, irritation, local dermatological reactions</td>
<td>Cautilli and Hozack 1994; Leggat et al. 2009</td>
</tr>
</tbody>
</table>
2.3.1.2 Biological impurities

A hospital-acquired infection (HAI) or a nosocomial infection is an infection the patient did not have when entering the hospital. These infections cause unnecessary costs and suffering (Wenzell 1995). The reported rates for HAIs are probably underestimated because many nosocomial infections appear at home, after the discharge of patients with a short period of hospitalisation. Most HAIs are associated with person-to-person contact. Airborne transmission is estimated to account for about 10% of all endemic HAIs (Eickhoff 1994).

Tuberculosis is known to be transmitted by air. Although the prevalence of tuberculosis continues to decline in most developed countries, the risk of tuberculosis remains for patients and health-care staff. Outbreaks of tuberculosis in association with health care are usually related to delays in diagnosis and treatment, or to the care of patients in sub-optimal facilities (Humphreys 2007). Tuberculosis bacteria can convert to a drug-resistant form when the affected person is treated insufficiently or the treatment falls by the wayside, and, in addition, multi-drug-resistant tuberculosis is being transmitted throughout the world at an extremely fast pace (Niu 2010).

Hospital-acquired Legionnaires’ disease has been reported by many hospitals (Sabria and Yu 2002). Potable water has been the environmental cause of almost all of the reported cases, and microaspiration is the major mode of transmission. Since the clinical manifestations are non-specific, and specialised laboratory testing is required, hospital-acquired legionellosis is easily underdiagnosed. Table 4 presents the airborne contribution to HAIs.
Table 4. Mainly airborne contribution to hospital-acquired infections (HAIs).

<table>
<thead>
<tr>
<th>Microbe</th>
<th>Where/how</th>
<th>What</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gram-positive bacterial infections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mycobacterium tuberculosis,</td>
<td>Classic disease transmitted by the airborne route; transported on aerosol</td>
<td>Tuberculosis</td>
<td>Jensen et al. 2005</td>
</tr>
<tr>
<td>Multi-drug-resistant tuberculosis</td>
<td>particles over long distances by convection currents; patients with pulmonary tuberculosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gram-negative bacterial infections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acinetobacter spp</td>
<td>Multiple-bed hospital</td>
<td>Respiratory, blood, wound infections</td>
<td>Beggs et al. 2008</td>
</tr>
<tr>
<td><strong>Fungal infections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspergillus fumigatus</td>
<td>Spores often enter hospital buildings through open windows or through</td>
<td>Infections in immuno-suppressed patients</td>
<td>Vonberg and Gastmeier 2006</td>
</tr>
<tr>
<td></td>
<td>mechanical ventilation ducts; construction work tends to liberate large</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>numbers of fungal spores into the air; Aspergillus spores are almost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>always present in unfiltered air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Viral infections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory viruses (e.g., influenza virus,</td>
<td>Mainly spread by droplet nuclei; influenza virus can remain viable in dust</td>
<td>Respiratory infections</td>
<td>Couch 1996</td>
</tr>
<tr>
<td>respiratory syncytial virus)</td>
<td>as long as 14 days.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.3.1.3 Physical factors

The International Labour Organisation lists physical hazards to health-care workers as follows: ionising radiation (diagnostic radiology, radiotherapy, nuclear medicine), optical radiations (ultraviolet, extremely bright visible light, infrared) including laser, noise, thermal climate (heat and cold), vibration, electric and magnetic fields, as well as ergonomic factors (Niu 2010).

Ionising radiation is used in medical care for both diagnostic and therapeutic purposes. It poses a threat to health-care workers mainly in radiological and radiotherapy departments, but also in laboratories, dental facilities, and electromicros-
copy units, as well as in nursing wards and operating theatres. Work involving the preparation and assay of radioactive pharmaceuticals and intervention radiology tends to be associated with the highest occupational exposure in the medical use of radiation. It is important that radiation protection measures be strictly followed and the staff be adequately shielded from radiation sources (Niu 2010).

Noise and vibration are not major problems in health care, except in dental and orthopaedic work. High-speed dental turbines and surgical drills can cause noise at levels of 80–90 dB (A) (Niu 2010). Extreme ambient temperatures are usually not major concerns for health-care workers in developed countries.

The musculoskeletal injuries of health-care workers are often associated with patient handling (Niu 2010). The lifting of patients is a major problem for nurses. Back injury is the commonest and most costly type of injury in health care. Ergonomically designed workstations have made the work postures used in many medical practices and procedures far more comfortable, and they have helped diminish injuries due to awkward work postures.

Experiences with violence at work are common amongst workers who are in contact with people under stress. Health-care workers are especially at risk of workplace violence. Experiencing violence can have both emotional and somatic consequences (Jackson et al. 2002, Miranda et al. 2010). A great deal of shift work is done in hospitals, and such work also challenges the health of health-care workers (Berger and Hobbs 2006). Hospital work is thus stressful in many ways. Lahtinen et al. (2004) has shown that psychosocial factors may affect workers’ perception of indoor air.

### 2.3.1.4 Role of ventilation

A multidisciplinary review of the role of ventilation in the airborne transmission of infectious agents in the built environment has shown that there are insufficient data for specifying and quantifying the minimum ventilation requirements for hospitals, schools, offices, homes, and isolation rooms in order to effectively prevent the spread of infectious diseases via the airborne route (Li et al. 2007). Sundell et al. (2007, 2011) found a great need for studies of ventilation and health in public buildings such as hospitals.

The hospital facility environment is essentially involved in disease transmission in the following two situations: 1) in cases in which patients are immuno-deficient and require protection from infections and 2) in cases of patients having contagious airborne pathogens that can cause diseases and illnesses amongst other patients or health-care personnel (Kalliokoski et al. 2003). In particular, the ventilation system is fundamental with respect to controlling the concentration of airborne contaminants within a hospital building. Thus the incidence of infections associated with
health-care facilities can be minimised if the ventilation standards suggested in the guidelines for specialised care environments, such as airborne infection isolation rooms (as in situation 2 mentioned above) and protective environment rooms (as in situation 1) are adhered to. There are also “alternative pressure rooms”, areas furnished with a ventilation system capable of switching pressure from positive to negative according to patients’ needs. However, according to the analysis of Cacciari et al. (2004), the use of alternative pressure rooms does not show very promising results.

2.3.2 PREVALENCE OF MOISTURE PROBLEMS IN FINNISH HOSPITALS

In the national survey of Finnish hospital buildings in 2005, 15% of the investigated building area was in need of immediate repair because of water damage; of the hospital ward area, even 24% was in the need of immediate repair (Reijula 2005). Table 5 presents the results of the evaluation of the hospital buildings.

Table 5. Repair needs according to type of space (Reijula 2005).

<table>
<thead>
<tr>
<th>Type of space</th>
<th>Area</th>
<th>In no need of repair, class 1</th>
<th>In need of further investigation, class 2</th>
<th>In immediate need of repair, class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m²</td>
<td>m²</td>
<td>%</td>
<td>m²</td>
</tr>
<tr>
<td>In-patient ward</td>
<td>151722</td>
<td>80498</td>
<td>53</td>
<td>34666</td>
</tr>
<tr>
<td>Laboratory</td>
<td>39877</td>
<td>31823</td>
<td>80</td>
<td>5775</td>
</tr>
<tr>
<td>Out-patient and X-ray departments</td>
<td>137520</td>
<td>90699</td>
<td>66</td>
<td>38061</td>
</tr>
<tr>
<td>Surgical suites</td>
<td>38815</td>
<td>31198</td>
<td>80</td>
<td>4700</td>
</tr>
<tr>
<td>Office</td>
<td>160844</td>
<td>138999</td>
<td>86</td>
<td>9634</td>
</tr>
<tr>
<td>Altogether</td>
<td>416841</td>
<td>261280</td>
<td>63</td>
<td>92836</td>
</tr>
</tbody>
</table>

2.3.3 OCCUPATIONAL DISEASES RELATED TO INDOOR AIR IN FINNISH HOSPITALS

All physicians in Finland are obligated to report work-related symptoms and diseases. FIOH keeps the Register of Work-related Diseases in Finland. The register contains all reported work-related diseases – not all of them have been accepted by insurance companies. Table 6 presents work-related diseases caused by mould amongst hospital workers during 2005–2009. Only the hospital branch, not, for example, health-care centres, are included in the numbers.
Table 6. Work-related diseases amongst workers in the hospital branch in Finland in 2005–2009 according to FIOH.

<table>
<thead>
<tr>
<th>Year</th>
<th>Asthma cases (n)</th>
<th>Rhinitis cases (n)</th>
<th>Hyper-sensitivity pneumonitis cases (n)</th>
<th>Eczema cases (n)</th>
<th>Other diseases (n)</th>
<th>Altogether</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>23</td>
<td>6</td>
<td></td>
<td>2</td>
<td>31</td>
<td>137</td>
</tr>
<tr>
<td>2008</td>
<td>18</td>
<td>10</td>
<td></td>
<td>1</td>
<td>7</td>
<td>67</td>
</tr>
<tr>
<td>2007</td>
<td>20</td>
<td>8</td>
<td></td>
<td>1</td>
<td>1</td>
<td>89</td>
</tr>
<tr>
<td>2006</td>
<td>20</td>
<td>11</td>
<td></td>
<td>3</td>
<td>35</td>
<td>89</td>
</tr>
<tr>
<td>2005</td>
<td>13</td>
<td>1</td>
<td></td>
<td>3</td>
<td>8</td>
<td>27</td>
</tr>
</tbody>
</table>

According to the register, the commonest single cause of work-related disease amongst hospital employees was indoor mould during 2005–2009.

Every year, 2–5 cases of work-related tuberculosis have also been reported. In 2009, 36 cases of the risk of being infected with tuberculosis were reported.

2.4. EXAMINATION OF EXPOSED WORKERS

2.4.1 CLINICAL PRACTICE

2.4.1.1 Group level/questionnaire surveys

Questionnaire surveys are commonly used to evaluate the prevalence and nature of indoor air symptoms and the quality of perceived indoor air. Some of them have been frequently employed, for example, the Royal Society of Health (RSH) questionnaire, issued by the Building Research Establishment in the United Kingdom and focused on office environments (Burge 1987), and the Miljö Medicin (MM) questionnaires used particularly in the Nordic countries (Andersson 1998). The Indoor Air Questionnaire of FIOH is based on the MM questionnaires, which are described in the Methods section.

The RSH questionnaire has been validated both in terms of reliable prevalence estimates and the detection of clinically accurate symptoms. It contains queries about symptoms and potentially associated variables (i.e., personal, psychosocial,
and occupational factors, as well as location). The eight SBS symptoms investigated are 1) dry eyes, 2) itchy or watery eyes, 3) blocked nose, 4) runny nose, 5) dry throat, 6) headache, 7) lethargy, and 8) dry, itchy or irritated skin. Symptoms are only included if they have been confirmed as “better on days away from the building.” Each symptom has to have occurred on at least in two separate occasions during the preceding 12 months. The results of the RSH questionnaire are calculated as the mean number of symptoms per respondent (from a list of eight), which is termed the person symptom index (PSI₈). When averaged across the building, it is called the building symptom index (BSI₈). In a shorter version, only five symptoms are used (PSI₅ and BSI₅), the skin symptoms, runny nose, and irritated eyes being excluded. The BSI₅ and PSI₅ have a more predictable distribution, and they have reference material from the BSI₅ for 42 British buildings (Burge 1987).

In Finland, the so-called Tuohilampi questionnaire is also used. It was created for epidemiological studies at the same time as the MM questionnaires were introduced into Finland (Susitaival and Husman 1996), but it has not yet established its place in OH services.

### 2.4.1.2 Individual level

Evaluating the relationships between indoor air and indoor-air-related symptoms is difficult due to the non-specificity of the symptoms and the complexity of the exposures. At the individual level, the difficulties are even greater than at the group level, mainly because of the differences in sensitivity and vulnerability amongst people and a lack of knowledge about which medical and psychosocial mechanisms are involved (Andersson 2008).

Andersson has stressed the need for a careful registration of a person’s medical and occupational history and a detailed description of how that person perceives the specific environment when he or she seeks OH services because of presumed indoor-air-related symptoms (Andersson 2008). In addition, the perception of symptoms must be discussed in detail regarding when they occur, how they change, or whether they change outside the workplace and whether other co-workers have similar symptoms in the same environment and if any actions have already been taken. A general clinical investigation and appropriate basic tests should then be performed when considered necessary. Some basic allergy tests can be carried out to exclude allergic diseases. When a building-related illness such as Legionnaires’ disease is suspected, adequate imaging and laboratory tests should be done to exclude or verify the diagnosis.

In Finland, there are national guidelines on how to examine persons exposed to mould and moisture damage, the so-called Majvik guidelines (Uitti et al. 2007). The guidelines were first published in 1998 and were then re-evaluated in 2007. There
are guidelines for both primary health care and special health care. In Finland, the occurrence of asthma, the exacerbation of asthma, allergic rhinitis, conjunctivitis, alveolitis or ODTS in relation to detected microbial exposure at work can be economically compensated by insurance companies as occupational diseases if they fulfil the required conditions (Viinanen et al. 2010).

2.4.2 SCIENTIFIC RESEARCH

At the group level, questionnaire surveys (e.g., RSH, MM40) and tailored versions are used. At the individual level, an arsenal of objective methods has been developed to assess the environmental impact on mucous membranes in the nose (rhinomometry, acoustic rhinometry, rhinostereometry, or proteins in nasal lavage fluid) and eyes (tear-film break-up time, number of inflammatory cells, etc.) (Norbäck et al. 2002). However, none of these methods is specific enough to be of crucial value in individual cases. Thus there is a need for standardised investigations and for longitudinal epidemiological studies to determine whether the observed effects should be interpreted as a variation within normal physiology or as early signs of impaired ocular and respiratory health. In regard to mould immunoglobulin G (IgG) antibodies, interpreting the results has proved to be difficult (Jaakkola et al. 2002; Taskinen et al. 2002; Hyvärinen et al. 2003).

2.4.3 INFLAMMATORY MEDIATORS IN NASAL LAVAGE FLUID

Cytokine is a general term for more than 100 small molecules of soluble proteins, which operate as messenger substances of a complex regulatory system controlling the functions in all the cells. The most fundamental cytokine groups for the immune system are interleukins (ILs), interferon, tumour necrosis factor alpha (TNF-α), and cell-type-specific growth factors. Cytokine production increases in infections and, during the development of an immune response, leads to an intensification of the body’s defence reaction. Mainly responsible for these functions are the so-called pro-inflammatory cytokines (e.g., IL-1, IL-6, TNF-α). Cytokines that suppress inflammatory reactions are called anti-inflammatory cytokines. (Silvennoinen and Hurme 2003)

Bronchoalveolar lavage and bronchial biopsies have been used to study the effect of exposure on the lower airways (Mussalo-Rahamaa et al. 2010). However, they are too invasive, as well as too time-consuming, to be used in population studies. The nose is the first part of the respiratory tract that comes into contact with airborne pollutants. Thus the inflammatory reactions occurring in nasal mucosa reflect the inflammatory potential of inhalable agents. Nasal lavage (NAL) with an isotonic
sodium chloride solution is a sampling method that has been applied to measure concentrations of inflammatory cells and pro-inflammatory cytokines in NAL fluid. Hirvonen et al. (1999) found an association between inflammatory markers in NAL fluid, a high prevalence of respiratory symptoms amongst the occupants, and chronic exposure to moulds in the indoor environment. Roponen et al. (2003a) discovered that there was a within-subject seasonal variation in the concentrations of nitrite, TNF-α, IL-1β, IL-4, and IL-6, the variation being at its lowest in winter. The differences between persons and genders were statistically significant. The authors concluded that the NAL method is the most suitable when a comparison can be made using test persons as their own controls. Roponen et al. (2002) also showed that microbial exposure as such does not invariably result in inflammatory changes detectable with the NAL method. They suggested that the type of microbial flora or microbial products in the occupational environment determines the pro-inflammatory potency of microbial exposure. Roponen and her co-workers (2001) investigated inflammatory mediators in NAL samples, induced sputum, and the serum of employees with rheumatic and respiratory disorders and suggested that mediators in NAL samples reflect occupational exposure to moulds, whereas possible indicators of existing disorders are detectable in serum. Purokivi et al. (2002) compared inflammatory elements in NAL samples and induced sputum after occupational exposure to microbes found in mouldy buildings and concluded that NAL may be a more sensitive indicator of direct exposure to different irritants than induced sputum. Stark et al. (2006) showed a link between markers of inflammation in NAL samples and experimental *A. fumigatus* challenge.

### 2.5 PROCESSES FOR RESOLVING INDOOR AIR PROBLEMS

According to the OS law, all hospitals in Finland are required to establish a work safety committee. The aim of this committee is to reduce or eliminate the dangers found in work tasks and the work environment. Moisture and mould problems are an issue of OS.

Because indoor air problems are often complicated, a multi-professional team is needed to resolve them. Lahtinen et al. (2008) have developed a model for resolving indoor air problems (Figure 1). The important work group in the resolving process is an indoor air work group, which consists of an OS officer, an OS delegate, an OH service professional, a property maintenance representative, a management representative(s), a target workplace supervisor, a target workplace employee representative, and, if needed, also an external specialist.
2.6. ECONOMIC AND PRODUCTIVITY IMPACT OF INDOOR AIR PROBLEMS

In 2007, Mudarri and Fisk assessed the economic impact of dampness and mould exposures using current asthma as the health end point. They estimated the proportion of current asthma cases attributable to dampness and mould in homes in the United States to be 21% (12%–29%). The annual cost of asthma that was attributable to dampness and mould exposure at home was estimated to be about USD 3.5 billion. The authors also examined the literature covering dampness and mould in schools, offices, and institutional buildings and found that risks from exposure in these buildings resemble the risks from exposure in homes. Sahakian et al. (2009) estimated an annual cost of USD 1.4 billion for excess respiratory-related sick leave amongst office workers exposed to workplace dampness in the United States.

A review by Seppänen et al. (2006) found a quantitative relationship between work performance and ventilation within a wide range of ventilation rates. The reviewed studies assessed the performance of various tasks in laboratory experiments and measured performance at work in real buildings. The studies typically indicated an improvement of 1%–3% in the average performance per 10 l/s × person increase in the outdoor air ventilation rate. The results showed a continuous increase in performance per unit increase in the ventilation rate from 6.5 l/s × person to 65 l/s × person; the increase was statistically significant up to 15 l/s × person.
A review by Niemelä et al. (2006) of 23 studies suggests that a link exists between typical building-related symptoms and productivity indicators such as task or work performance or absence from work.

In 2011, Fisk et al. showed that some measures to improve the indoor environmental quality of offices in the United States, such as increasing ventilation rates when they were below 10 or 15 l/s per person, adding outdoor air economisers and controls when absent, eliminating winter indoor temperatures of >23°C, and reducing dampness and mould problems, will save energy while improving health and productivity.
3 AIMS OF THE STUDY

The aims of the present study were:

1) To assess the perceived indoor air quality (IAQ) and the extent of indoor-air-related symptoms of hospital employees. (I)

2) To evaluate the effects of the condition of the building and ventilation on the perceived IAQ and indoor-air-related symptoms and to assess the feasibility of using the Indoor Air Questionnaire in hospitals. (II, III)

3) To assess the feasibility of tools for examining symptomatic employees working in moisture- and mould-damaged buildings, especially the feasibility of nasal lavage. (IV)

4) To assess the functionality of a process for resolving indoor air problems and to evaluate the role of key players, especially the role of OH professionals, in the process. (V)
Indoor air can be defined as the air we breathe inside a building. In principle, there are two definitions for indoor air. Some professionals consider “indoor air” to be the air inside a certain area surrounded by structures, while others define indoor air as being limited only to spaces with no discharge from industrial production. In hospitals, some activities produce some discharge, such as the residues of anaesthetic gases and pharmaceutical products. However, in the present study, it was decided to include the air in hospitals under the term “indoor air”.

IAQ in occupational settings such as hospitals depends on the condition of the building, the condition and functioning of the ventilation systems, and the work processes (Figure 2).

**Figure 2.** Basic elements of indoor air quality (IAQ) in occupational settings.
4.1 PARTICIPANTS AND BUILDINGS

4.1.1 HOSPITAL DISTRICTS

The planning of the present Finnish hospital district system started as early as the 1930s, and it was implemented in the 1950s. Each hospital district produces specialised health-care services based on the need of the population living in the region. These services supplement the services of basic health care produced by local health-care centres. In addition, each hospital district takes care of research, development, and education in its area, in cooperation with the health-care centres.

The hospital districts differ considerably in size. Nowadays there are 20 hospital districts in Finland. At the end of 2009, the biggest one – the hospital district of Helsinki and Uusimaa – had a population of over 1.5 million inhabitants, while the smallest – the hospital district of Eastern Savo – served approximately 46 000 inhabitants. In the beginning of 2010, the number of the member municipalities varied between the districts, from 6 member municipalities (Länsi-Pohja) to 35 (Pohjois-Pohjanmaa). In the biggest hospital district, there were about 21 000 employees and approximately 3300 beds, while, in the smallest, there were only 550 employees and 219 beds.

Each hospital district has one or several hospitals and other operational units. Approximately one quarter of the population, in other words, 1.7 million, use the hospital services of the hospital districts during a year. Almost all of the babies born in Finland are born in these hospitals, and some 370 000 operative procedures are carried out each year. The round-the-clock duty of specialist medical care has been centralised to the central hospitals, and, in many areas, the night-time and weekend duty of the health centres has been shifted to the hospitals.

According to the Association of Finnish Local and Regional Authorities, the maintenance costs of the buildings in the health-care field were EUR 320 million (EUR 4/m² per month) in 2003. The costs invested in the construction of new buildings and the enlargement of old ones amounted to EUR 206 million.

4.1.2 STUDY POPULATION IN THE QUESTIONNAIRE SURVEYS (STUDIES I–III)

Ten hospitals situated in different parts of the country were chosen for the questionnaire surveys. The chosen hospitals represented the different eras of construction. The questionnaire forms were sent to the staff of the inpatient wards, the outpatient clinics, the laboratories, the operating theatres, the radiology departments, and the rehabilitation units. On average, the questionnaires were presented to one third of
the personnel of each hospital. The surveys were conducted in collaboration with the hospital OH services. Altogether 5598 forms were sent out, and 3811 employees returned the questionnaire. The overall response rate was 68% (varying from 57% to 90% between hospitals). Of these participants, 90.5% were women, and 10.3% were current smokers. The mean age and gender distributions of the respondents in the survey were similar to the figures for Finnish hospital workers according to the National Institute for Health and Welfare. In study III, the number of the respondents was a little lower (n=3739) than in studies I and II, because one of the buildings was left out of the ventilation survey.

4.1.3 STUDY POPULATION IN THE CASE–CONTROL STUDY (STUDY IV)

Altogether 28 employees of a water-damaged outpatient clinic participated in this part of the study. The control group consisted of 20 voluntary employees from other departments within the same hospital, with no known moisture or mould problem. Exclusion criteria included active infectious disease in the respiratory tract and current mould or moisture problems at home. The cases and controls did not differ significantly concerning gender, age, or smoking. NAL was performed on 26 members of the exposed group and on all 20 members of the control group. A follow-up was conducted with 16 members of the exposed group 6 months after a thorough renovation and with 8 members of the control group.

4.1.4 INTERVIEWED PERSONS (STUDY V)

Interviews were conducted in seven hospital districts. In four of the targeted hospitals, personnel in both OS and OH were interviewed. In three of the hospitals, it was also possible to interview either an infection control nurse or the physician responsible for hospital hygiene. Altogether 23 persons were interviewed, 5 of which were men and 18 were women. A total of 12 of the 23 represented OH care, 8 worked in OS (4 officers, 4 delegates), and 3 specialised in hospital hygiene (two infection control nurses, one infection control physician). In addition, 2 OH representatives took part by submitting written answers to the questions presented. Altogether 5 of the OH participants were physicians and 9 were nurses; all were experienced professionals.
4.2 METHODS

4.2.1 INDOOR AIR QUESTIONNAIRE (STUDIES I–III)

The questionnaire used in this part of the study was the Indoor Air Questionnaire of the Finnish Institute of Occupational Health (FIOH) (Reijula and Sundman-Digert 2004). It is based on the Örebro indoor-climate questionnaire with 40 questions (MM-40). The MM questionnaires were developed at the Department of Occupational and Environmental Medicine in Örebro, Sweden, by Kjell Andersson. His primary intention was to create a simple and short (at most 2 pages) questionnaire with valid, clear, and reliable questions (Andersson 1998). In Finland, FIOH obtained permission to translate the basic MM questionnaire into Finnish, and the Finnish version was established in 1995.

It has four parts, the first of which deals with the work environment, the second with work arrangements, the third with the allergy history of employees, and the fourth with work-related symptoms. The occurrences of environmental problems (draught, dry, stuffy air, etc.) are recalled from the past 3 months. The rationale for choosing the 3-month period is that it is long enough to avoid memory effects and short enough to permit efficient follow-up studies after remedial measures have been taken (Andersson 1998).

The part concerning allergy history deals with past or present asthma, allergic rhinitis, and atopic eczema. Symptoms attributed to indoor air at work are also reported for the past 3 months, and they are further explained by specifying whether the symptoms are weekly and whether the persons attribute the symptoms to their work environment. The present study focused on symptoms that occurred every week and were attributed to the work environment.

The validity of specific questions has been tested against the judgement of a physician and information from available external sources, and it seems to be acceptable (Andersson and Stridh 1992). The test–retest reliability has been tested in several studies, and it seems to be acceptable for both office and domestic buildings (Andersson and Stridh 1992; Sundell 1993).

The questions have the following three alternative answers: “yes, often” “yes, sometimes” and “no, never”. In practice, the first alternative is defined as a positive answer. A methodological study comparing different frequency scales in offices reported that “often” in this context is equivalent to at least “3–4 days each week” (Raw et al. 1994). Each symptom has a follow-up question asking whether the respondent attributes the symptom to a specific environment. Roys et al. (1994) compared this question with a question concerning “better on days away from the
office” and concluded that the difference in the wording had no effect of the number of symptoms that were counted as “building-related”.

Indoor air problems are multifactorial in origin, and, in many cases, the psychosocial environment also plays a significant role in the outcome of the problem (Lahtinen et al. 2004). The psychosocial work environment was evaluated with the following questions:

- Do you regard your work as interesting and stimulating?
- Do you have too much work to do?
- Do you have any opportunity to influence your working conditions?
- Do your fellow workers help you with problems you may have in your work?

Before sending the questionnaire to the hospital workers, it was somewhat modified in that a question concerning the smell of mould was added to the environmental complaints, questions on fever or chills, shortness and wheezing of breath, and muscle and joint pain were added to the symptoms, and, as to allergy history, a question was added about recurrent respiratory infections during the last 12 months. These changes were based on the knowledge that 18% to 20% of hospital workers detect the smell of mould in their work environment according to the general OH survey conducted by FIOH (Kauppinen 2004) and the growing number of cases of work-related asthma amongst hospital workers. The question concerning a “heavy head” was deleted.

4.2.2 TECHNICAL EVALUATION OF THE BUILDING (STUDY II)

The condition of the hospital buildings was charted by sampling representative hospitals, so that, from each of the hospital districts, one hospital (which could contain more than one hospital building) was selected. A construction expert specialised in moisture damage and an occupational hygienist inspected the condition of the hospital, especially looking for signs of moisture damage, and estimating the level and extent of such damage; they also performed the necessary structural studies. At the same time, the hospital ventilation system was examined, and the possible deficiencies of the system were charted by a ventilation expert. The investigated premises were divided into the following three groups: in need of immediate repair, in need of further investigation, and not in need of repair. If the experts found damage or circumstances that needed immediate interference, the premise was classified as being in need of immediate repair. If they saw a risk structure or other
circumstances that needed further investigation, the premise was classified as being in need of further investigation. In the rest of the cases, the premises were classified as being in no need of repair.

### 4.2.3 TECHNICAL EVALUATION OF THE VENTILATION SYSTEMS (STUDY III)

Each hospital building had several, in some cases, even tens of different ventilation units. The age and condition of the ventilation systems did not necessarily correspond with the age or condition of the building itself; the same building might have both new and modern ventilation units, as well as old systems that were in need of extensive repair. It was not possible to carry out the evaluation by measuring airflow and pressure ratios in every department of each hospital. As the airflow and pressure ratios may fluctuate daily and weekly, the pressure ratio should be followed for at least a week if even some kind of estimation is to be made of the ventilation. The evaluation of the ventilation was thus carried out “en bloc”, as a multi-stage survey including a background questionnaire, inspections, interviews of those responsible for the maintenance of the ventilation systems, and interviews of the occupants of the building. The condition, performance, hygiene, sufficiency, and need for improvement in the hospital ventilation systems were evaluated. The inspection utilised the knowledge of the technical personnel working for the hospitals, combined with on-the-spot inspections. The sufficiency of the ventilation was estimated on the basis of the design plans, measurement records, and information about the building automation system. The hygiene of the systems was estimated visually. The evaluation included an estimation of the cleanliness of the air-handling units and ducts, possible fibre sources inside the ventilation systems, the location of the outdoor air intake, possible moisture damage to the air-handling unit, and the filtration class of the supply air. Other matters assessed were the overall cleanliness of the machine room, the cleanliness and accessibility of the access routes and maintenance practices. Samples were collected from the supply air ducts for the assessment of the amount of man-made mineral fibres.

The inspection and subsequent analysis of the collected data required approximately a week for each hospital. The same professionals carried out the inspection in all of the hospitals. They had many years’ experience in estimating the condition and performance of ventilation systems in buildings with an indoor air problem. The results of the inspection were summed up and evaluated together with the hospital technical staff during the final interview. The condition, performance, and modernity of the ventilation systems of the entire hospital were classified on a three-grade scale. Table 7 presents the criteria for the evaluation. The classification gives an overview of the ventilation systems of each hospital as a whole.
Table 7. Criteria for the classification of the ventilation systems.

<table>
<thead>
<tr>
<th>Estimate of condition, performance, and modernity of the ventilation systems</th>
<th>Evaluation criteria</th>
</tr>
</thead>
</table>
| **Good and modern** | • Age of ventilation system less than 20 years  
• Ventilation system in good condition for the most part  
• Airflow rates and ventilation equipment suitable for hospital premises |
| **Need for repairs or improvement** | • Age of ventilation system less than 30 years  
• Ventilation system in good condition but partial renewal or partial repair would be beneficial from both economic and performance perspectives  
• Airflow rates and ventilation equipment mainly suitable for hospital premises |
| **Need for extensive repairs** | • Technical lifespan of the ventilation system expired (over 30 years old) or the system in such poor condition that partial repairs no longer feasible  
• Age of the ventilation system over 20 years and not meeting the purposes of the facilities  
• Age of the air ventilation system over 20 years and in need of replacement |

4.2.4 CASE–CONTROL TRIAL (STUDY IV)

4.2.4.1 Microbial exposure

For the assessment of exposure air, surface and material, samples were taken from the target water-damaged clinic. The air samples contained microbes that indicate moisture or mould damage (*Streptomyces*, *Rhodotorula* and *Aspergillus*). The surface samples contained elevated levels of bacterial growth and moderate levels of fungi (*Acremonium* and *Aspergillus* genera). The material samples contained elevated microbe levels, the dominant species being species commonly indicating moisture damage (*Aspergillus versicolor*, *Acremonium*, and *Streptomyces*). In addition, *S. chartarum* was found. One of the three samples taken for toxin measurements contained the mycotoxins satratoxin and sterigmatocystin.

4.2.4.2 Clinical examination and laboratory tests

Every participant went through an interview on indoor-air-related symptoms and a medical examination, which focused on the nasal mucous membranes and nasal
fluid, conjunctiva, pharynx, skin, and lung auscultation. Blood eosinophils, total serum IgE, and microbe-specific IgE and IgG antibodies to *Acremonium kiliense*, *A. versicolor*, *Fusarium moniliforme*, *Phoma betae*, *S. chartarum*, and *Thermoactinomyces vulgaris* were analysed from blood samples. Microbial antibodies were determined at the laboratory of the Skin and Allergy Hospital of the Helsinki University Central Hospital with enzyme-linked immunosorbent assay (Pharmacia CAP System specific IgE and IgG).

### 4.2.4.3 Pulmonary function tests

The pulmonary function tests for flow capacity spirometry included forced vital capacity (FVC), forced expiratory volume in 1 second (FEV₁), the ratio of FEV₁ to FVC (FEV₁/FVC), and maximal mid-expiratory flow (MEF₅₀). A bronchodilatation test was performed using a spacer with a 0.4 mg (2 x 0.2 mg) salbutamol dose aerosol. The histamine provocation test was used to assess bronchial responsiveness. Based on the FEV₁ values and symptoms, the dosage of histamine was 0.02 mg, 0.1 mg, 0.4 mg, and 1.6 mg.

### 4.2.4.4 Allergy tests

A skin prick test with 12 allergens (birch, alder, timothy, meadow fescue, mugwort, *Cladosporium herbarum*, cat, dog, horse, dust mite *Dermatophagoides farinae*, dust mite *Dermatophagoides pteronyssinus*, and latex) was performed on the inner forearm, and the skin reaction was read after 15 minutes. The test result was considered positive if the allergen caused a skin reaction of at least 3 mm in diameter and the control solution caused the expected reaction. The test solutions were commercial extracts (Nordic, ALK-Abello, Round Rock, Texas, USA; 10 HEP [histamine equivalent prick]).

### 4.2.4.5 Nasal lavage

An ear, nose, and throat specialist performed the NAL after confirming that the participants had not used either antihistamine or corticosteroid medication during the previous week. Careful anterior rhinoscopy with a nasal speculum was carried out on all of the patients. The condition of the nasal mucosa and the presence of polyps or other pathologies were evaluated. NAL was performed with a latex urine catheter (Foley 14). The balloon of the catheter was filled with air and pushed gently against the nostril. The nasal passages were flushed with 10 ml of a sodium chloride
4.2.4.6. Cytological staining

An aliquot of the NAL fluid sample was taken aside, fixed in ethanol (1:2), and stored at +4°C until cytospun on microscope slides and stained with Papanicolau stain. The remaining native NAL sample was centrifuged (10 minutes at 250 g at +4°C), and the cells were re-suspended in 2 ml of the supernatant, while the rest of the supernatant was aliquoted and stored at −70°C for cytokine analysis. Of the re-suspended cells, 100 µl were cytocentrifuged (Cytospin, Shandon Ltd., Cheshire, England) on a slide, and the cells were stained with May-Grünwald-Giemsa stain. The cell population on the cytospin slides was differentiated by counting at least 200 cells under light microscopy. The remaining cells were re-suspended in Trizol Reagent (Invitrogen, GIBCO BRL, New York, NY, USA) and stored at −70°C for later isolation of the ribonucleic acid.

4.2.4.7 Nasal lavage fluid measurements

The supernatants were studied for proteins, myeloperoxidase (MPO), eosinophilic cationic protein (ECP), TNF-α, and IL-6. MPO and ECP were studied at the laboratory of the Skin and Allergy Hospital of the Helsinki University Central Hospital (Pharmacia MPO radioimmunoassay and CAP System ECP fluorescent-enzyme immunoassay; Pharmacia & Upjohn Diagnostics AB, Uppsala, Sweden). TNF-α and IL-6 were studied at FIOH. The TNF-α and IL-6 concentrations of the NAL fluid were measured with commercial kits (Quantikine High Sensitivity kits from R&D Systems, Minneapolis, MN, USA) according to the manufacturer’s instructions. The detection levels of the TNF-α and IL-6 were 0.18 pg/ml and 0.09 pg/ml, respectively.

The original examination and the follow-up measurement were carried out at the same time of the year.

4.2.5 SEMI-STRUCTURED THEME INTERVIEWS (STUDY V)

The method chosen for this part of the study was the theme interview. The interviews were conducted by one person on the basis of previously defined themes. All of the
interviews were recorded and transcribed. The interview material was classified according to data-orientation with the help of software for analysing qualitative data, Atlas.ti (Muhr 1997). The aim of the analysis was to cover the entire spectrum of the interviewees’ opinions. The results were reported as a description explicating into a text with material examples. The interview themes used for OH care and OS were the following:

- How do different actors see their role in handling indoor air problems?
- How great a workload does indoor air problems cause?
- Are there enough tools for handling indoor air issues?
- How does the co-operation between different parties work?
- What kinds of problems have been encountered in the handling of indoor air problems?
- Does experience of successfully handled cases exist?

The themes were broadened with additional questions in the interview itself. In addition, the OS representatives were asked how OS was arranged in their hospitals. The hospital hygiene representatives were asked how indoor air problems show up in their work and whether they participate in solving these problems.

### 4.3 STATISTICAL ANALYSES

The statistical analyses of the results, including chi-square tests, differences in proportions, and logistic regressions, were carried out using an SAS program package (version 9.1, SAS Inc., Cary, NC, USA). In the survey studies, the differences were calculated between facilities with immediate need of repair and those with no need of repair (II) and between hospitals with good ventilation and those with poor ventilation (III). Logistic regression was used to examine the association between perceived heavy workload and the need for repair due to reported general symptoms (fatigue, headache, difficulties in concentrating) (II).

In study IV, the statistical differences in the levels of the inflammatory cells, pro-inflammatory cytokines, and mould-specific antibodies between the groups were tested using the non-paired t-test (IV).
4.4 ETHICAL CONSIDERATIONS

The study protocol of the case–control study was approved by the research committee of the hospital in question, and the patients were enrolled after their informed consent had been obtained verbally. The questionnaire surveys were conducted with the help of the hospital OH personnel, who were responsible for the collection of the data. In the interview study, all of the interviewed persons gave their informed consent prior to their inclusion in the study.
5 RESULTS

5.1 COMPLAINTS AND SYMPTOMS OF THE HOSPITAL WORKERS IN RELATION TO INDOOR AIR QUALITY (STUDY I)

Figure 3 presents the complaints, and Figure 4 shows the symptoms associated with indoor air and reported by the hospital workers in the survey in comparison with data from the office workers in the reference material. The commonest problems with the work environment were dry air, stuffy air, noise, and draught. The odour of mould was reported by 12% of the participants in the survey.

![Figure 3. Indoor air complaints reported by the hospital and office workers. The p-value was calculated for the differences between the hospital and office workers. *** = p<0.001, ** = p<0.01, * = <0.05. a) The office workers were not asked this question.](image)

The commonest symptoms associated with the work environment were irritation of the nose, hands, and eyes, as well as fatigue. In addition, irritation of the throat, facial skin irritation, headaches, and cough were also present.
Some of the participants in the survey reported previous allergic diseases. Asthma was a problem for 10% of the participants, 42% had experienced hay fever or other allergic rhinitis, and 28% had atopic eczema. Compared with the office workers, the prevalence of asthma and allergic rhinitis was higher. In addition, 26% reported recurrent respiratory infections during the past 12 months.

Also 82% of the respondents considered their work to be often interesting and stimulating, 78% stated that they would often receive help from their colleagues in problematic work situations, and 21% answered that they were often able to influence their work and work conditions. A total of 22% of the respondents estimated their workload to often be too great, and 64% estimated that they sometimes had too much work to do. Compared with the office workers, the hospital staff more often reported that their work was interesting and stimulating, and they more often felt that they received social support, but were less often were able to influence their work. Workload was experienced as somewhat higher in hospitals.

5.2. COMPLAINTS AND SYMPTOMS OF THE HOSPITAL WORKERS ACCORDING TO THE NEED FOR REPAIRS IN THE HOSPITAL BUILDINGS (STUDY II)

Altogether 15% of the total area of the studied hospital buildings was found to be in need of immediate repair. The most immediate need was reported for the patient wards, where 24% of the studied facilities were in need of immediate repair, whereas less than 10% of the other units had a need for immediate repair. The commonest
causes for the need of immediate repair were problems found in toilets, washrooms, and showers. Four fifths of the studied hospitals had problems in these facilities. Other typical problems were moisture damage in the foundation structures or intermediate floors and damage in outer walls, for example, contaminated and moist insulation in buildings without a crawl space.

The association of the complaints and the condition of the hospital buildings is shown in Figure 5. Indoor air problems were more commonly reported for facilities requiring immediate repair than for other facilities, however, not because of noise, draught, static electricity or low room temperature, dim light, glare or reflections, or environmental tobacco smoke. Stuffy and dry air, unpleasant odours, smell of mould, dust or dirt, varying temperature, and static electricity were complained about more often in premises with an immediate need of repair than in those with only a need for further investigation. The smell of mould was reported more often in the facilities requiring further studies than in those that did not require any repair.

Figure 5. Complaints of the hospital workers according to the need for repair in the building. The p-value was calculated for the differences between no “need for repair” and “immediate need for repair”. *** = p<0.001, ** = p<0.01, * = <0.05.

Figure 6 presents the indoor-air-related symptoms of the hospital workers according to the need for repair in the building. Symptoms were the most commonly reported in facilities requiring immediate repair; in the buildings with a need for further investigations, symptoms were reported more often than in buildings where there was no need for repair.
The commonest symptoms in the facilities and with immediate need for repair were irritation of the eyes, nose and hand skin and a hoarse, dry throat. In addition cough, headache, and irritation of facial skin and scalp or ears were reported more often in the facilities requiring immediate repair than in those with no need for repair. Workers in the facilities with a need for further investigations had more fatigue, headache, cough, shortness of breath, and irritation of eyes and facial skin than did those in buildings without a need for repair.

Figure 6. Indoor-air-related symptoms of the hospital workers according to the need for repair in the building. The p-value was calculated for the differences between no “need for repair” and “immediate need for repair”. *** = <0.001, ** = p<0.01, * = p<0.05.

Allergic diseases showed no significant differences between the groups. The most recurrent respiratory infections occurred in facilities requiring immediate repair (31.2%), and the fewest were reported in the facilities with no need of repair (22.8%); facilities requiring further studies fell in between (28.1%).

A heavy workload was reported more often in the facilities requiring immediate repair than in those with no need of repair (p <0.01). The need for immediate repair was not connected with the other characteristics of the psychosocial environment. The association between reported general symptoms (fatigue, headache, difficulties in concentrating) and the need for repair and, on the other hand, perceived heavy workload was examined with logistic regression. Both factors were found to be associated with general symptoms, but a heavy workload explained fatigue and difficulties in concentrating better than the need for repair did.
5.3 COMPLAINTS AND SYMPTOMS IN RELATION TO THE CONDITION OF THE VENTILATION (STUDY III)

According to the survey summaries, the central hospitals were ranked as follows: good, if most of the ventilation systems were good and modern (hospitals 7–10 in Figure 7); poor, if most of the ventilation systems were in need of extensive repair (hospitals 1–4 in Figure 7); and moderate, if there were approximately as many good and modern ventilation systems as those in need of extensive repair (hospitals 5–6 in Figure 7). Four of the hospitals had ventilation systems that were “en bloc” in good condition, in another four they were in poor condition, and in two the systems were in moderate condition. Figure 7 presents the results of the evaluation of the ventilation systems in each hospital.

The commonest ventilation problems were insufficient ventilation of the facilities, uncontrollable temperature conditions, draught and problems with the removal of impurities worsened by the lack of local extraction, and insufficient hygiene of the ventilation system.

Figure 7. Condition of the ventilation systems in each hospital and the mean value.

Figure 8 presents the indoor air complaints of the hospital workers according to the state of the ventilation system. Figure 9 shows the symptoms of the hospital workers in relation to the indoor air according to the state of the ventilation system.
Figure 8. Complaints of the hospital workers according to the state of the ventilation system in their workplaces. The p-value was calculated for the differences between good and poor ventilation. *** = $p<0.001$, ** = $p<0.01$, * = $p<0.05$.

Figure 9. The hospital workers' symptoms that were related to the indoor air according to the state of the ventilation system. The p-value was calculated for the differences between good and poor ventilation. *** = $p<0.001$, ** = $p<0.01$, * = $p<0.05$. 
On average, the hospital workers occupying buildings with good ventilation (1054 of the respondents in the survey) reported the fewest environmental complaints. In the hospitals with poor ventilation (1843 respondents in the survey), the workers most commonly reported almost all of the environmental complaints registered. The difference between the hospitals with good and poor ventilation was statistically significant regarding draught, dry air, too low or varying temperature, noise, dim light or reflections, dust and dirt, and smell of mould. In addition, the workers in the hospitals with good ventilation reported fewer symptoms related to the indoor air. The difference between the hospitals with good and poor ventilation was statistically significant regarding all the symptoms, except headache, nausea and dizziness, difficulties in concentrating, fever or chills, shortness of breath, and muscular or joint pain.

The workers in the hospitals with moderate ventilation (842 respondents) reported complaints less often than did those in the hospitals with poor ventilation, but more often than did those in the hospitals with good ventilation. With regard to the symptoms, the workers in hospitals with moderate ventilation reported symptoms more often than did those in the hospitals with good ventilation and almost as often as the workers in the hospitals with poor ventilation.

Allergic rhinitis was reported slightly less often in the hospitals in which the ventilation was ranked as good than in the hospitals in which the ventilation was evaluated as being moderate or poor (p=0.05). For asthma, allergic dermatitis or atopic conditions, there were no statistical differences between the groups. The same number of recurrent respiratory tract infections during the past 12 months was reported in all the hospitals under study, independent of the conditions of the ventilation systems.

Work was more often regarded as interesting and inspiring in the hospitals in which the ventilation systems were considered good than in the hospitals in which they were poor (p=0.01). There were no differences between the groups regarding social support, influence over one’s work, and work intensity.

The condition of the building itself was evaluated, on average, as being as good in the hospitals with good ventilation as in those with poor ventilation (Figure 10).
Figure 10. Condition between the ventilation system and the building itself. Hospitals according to the percentages of area in which the condition and the ventilation of the building is good: ● = hospital with good ventilation, ◆ = hospital with moderate ventilation, ▲ = hospital with poor ventilation.

5.4 CLINICAL EXAMINATION OF THE SYMPTOMATIC WORKERS (STUDY IV)

5.4.1 SYMPTOMS AND FINDINGS

All but 1 of the 28 employees working in the water-damaged clinic reported indoor-air-related symptoms at work. The symptoms appeared at the workplace and disappeared after the workers left the building. Six employees had been diagnosed with asthma, and three had had allergic rhinitis during the past 5 years. During the follow-up with NAL after the renovation, the exposed employees reported fewer symptoms, especially irritation symptoms of the mucosa. The prevalence of symptoms related to the indoor air amongst the employees in the control group did not differ from the corresponding prevalence of the general population.

There was no significant difference in the clinical findings (anterior rhinoscopy, inspection of the throat, eyes and skin, and pulmonary auscultation) amongst the exposed workers and the control group.
5.4.2 EVALUATION OF ATOPY

The cases and controls of study IV did not differ concerning a positive skin prick test to common inhalant allergens, total serum IgE, total blood eosinophils, or pulmonary function tests.

The medical history for past or present eczema, rhinoconjunctivitis, or asthma was similar for both the exposed and the control groups. Of the controls, 10% had asthma, which was also the reported asthma prevalence for hospital workers (study I).

5.4.3 MOULD-SPECIFIC ANTIBODIES

The mean level of *S. chartarum*-specific IgG antibodies was somewhat higher ($p<0.02$) for the employees working in the water-damaged building than for the controls working in a healthy building (Figure 11). No significant differences in the levels of IgG antibodies specific to other moulds were found between the two groups.

No significant differences were determined for mould-specific IgE antibodies between the cases and controls.

![Figure 11](image.png)

*Figure 11. Stachybotrys chartarum* immunoglobulin G (IgG) antibodies before the renovation.*
5.4.4 CELLS AND CYTOKINES IN NASAL LAVAGE FLUID

NAL was used as a working tool in evaluating the exposure to mould and moisture microbes.

In the first NAL samples, the number of neutrophils of those exposed was lower than that of the control group (p= 0.03). However, the exposed persons had more (p = 0.04 and 0.02, respectively) columnar epithelium cells and macrophages (Figure 12). The differences in the levels of the NAL eosinophils, lymphocytes, and mast cells were not significant between the exposed and control groups. In the follow-up measurements, the differences between all of the cell counts disappeared.

The levels of TNF-α in the NAL fluid were significantly reduced for the persons working in the moisture-damaged building when these levels were compared with those of the control group (p<0.03). The levels of IL-6 were also slightly reduced in the exposed workers when they were compared with those of the controls (Figure 13). The follow-up study after the renovation showed no differences in the NAL cytokines between the exposed and control groups. No statistically significant differences between the groups were found in the levels of ECP and MPO in either the first or the follow-up study.

![Figure 12](image-url)

*Figure 12.* Fluid cell findings for the nasal lavage of the exposed workers and the control group before the renovation. The cells are shown as the values of the total number of cells counted. The horizontal lines represent the mean values.
**Figure 13.** Tumour necrosis factor alpha (TNF-α) and interleukin-6 (IL-6) in the nasal lavage fluid before the renovation. The horizontal lines represent the mean values.

5.5 **INDOOR AIR PROBLEMS IN HOSPITALS AS A CHALLENGE FOR OCCUPATIONAL HEALTH CARE AND OCCUPATIONAL SAFETY (STUDY V)**

5.5.1 **ROLES**

The interviewed OH professionals felt that their main role was to examine and treat symptomatic patients, as well as to evaluate health risks. They had also been obliged to take the role of a communicator of information and an initiator of tangible measures with respect to indoor air problems, because information on an indoor air problem was generally first communicated to an OH professional. From the point of view of the other involved parties, the role of OH professionals was rather unclear. Even though a safe and healthy work environment is the responsibility of employer, symptomatic employees sometimes blamed OH professionals if repairs were delayed. The OS representatives viewed their task as starting the process, taking the process further, handling related psychosocial conflicts, co-ordinating the process, arranging meetings, informing, and sometimes also arranging training on indoor air issues.
5.5.2 WORKLOAD AND RESOURCES

According to the interviewees, indoor air problems had troubled OH services to varying degrees. The problems usually occurred as demands to “put out fires”, and OH resources did not have such flexibility. About every fifth visit of an OH professional to the workplace in the hospitals under study was carried out because of an indoor air problem, approximately every tenth visit to the workplace was estimated to revolve solely around indoor air issues, but indoor air problems always came up at ordinary, regular workplace visits. A few patients with indoor-air-related problems are seen weekly at OH units. In connection with renovation work, the number of visits increased. Since the patient records did not have a special code for indoor air problems, the number of visits in question is an estimate made by the interviewees. It was also estimated that giving advice on indoor air issues by e-mail and phone took 0.5–3 hours a week. All in all, it was estimated that the workload caused by indoor air problems averaged 1–1.5 hours a week.

According to the interviews, the OH units would have needed more physicians, while the situation concerning nurses was better. In most of the hospitals, the OH physician’s services were bought from a private clinic. Thus the physician easily remained an outsider with respect to indoor air matters. His or her work might have been too centred on working with patients rather than visiting workplaces.

All of the hospitals had an OS committee as a part of their co-operation board. The number of OS delegates was found to be too small, as all of the interviewed OS representatives felt that indoor air problems increased their workload significantly. Indoor air problems were considered one of the biggest OS problems in hospitals.

5.5.3 TOOLS

The Indoor Air Questionnaire (Andersson 1998; Reijula and Sundman-Digert 2004) was familiar to all of the interviewees, and it was considered a good tool for documenting and illustrating the data. The questionnaire also usually gave a realistic picture of the situation in the target department; the number of complaints and symptoms was often less than what was expected according to the clinical contacts. As a follow-up tool, the questionnaire was not implemented in the studied hospitals. Some of the interviewees felt that interpreting the Indoor Air Questionnaire was easy with no risk for misinterpretation; others felt great uncertainty in interpreting the survey data.

The use of microbe-specific IgG antibodies (Jaakkola et al. 2002a; Taskinen et al. 2002) in evaluating exposure to moisture-damage moulds had been abandoned in many of the hospitals. All of the parties who had used IgG antibodies as a tool had experienced problems with interpreting the results.
The follow-up of peak expiratory flow (PEF) was considered a good tool by the interviewees for assessing possible lung function variations during shifts.

The tools used for OS varied. In some hospitals OS personnel were able to take samples of material, air, surface dust, and fibres. Measurement devices for noise, temperature, moisture, and carbon dioxide belonged to the standard selection of tools. A digital camera and a smoke pipe were also commonly used. The technical department usually provided a surface moisture meter.

Training on the topic was considered sufficient. Practical, guidebook-like information, unification of study recommendations, and best practices, which would facilitate working with a difficult problem, were required. The hospitals also needed an operating action model for solving indoor air problems in hospital environments.

5.5.4 CO-OPERATION

The OH personnel in the hospitals co-operated primarily with OS professionals in solving indoor air problems. Visits to the problem targets were usually conducted together. Sometimes a representative from the technical department also participated in the visits. The OH personnel considered co-operation with OS professionals to be good in all of the target hospitals.

The main partner for OS activities was the OH unit, which had a representative in the OS committee, usually an OH nurse. OS representatives usually participated in the workplace visits arranged by an OH unit. Common projects for solving difficult indoor air problems had strengthened the co-operation, but problems with co-operation were experienced at times, due to turnover amongst the OH personnel.

According to some of the interviewees, the co-operation with the hospital’s technical department was more challenging. The monetary and personnel resources of the technical department for handling indoor air problems were limited, while ongoing renovations and construction of new facilities occupied the staff and consumed money. Information on repairs, further measures taken, or results were not automatically reported to the OH unit. However, the hospital employees always asked the OH personnel about the progress of repairs when visiting an OH unit.

Interprofessional groups, called “indoor air groups” (Lahtinen et al. 2008), handled indoor air problems at three of the seven central hospitals under study. The group always included an OH and an OS representative. The OS staff felt that the co-operation with all of the parties involved was better when the hospital had established an indoor air group.
5.5.5 PROBLEMS

The OH unit was burdened with the workers' often unrealistic expectations to solve the indoor air problem, even though they were unable to directly affect the cause of the problem. The users of the facilities hoped for a quick solution, but repairs were often delayed and did not always solve the entire problem. The multi-disciplinary nature of the matter and difficulties in getting information on what other parties had done made the work demanding. A working indoor air group was considered helpful in getting information.

A particularly difficult problem was the lack of knowledge about the exact cause and mechanisms of the health effects related to indoor air problems, especially to moisture damage. Furthermore, health-based threshold levels have not been determined for microbial substances. Thus much insecurity was experienced concerning risk assessment. Relocation and moving to alternative work facilities was difficult, as there were no other facilities available for use. There was also a lack of additional facilities for temporary use, as no functions could suddenly be closed down. The most sensitive employees were symptomatic throughout the hospital. They could also spread nervousness amongst their colleagues. In such cases, the OH unit often received negative feedback from at least one party involved with the problem.

During medical consultations, a risk assessment was carried out only from the patient's point of view. As a result, physicians felt that they were being recruited to be their patient's advocate. However, the indoor air group was compelled to take a group-level point of view of the risk evaluation. This approach was also considered difficult because someone in the same facility may be very symptomatic while others had no symptoms at all.

Those who worked with indoor air problems often encountered dismissive attitudes. On a general principle level, everybody saw the problem and understood it, but it was not always considered as an important a health risk, even though it was that for some of the employees.

5.5.6 SUCCESSFUL EXPERIENCES

Although the handling of indoor air problems was often considered a laborious and slow process, there were also positive experiences. The interviews regarding the successful cases emphasised good co-operation, the well-timed, adequate, and open flow of information, the active role of the superior in the target hospital, and success in convincing decision makers. Thorough research and repairs also facilitated the solution of the problem. Some employees had been successfully relocated.

Problems caused by fibres were found to be the easiest to handle. In some cases, adjusting the amount of ventilation and its division had yielded good results in
target hospitals. Moisture or mould damage limited to a relatively small area of the hospital had also been successfully repaired.

5.5.7 HOSPITAL HYGIENE PERSONNEL

The role of the hospital hygiene personnel (infection control nurses and infection control physicians) in regard to indoor air problems was small and mainly focused on patient safety. The need for additional resources appeared in all of the interviews.

5.6 PROPOSAL FOR THE ASSESSMENT AND CONTROL OF HOSPITAL INDOOR AIR ON THE BASIS OF THE LITERATURE REVIEW AND THE RESULTS OF THE STUDIES

This study introduces a new approach to the assessment of hospital buildings. A diagram of the process is presented in appendix 1. Especially the ventilation systems of hospitals are so complicated that a comprehensive evaluation is impossible, even with ventilation measurements. Airflow and pressure ratios can change during a week and even a day. Therefore, pressure ratios should be monitored for at least a week to achieve some kind of evaluation. With systematic follow-ups, possible indoor air problems may be caught early, and thus the appearance of symptoms may be prevented.
6 DISCUSSION

The present study emerged from the concern of the National Trade Union of Nurses due to an increased number of occupational diseases related to mould exposure among hospital workers. At the same time – in the beginning of the 2000s – most of the hospital buildings in the 20 central hospital districts of Finland were already so old that they were at the end of their life cycle and in need of thorough renovation. Furthermore, the interviews for the “Work and Health in Finland 2003” survey carried out by FIOH (Kauppinen et al. 2004) revealed that about 20% of social and health-care workers had reported mould odour in their work environment.

The present study consisted of cross-sectional surveys concerning the perceived symptoms related to the indoor air of hospitals. It includes a classification of the condition of the buildings and their ventilation, interviews on the recognition and resolution of indoor air problems, and a thorough clinical examination of hospital workers from a moisture-damaged hospital ward.

6.1 SURVEY STUDIES

6.1.1 QUESTIONNAIRE SURVEYS

The Indoor Air Questionnaire of FIOH is a validated and standardised questionnaire. It has been widely used in office buildings, but only occasionally used in hospitals (Reijula and Sundman-Digert 2004). Thus the reference group for the first comparison had to be taken from office buildings. It was known that, due to the high prevalence of moisture damage in the national building stock, the reference material included some buildings with moisture problems. Nevertheless, a clear picture was obtained of the difference between the hospitals and offices.

The Indoor Air Questionnaire was sent to a third of hospital employees in collaboration with the hospital OH personnel. Even though the OH personnel were instructed to deliver the questionnaires randomly, it is possible that more copies were sent to departments with known indoor air problems, especially moisture damage, than to others. However, in the questionnaire survey, the proportion of respondents who worked in areas needing immediate repair was equal to the percentage of those working in a relevant area in the building inspection. The surveys
and workplace investigations were blinded so that the respondents did not know the results of the investigations and the investigators did not know the results of the survey. It is, however, possible that the indoor air problems were so obvious in some hospital departments that the workers were aware of them when they responded to the questionnaire survey.

In the questionnaire surveys, the total response rate was 68%, which can be considered high enough to represent the whole material. The mean age and gender distributions of the respondents were similar to the figures for hospital workers in Finland. Compared with the reference material, the relative numbers of women and non-smokers were higher in the hospital material than in the office material. Thus they compensate each other, as women more often report environmental complaints than men, while non-smokers report such complaints less frequently than smokers (Reijula and Sundman-Digert 2004).

Allergic employees more often report work-related symptoms than non-allergic ones do (Reijula and Sundman-Digert 2004). In the present study, the hospital employees more often reported previous allergic diseases than the office workers did. This finding may explain some of the differences between the hospital facilities and the offices. The target hospitals were situated all over the country, and the departments to which the questionnaire was sent represented typical hospital activities. Thus the results can be generalised with respect to Finnish hospitals.

6.1.2 BUILDING AND VENTILATION CHARACTERISTICS

The experts who assessed the buildings and ventilation systems were very experienced, as they had assessed many similar buildings earlier in the same way. The investigators did not know which departments had participated in the survey, nor did they know the results of it.

Due to the lack of proper design instructions, many mistakes had been made in the design of the ventilation systems, which had led at times, for example, to bare fibre sources. In Finland, only minimum demands have been given in the National Building Code of the Ministry of Environment. Some space-specific guidelines, for instance, for hospital pharmacies, have been issued by the National Agency for Medicines. All of the investigated ventilation systems fulfilled or exceeded the existing design minimum criteria at the time the buildings were constructed. Since then, however, the demands have increased. Today, it would be desirable to draw up uniform design criteria for ventilation in different hospital spaces. The expected lifespan of ventilation systems in hospitals is about 20–30 years, thus usually not as long as the lifespan of the building itself. Hospital buildings have generally been maintained better than their ventilation systems, probably because problems with
ventilation are not visible to the user in the same way as problems in the building. As the renovation of ventilation systems is difficult and expensive, renovation projects are often postponed.

In addition to affecting the work atmosphere, insufficient ventilation decreases efficiency and productivity at work (Niemelä et al. 2002; Seppanen and Fisk 2006). Poorly functioning ventilation may be a considerable health risk for some patients (Li et al. 2007), as the role of airborne pathogens in hospital infections has been underrated (Beggs et al. 2008). Hospital buildings are under constant repair. Renovation dust usually contains microbes, for example, *Aspergillus* spores (Abdel Hameed et al. 2004). A hospital infection caused by the *Aspergillus* fungus may spread through the ventilation system (Haiduven 2009). Therefore the role of ventilation in controlling the spread of impurities cannot be over-emphasized. Ventilation in tropical hospitals may be different, and the results from a Finnish study can thus not be generalised to them (Escombe et al. 2007).

### 6.1.3 COMPLAINTS, SYMPTOMS AND ILLNESSES IN RELATION TO THE CONDITION OF A BUILDING AND ITS VENTILATION

The characteristics (gender, age, etc.) of employees in the three groups of hospital buildings formed according to the condition of the building and ventilation did not differ significantly. The condition of the ventilation systems is a confounding factor in comparisons of the effect of the condition of the buildings and vice versa. The condition of the hospital buildings with good and poor ventilation was roughly equally distributed between the groups. The ventilation classification was, however, reported at the hospital level. Thus, it is possible that some respondents in the hospitals with good ventilation came from poorly ventilated departments, and vice versa. This possible error reduces the differences observed; the real differences may thus have been larger.

Irritation symptoms were commoner in the moisture- and mould-damaged facilities than in the undamaged facilities, as expected according to the results of previous studies (Bornehag et al. 2001, 2004; Fisk et al. 2007). The number of reported symptoms was highest for the facilities that required immediate repair, it was somewhat lower for those that needed further investigation, and it was the lowest for those that required no repair. This finding suggests a dose–response relationship, which usually is interpreted as defending causality, according to the Hill criteria (Hill 1965).

Many studies have found that the risk of wheezing is increased in moisture- and mould-damaged buildings (Strachan et al. 1988; Brunekreef et al. 1989; Platt et al. 1989; Dekker et al. 1991; Wan and Li 1999), but the present study did not show a clear difference concerning this particular symptom. However, cough was reported
more often in the facilities requiring further studies, and in the facilities requiring immediate repair, than in the facilities not needing repair. The prevalence of asthma and allergic rhinitis was higher for the hospital employees than for the reference material comprised of office workers. Many studies have shown that the risk for asthma is higher in moisture- and mould-damaged buildings (Waegemaekers et al. 1989; Brunekreef 1992; Ruotsalainen et al. 1995; Thorn 2001; Jaakkola et al. 2002b). The present study did not find a significant difference in the prevalence of asthma, allergic rhinitis, or atopic eczema between the groups. As the study was cross-sectional, it is possible that new cases of asthma had been moved away from the moisture-damaged environment.

Recurrent respiratory infections were found more often in the facilities that required further investigations than in those that did not, as well as in the facilities requiring immediate repair rather than in those requiring further investigation. This finding supports the view that the prevalence of respiratory tract infections increases in moisture- and mould-damaged buildings, a finding that has also been reported in earlier studies (Dales et al. 1991; Brunekreef 1992; Koskinen et al. 1999).

The perception of indoor air as dry was common in all of the hospitals, as the survey was conducted during the cold season, which requires that buildings be heated in Finland. In study II, dry air was found to be associated with the need to repair moisture damage. The perception of dry air also correlated with the performance of the ventilation system (study III).

In general, the profiles for complaints were similar in both cases, except that the perception of stuffy air and unpleasant odours was related to the need for repair but not to poor ventilation, while draught and noise were related to poor ventilation but not to the need for repair. The source of the noise was not defined in the present study. Nordström et al. (1995) has suggested that ventilation noise should be reduced in hospitals.

In regard to the reported symptoms, the irritation symptoms correlated also with the state of the ventilation system. The irritation symptoms can probably be explained by the fact that impurities remain for a longer time in the indoor air when the ventilation is poor. Fatigue was found to be associated with insufficient ventilation, as it was in a previous study (Jaakkola and Miettinen 1995).

Previous studies (Wargocki et al. 2002; Seppänen and Fisk 2004) have shown that poor ventilation increases the number of short sick leaves. However, in study III, the number of reported recurring respiratory tract infections amongst the staff did not seem to depend on the ventilation. On the other hand, the need for repairs in hospital buildings increased the number of recurring respiratory tract infections (study II).
6.2 NASAL LAVAGE STUDY

6.2.1 STUDY POPULATION AND CLINICAL FINDINGS

The size of the groups attending the NAL examination was small. However, almost all of the workers in the target department participated. The workplace exposure of the cases was verified by inspection and environmental samples. The controls were working in another department, without any known indoor air problems. The possibility of mould exposure amongst the controls was not examined by specific measurements at their workplace. Nor were any of the participants’ homes examined. Toxins were measured only in water-damaged material samples, not in indoor air. Thus direct evidence of an exposure to toxins could not be confirmed in the present study. It is possible that mycotoxins, carried by respirable dust, mould spores, or mycelium fragments, find their way to the breathing zone of a person although they do not evaporate at normal temperatures.

In the water-damaged hospital department investigated in this study, nearly all of the employees were symptomatic according to the Indoor Air Questionnaire Survey and interviews carried out by OH personnel. According to the material samples and the IgG findings, the workers had been significantly exposed to a toxin-producing strain of *S. chartarum* and at least one of its toxins.

In antibody and skin prick tests, the use of extracts from raw microbial materials from the building was not possible, and, therefore, commercially available microbial test extracts had to be used. Not all of the moulds identified in the studied hospital environments were available in the commercial microbial test panels. In an ideal situation, the mould extract should have been produced from the species found in the relevant building. According to previous literature, it is, however, difficult to get stable mould extracts containing relevant allergens (Kauffman et al. 1984; Wallenbeck et al. 1984; Aukrust et al. 1985; Steringer et al. 1987). Even though the symptoms of persons exposed to the indoor air of water-damaged buildings resemble allergic symptoms, the symptomatic persons are rarely found to have IgE antibodies or to test positive to moulds in a skin prick test (Reijula et al. 2003). In accordance with this finding, only two employees tested positive to moulds in the skin prick test administered in the present study. Moreover, atopy did not have a significant effect on the prevalence of symptoms. This finding suggests that the symptoms of the exposed persons were not likely to have been induced by IgE-mediated mechanisms, as the previous literature also indicates (Reijula 2003).
**6.2.2 NASAL LAVAGE METHOD**

Roponen et al. (2003a) have already shown that variations between individual NAL findings concerning cytokine measurements are high. In the present study, high variations in the cytokine levels were also found between individuals. We chose the cytokines in the present experiment according to previous findings from other studies. In a recent study, Stark and his co-workers showed that IL-1β and IL-4 levels increase during mould exposure in moisture-problem buildings (Stark et al. 2006). On the other hand, IL-4 is related to a T helper cell 2/IgE mediated allergic response, which also, according to our previous findings, has not been a dominant factor associated with mould exposure.

**6.2.3 CONTENTS OF NASAL LAVAGE FLUID**

Cell and cytokine findings from NAL are a good indicator of the state of inflammation in the nasal mucosa. In an earlier study, staff exposed to moulds at a mould-damaged school had significantly higher levels of TNF-α, IL-6, and nitrogen oxide at the end of the spring semester than an unexposed control group did (Hirvonen et al. 1999; Purokivi et al. 2001). These inflammation mediator levels decreased to the levels of the control group during the 2.5-month summer holiday. The nitrogen oxide and IL-6 production increased again as the exposure continued during the autumn semester. In a Swedish study conducted on workers in a moisture- and mould-damaged building and workers in a control building, the ECP, MPO, and albumin levels in the NAL samples were higher amongst the workers in the moisture- and mould-damaged office building than amongst their counterparts in a control building (Walinder et al. 2001). In a study on sawmill workers, it was, however, found that exposure to microbes does not always lead to inflammatory changes detectable with the NAL method (Roponen et al. 2002).

In the present study, the number of macrophages and columnar epithelial cells in the NAL was higher in the study group than in the control group, whereas the number of neutrophils was lower in the study group than in the control group. In contrast to the NAL study reported earlier, the TNF-α and IL-6 levels in the NAL fluid of the mould-exposed persons were significantly lower than in the control group.

Since the pro-inflammatory cytokines TNF-α and IL-6 are primarily produced by macrophages, the results indicate that the ability of the nasal macrophages to secrete pro-inflammatory cytokines is impaired in exposed persons, even though the number of macrophages in NAL samples increases.

Interestingly, no significant differences in the number of NAL cells or the levels of pro-inflammatory cytokines were found between the exposed and control groups in the follow-up study after the renovation; this finding suggests that the impaired
immune response was likely to be due to exposure to immuno-modulatory substances present in the moisture-damaged building.

In certain situations, exposure to moulds seems to lead to an activation of the immune system that can be detected with the NAL method (Hirvonen et al. 1999). However, in some cases, exposure to moulds does not seem to cause a change in the pro-inflammatory cytokines of NAL samples (Roponen et al. 2002). According to our results, exposure to the toxin-producing mould *S. chartarum* may lead to a partial suppression of the immune system, as indicated by the impaired production of macrophage-derived pro-inflammatory cytokines and decreased levels of neutrophils in the nasal mucosa. It should be noted, however, that the IgG levels against *S. chartarum* were elevated in the exposed group; this finding suggests that at least the humoral immune response is not impaired. Because the symptoms, as well as the inflammatory findings, returned to normal after the termination of exposure, it is anticipated that the two are linked.

Study IV thus showed that NAL is a suitable method for revealing inflammation in the nasal mucosa of persons exposed to mould and moisture. However, it is important to define both the NAL cells and the pro-inflammatory cytokines. Additional research is needed to ascertain which factors in the indoor air of a moisture- and mould-damaged building cause the immune response in nasal mucosa and why the type of the response may differ in different moisture and mould environments. Before that has been accomplished, no feasible reference values can be defined, and the NAL method is not usable in OH practice.

### 6.3 INTERVIEW STUDY

#### 6.3.1 STUDY POPULATION AND INTERVIEW THEMES

In study V, the focus group consisted of 23 professionals who represented seven hospital districts. Altogether 12 of them represented OH services, 8 came from the OS field, and 3 were employed in infection control units. Two OH nurses took part in the interviews by submitting written answers to the questions. The opinion of the technical department was obtained through the OS personnel; four OS representatives were from technical departments. The interview circuit was stopped when the interviewer felt that new interviewees did not provide additional information – the so-called “saturation point” was achieved. There were certain themes to be sorted out in the interviews, but there was also the desire to be open to any new issues that might appear during the discussion. Thus semi-structured interviews were chosen as the research method. All of the interviews
were recorded and transcribed so that no information would be lost. The purpose of the analysis was to reveal the entire spectrum of the interviewees' opinions. The interviewer was experienced in the topic covered, which is usually considered a strength (Ruusuvuori and Tiittula 2005)

6.3.2 OCCUPATIONAL HEALTH AND THE CHALLENGE OF INDOOR AIR PROBLEMS

The OH personnel themselves saw their role as focusing on the examination of symptomatic patients and the assessment of the health risk in the work environment. For the other parties involved, the role of the OH personnel was not that clear. They seemed to have held a central role in bringing indoor air problems to the attention of management. Symptomatic workers at a workplace actively contact OH personnel. For an individual worker, it is often easier to talk to a familiar nurse or physician than to an unknown person responsible for maintenance, especially if the employee has met with dismissive attitudes on previous occasions. However, there are many indoor air problems that should be directly handled by technical staff. OH personnel should not stay in this role of mediator. The employer should actively take responsibility for the health and safety of the work facilities, also in regard to moisture-damage problems. In OH, the role of nurses was emphasised with respect to indoor air problems because of the lack of physicians and their outside role.

According to the interviewees, the forms of co-operation required further development. In particular, information on repair measures was not conveyed effectively enough. The existence of an indoor air group improved the transfer of information between the different parties.

Indoor air problems caused a considerable workload for the OH professionals because environmental complaints and symptoms were common and the nature of the problem was complicated.

Not many tools were available for investigating exposed employees; at the group level there was the Indoor Air Questionnaire, and at individual level, a PEF follow-up could be used when asthma was suspected. The PEF follow-up at the workplaces seemed to be essential in studying work-related asthma, according to the interviewees. However, only half of the workers that had been sent to the FIOH for follow-up had had their PEF examinations performed properly (Sauni et al. 2009).

The national Indoor Air Questionnaire provided by FIOH (Reijula and Sundman-Digert 2004) was a familiar tool to everyone, but it was not employed in the best possible way. The use of the questionnaire as an OH tool should thus be incorporated into ordinary hospital OH activities.

Most of the OH units had abandoned the use of microbe-related IgG antibodies because interpreting the results was problematic (Jaakkola et al. 2002a; Taskinen
et al. 2002; Hyvärinen et al. 2003). It has been requested that a better tool be developed for evaluating exposure.

IAQ should be systematically monitored in hospitals so that possible problems can be detected at an early stage. OH personnel should consider indoor air problems in their annual action plan.

The OH personnel usually regarded indoor air problems as difficult for many reasons. Employees expected a fast solution, but, in practice, repairs almost always had to be waited for. The problem did not always disappear with the first renovation either. Other parties are responsible for the repairs, but the employees’ concern regarding their own health becomes the OH personnel’s responsibility.

The assessment of a health risk was considered difficult in a situation involving a moisture and mould problem, especially in situations in which the closing down of the workplace had to be considered. Hospitals have a general shortage of space, and it is difficult to find temporary facilities, especially for a longer period of time. Moving hospital functions from one location to another is difficult also because the departments are designed to be stationary. In these situations, it is not easy to find solutions that will satisfy all parties. Those who have been exposed to moulds from moisture damage may remain sensitive towards impurities in the indoor air environment (Patovirta et al. 2004). For such a person, it can be extremely difficult to find a suitable workplace. It was often difficult to prove a direct and undisputable connection between the indoor-air-related disease of the employee and the work environment. Occupational diseases from moisture damage are only a part of the symptoms and diseases related to the indoor air environment. However, it is exactly these cases that are thoroughly charted. OH information systems should be developed so that all symptoms and diseases that are suspected of being work-related are easy to chart. Even without indoor air problems, hospital buildings are under constant repair due to the ageing of the buildings and functional changes of the hospital organisation. Currently, repairs are performed while wards are closed, but the staffs in adjacent wards may complain of indoor air symptoms to the OH personnel.

The interviewees did have some experience with success, but only in a few instances; this finding depicts the nature of the problem (Lahtinen et al. 2002). The issues in question are usually a cluster of problems, in which structural problems, such as moisture damage, are connected to poorly functioning ventilation, which in turn is connected to the perceived symptoms and the fear of getting sick. When different parties are working on their own without knowing what the other parties are doing, they may even convey contradicting information. A thorough investigation of the situation and effective co-operation between all parties were emphasised in the successful handling of larger problems.
7 CONCLUSIONS

1. Complaints and symptoms related to indoor air were commoner amongst the employees in Finnish hospitals than in Finnish office environments. The commonest complaints were dry and stuffy air, noise, draught, and unpleasant odours. Irritation of the nose, hands, and eyes, as well as fatigue, formed the commonest symptoms related to indoor air.

2. The Indoor Air Questionnaire seemed to function well also in hospital environments. Both moisture damage and ventilation deficiencies ended up being involved with increased complaints and symptoms in the questionnaire survey amongst the exposed employees. The need for repair explained stuffy air and unpleasant odours better, while the experience of draught and fatigue were typical in relation to poor ventilation. In general, the condition of ventilation systems had not been taken care of as well as the building structures had been. More attention should thus be paid to hospital ventilation. The Indoor Air Questionnaire profile of hospitals with no need of repair and good ventilation can be used as reference material in future indoor air questionnaire surveys of hospital environments.

3. Toxin-producing microbial growth in a water-damaged building may cause immune-suppression in nasal mucosa and lead to a decrease in neutrophil counts and TNF-α levels. The findings in NAL fluid can suggest immuno-activation or immuno-suppression in nasal mucosa. Further research is needed to ascertain which factors in the indoor air of moisture-damaged buildings affect the type of human immune responses.

   For research purposes, at the group level, NAL is a potential method for examining inflammatory responses in work-related mould exposure. In the clinical practice of OH, the NAL method cannot be applied before further research.

4. The character of indoor air problems emphasises the importance of multi-professional collaboration. An indoor air work group is a good forum for such collaboration, and it should be established in every hospital. The roles of the technical department and the OH unit need to be clarified. Hospitals should create an action model for solving indoor air problems. OH personnel need to consider indoor air problems in their annual action plan. The use of the Indoor Air Questionnaire should be established in every hospital as a proper tool for assessing indoor air-related symptoms before and after renovations. Knowledge of relevant risk communication needs to be improved.
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APPENDIX 1

Assessment of IAQ and resolution of IAQ problems in hospital buildings

Perceived IAQ - questionnaire surveys
Condition of building - walk through - material and dust samples if needed
Condition of ventilation - walk through - dust samples if needed
Discharges from hospital processes e.g. anaesthetic gases

Complaints & symptoms < hosp. ref. mat
Complaints & symptoms > hosp. ref. mat
No problems
Problems detected
No problems
Problems detected
Yes
No

Information - employee - OS - tech.

Indoor air group - representative of employer - OS (officer and delegate) - OH - tech - rep. of employees

Needed further investigations and measurements
Repair or repair plan and schedule
Renovation
Follow-up questionnaire

Concentration measurements

Info
Info
Info
Info

Complaints and symptoms > hosp. ref. mat

Ok

Info