Aalto-yliopisto
Insinööritieteiden
korkeakoulu

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Indoor air problems in hospitals and effectiveness of repairs

Master's thesis submitted for verification of professional development for the degree of Master of Science (Technology).

Espoo 23 November 2015
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Title of thesis Indoor air problems in hospitals and effectiveness of repairs

Degree programme Civil engineering

Major/minor Building materials and physics **Code** IA3017

Thesis supervisor Professor Heidi Salonen

Thesis advisor(s) Juha Rantasalo

Date 23 November 2015 **Number of pages** 67 **Language** Finnish

Abstract

Indoor air problems in hospitals are common and eliminating the problems often requires urgent repairs. The causes of health problems, costs of indoor air problems and effectiveness of repairs are not known well enough.

The aim of this study is to explore different approaches to indoor air problems in different hospitals. A further aim is to compare the effectiveness and costs of repairs related to indoor air. The aim is to find the most cost-effective methods.

The study includes an email questionnaire, which intended to collect information about the most severe indoor air problems and the effectiveness of repairs in Finland and in other European countries. In addition, two interviews were conducted to obtain more specific information about indoor air problems at Kuopio University Hospital and Helsinki University Hospital. The study also examined indoor air problems and repairs at Turku University Hospital in more depth.

Staff experienced more different types of symptoms in Finnish hospitals than abroad. In Finnish hospitals, 10–30 per cent of personnel were estimated to have experienced symptoms. In foreign hospitals, the rate was less than 1 per cent.

In Finnish hospitals, the most severe indoor air problem was VOC emissions from plastic flooring. Foreign hospitals had two different answers: microbes and other impurities, and the physical attributes of indoor air, such as temperature. In both cases, the problem was caused by inadequate ventilation systems.

It was impossible to precisely analyse the effectiveness of repairs with the collected data. Finnish hospitals had poor experiences with compartmentalisation repairs. Repairs for plastic flooring were considered effective. According to foreign hospitals, repairs targeting ventilation systems are effective.

The exact costs of problems related to indoor air quality were unknown in Finland and abroad. By separating the costs related to indoor air quality and analysing the effectiveness of repairs, the cost effectiveness of repair methods related to indoor air could be improved. Indoor air quality working groups are one method of improving practices and intervening in indoor air quality problems. Developing a system for indoor air working groups to analyse repairs and separating out the costs would improve the possibilities of solving indoor air problems cost-effectively.

Keywords Indoor air, hospital, repair

Tekijä Mikko Närvänen

Työn nimi Sairaaloiden sisäilmaongelmat ja korjaustoimien vaikuttavuus

Koulutusohjelma Rakenne- ja rakennustuotantotekniikka

Pää-/sivuaine Rakennusmateriaalit ja -fysiikka **Koodi** IA3017

Työn valvoja prof. Heidi Salonen

Työn ohjaaja(t) Juha Rantasalo

Päivämäärä 23.11.2015 **Sivumäärä** 67 **Kieli** Suomi

Tiivistelmä

Sairaalarakennusten sisäilmaongelmat ovat yleisiä ja ongelmien poistaminen vaatii usein kiireellisiä korjaustoimenpiteitä. Terveyshaittojen aiheuttajia, sisäilmaongelmista aiheutuvia kustannuksia ja korjaustoimien vaikuttavuutta ei kuitenkaan tunneta tarpeeksi hyvin.

Tutkimuksen tarkoituksena on tutkia eri sairaaloiden toimintatapoja ja yleisimpiä sisäilmaongelmien aiheuttajia. Lisäksi tarkoituksena on vertailla sisäilmaongelmista aiheutuneiden korjausten vaikuttavuutta ja kustannuksia. Tavoitteena on löytää parhaita toimintatavat ja kustannustehokkaimpia korjausmenetelmiä.

Tutkimuksessa toteutettiin sähköpostikysely, jossa kerättiin tietoa sairaaloiden vaikeimmista sisäilmaongelmista ja korjaustoimien vaikuttavuudesta Suomessa sekä muualla Euroopassa. Lisäksi tehtiin tarkentavat haastattelut Kuopion yliopistollisessa sairaalassa ja Helsingin yliopistollisessa keskussairaalassa. Tutkimuksessa tarkasteltiin Turun yliopistollisen keskussairaalan U-sairaassa havaittuja sisäilmaongelmia ja niihin liittyvien korjaustoimien vaikuttavuutta.

Suomalaisissa sairaaloissa oli esiintynyt kaikkia kysyttyjä oireita ja oireilijoiden määrän arvioitiin olevan 10-30% henkilökunnasta. Ulkomaalaisissa sairaaloissa puolestaan oireiden esiintyminen oli huomattavasti vähäisempää pääosin alle 1%.

Suomalaisissa sairaaloissa yleisimmin vaikeimmaksi koettu ongelma oli muovimattojen VOC-päästöt. Ulkomaisten sairaaloiden vastauksissa oli kahta tyyppiä. Toisissa keskiössä olivat mikrobit ja muut epäpuhtaudet ja toisissa ilman fyysiset ominaisuudet, kuten kuumuus. Suurimmaksi ongelmaksi molemmissa tapauksissa ilmoitettiin ilmanvaihdon riittämättömyys.

Korjausten vaikuttavuudesta ei tutkimuksen perusteella voitu tehdä vahvoja johtopäätöksiä. Suomessa kapseloinneista oli huonoja kokemuksia ja muovimattojen vaihtaminen koettiin hyväksi. Ulkomailla ilmanvaihtoon liittyvät korjaukset koettiin parhaiksi.

Kustannuksista ei ollut tarkkaa tietoa Suomessa eikä ulkomailla. Kustannusten seurannan kehittäminen ja korjausten vaikuttavuuden analyyttinen seuranta parantaisi tietoutta sisäilmaongelmien kustannustehokkaasta ratkaisusta. Sisäilmatyöryhmät ovat keino prosessien kehittämisessä ja ongelmiin puuttumisessa. Kustannusten ja vaikuttavuuden seurannan kehittäminen sisäilmatyöryhmissä parantaisi mahdollisuuksia ongelmien tehokkaaseen ratkaisemiseen.

Avainsanat Sisäilma, sairaala, korjaus

Foreword

This work was commissioned by the Association of Finnish Hospital Engineering (Suomen Sairaalatekniikan yhdistys ry, hereinafter referred to as AFHE), and I would like to thank them for their cooperation and for making my thesis possible.

My instructor was Juha Rantasalo, Director of Technology at Turku University Hospital and Chairman of AFHE. I would like to thank him for his good work as my instructor and the interesting choice of research topic.

My work was supervised by Professor Heidi Salonen. Thank you for the support and professionalism, which was invaluable in terms of completing this thesis.

I would like to thank the engineering students and graduate engineers of Pepan Petoni for making my student years incredibly fun and helping me to cope through the long days of studying.

Thanks to my family and friends, and especially to Marjo for the encouragement and for occasionally taking my mind off my thesis.

Espoo 23 November 2015

Mikko Närvänen

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Abbreviations

FID	Flame ionization detector
GC	Gas chromatography
HUCH	Helsinki University Central Hospital
Kys	Kuopio University Hospital
MMVF	Man-made vitreous fibres
MVOC	Microbial volatile organic compounds
Oys	Oulu University Hospital
PAS	Photoacoustic spectroscopy
PID	Photoionization detector
PPM	Parts per million
AFHE	Association of Finnish Hospital Engineering (Suomen Sairaalatekniikan yhdistys ry)
Tays	Tampere University Hospital
Tyks	Turku University Hospital
VALSAI	National Hospital Real Estate Development Project
VOC	Volatile organic compounds

1 Introduction

Indoor air quality problems are common in hospitals. There is no comprehensive overview of the problems or methods to investigate and rectify them. Good indoor air quality is very important for human health as, in developed countries, people spend over 90 per cent of their time indoors (Salonen et al. 2009). In hospitals, indoor air quality problems are even more critical because hospitals often accommodate immunocompromised patients.

The majority of Finland's hospitals are old and there is a major repair backlog: in 2005 this stood at EUR 400 million. Poor indoor air quality in the workplace reduces employee satisfaction and work efficiency. It also decreases productivity and may cause occupational diseases (Reijula 2005). Between 1996 and 2002, 108 professional diseases were reported as having been caused by indoor air quality problems in relation to hospital work (Reijula et al. 2012). The problem is therefore substantial from the perspectives of finance and public health.

In recent decades, this has been a topic of interest for researchers, organisations in the real estate and construction sectors, and ordinary citizens. Significant media attention has ensured that the topic has remained in the public eye from year to year. (Reijula et al. 2012)

The operating methods and repairs that will resolve problems related to indoor air quality are at the heart of solving the problems. Operating methods have been developed for workplaces by organisations such as the Finnish Institute of Occupational Health (Salonen et al. 2014). However, there is no precise information about how hospitals have adopted the operating methods. No comprehensive research has been conducted to evaluate the effectiveness of repairs to hospital buildings. As hospitals spend millions of euros rectifying indoor air quality problems every year, selecting the correct repair methods could potentially lead to considerable savings.

This work was commissioned by the Association of Finnish Hospital Engineering (AFHE) in collaboration with the European department of the International Federation of Hospital Engineering (IFHE). AFHE feels that the indoor air quality problems in hospi-

tals are so severe that further research should be conducted so that operations can be improved. There is also insufficient knowledge of the effectiveness of repairs related to indoor air quality problems in hospitals.

The purpose of this thesis is to identify the most common indoor air quality problems in hospital buildings, the effectiveness of corrective actions, and the costs caused by indoor air quality problems. The thesis also intends to study operating processes related to indoor air quality problems and to compare them between different hospitals. This thesis includes a European section that strives to identify good operating practices from outside of Finland and to compare the indoor air quality problems in Finnish hospitals with the problems in hospitals abroad.

2 Theory and description of prior knowledge

2.1 Meaning and definition of good indoor air quality

According to the Ministry of the Environment's definition (2013), good indoor air is odourless and contains no impurities that are hazardous to the health of users. Good indoor air quality is achieved by preventing harmful emissions and ensuring adequate ventilation. Not all harmful emissions can be prevented – examples include the impurities caused by human metabolism – so the ventilation system must remove these impurities. Class M1 products are recommended for construction and renovation (Ministry of the Environment 2013).

The Finnish indoor climate classification (2008) classifies indoor air into three groups: Classes S1, S2 and S3. "The quality of the indoor air in classes S1 and S2 is good and there are no disturbing odours on the premises. Premises and structures with indoor air have no damage or sources of impurities that could reduce the air quality. The temperature conditions are good. Draughts do not usually occur but overheating is possible on summer days. The premises have good sound and lighting conditions corresponding to their purpose of use." (Indoor climate classification 2008)

When referring to indoor air, the quality of the indoor climate and indoor environment are often also mentioned. The indoor climate is a broader concept than indoor air. "Indoor climate" refers to the internal climactic conditions within a building. The definition of indoor climate includes the indoor air, as well as the physical properties. They can be grouped as set out below (Finnish Society of Indoor Air Quality and Climate 2015).

The characteristics of indoor air include:

- Gaseous indoor air compounds
- Particulate impurities in indoor air

Physical properties of indoor air:

- Air movement
- Temperature
- Humidity

- Noise
- Lighting
- Radiation

2.2 Key impurities in indoor air

2.2.1 Microbes and their metabolic products

Microbes are part of the human habitat and they are always present in indoor air. In addition to the ordinary microbes in indoor air, microbes from outdoor air can pass into indoor air. Microbes in indoor air can affix themselves to structures, so there are almost always small quantities of microbes in structures.

Microbes require nutrients, moisture and a suitable temperature in order to grow. Buildings contain many different sources of nutrients for microbes. Even dust that has accumulated on surfaces may provide sufficient nutrition for microbes. In practice, indoor premises are always at a suitable temperature for microbes to grow. The most important factor for microbial growth is moisture. (Residential Health Guide 2008)

Moisture damage is considered to be a significant factor in mould damage. The humidity of indoor air does not directly affect microbial growth. Moisture damage can be caused by factors such as humidity condensing in structures, burst pipes, ground moisture passing into structures or defective structures. (Residential Health Guide 2008)

2.2.1.1 Fungi and bacteria

Penicillium is the most common genus of fungi in indoor environments, and it can produce toxins or be allergenic. More than 500 subspecies are recognised but they are difficult to identify. Small spores can float long distances and they easily detach in the mycelium. In the initial phases of moisture damage and during demolition work, they constitute the majority of respirable spores. (Putus 2014)

Aspergillus fungi occur everywhere in human habitats. They grow rapidly and certain substrates favour their growth at the expense of fungi that grow more slowly. The pres-

ence of the *Aspergillus* genus in indoor air points towards moisture damage. The *Aspergillus* family of fungi is used to indicate moisture damage. (Putus 2014)

More than 180 species of fungi from the *Chaetomium* genus are known to grow in the wild. *Aspergillus fumigatus* promotes the growth of *Chaetomium* by producing nutrients for it (Aru et al.1997). In buildings with moisture damage, it often grows in substrates containing cellulose. *Chaetomium* is on the list of indicators of moisture damage. It is usually detected in buildings with long-term and severe moisture damage. (Putus 2014)

Fusarium fungi are indicators of moisture damage in buildings. However, they are not very common in sites affected by moisture damage. If they are detected, the situation should be treated very seriously as their presence indicates advanced moisture damage. People are normally exposed to them while doing agricultural work because they grow within the culms of grains and hay. For this reason, they can occur in buildings that use natural materials such as straw, peat or recycled materials. (Putus 2014)

Stachybotrys chartarum is the best known genus of fungi and one that has been extensively studied. It appears in the form of dark patches on surfaces such as gypsum cardboard board or paper surfaces. It is an indicator of moisture damage. However, it does not occur in the early stages of damage, so when it is detected, it indicates advanced moisture damage. It appears in the form of a dark or black growth. It has a large, usually oval-shaped, spore covered in slime, which does not float through the air very well. It most commonly grows in gypsum materials. (Putus 2014)

2.2.1.2 Actinobacteria (ray fungus)

Actinobacteria, also known as ray fungus, are Gram-positive bacteria that form endospores and mycelia. In terms of the preconditions, properties and environment for their growth, they resemble microfungi in several ways (Putus 2014). The *Streptomyces* genus, which belongs to the Actinobacteria phylum, is often connected with moisture damage, and they have a typical odour of soil and underground cellars. Actinobacteria thrive in moist conditions and are considered an indicator of moisture damage. (Finnish Society of Indoor Air Quality and Climate 2015) Actinobacteria are able to grow in extreme conditions, such as acidic or alkaline conditions, heat and under enormous pres-

sure at the bottom of the ocean. Experiments have shown that Actinobacteria can grow in alkaline conditions of up to pH 10, meaning that they are able to grow in concrete and other materials. (Putus 2014)

2.2.1.3 Structural components of microbes

Poor indoor air conditions do not just expose building occupants to living bacteria – they also lead to exposure to the structural components and products of microbial metabolism, such as cell wall structures and DNA. These components are identified with the help of receptors. When the receptors are activated, they cause neurotransmitters related to inflammation to be secreted from the cell. (Reijula et al. 2012)

The cell wall structure of fungi contains chitin and beta-glucan, which have been found to have effects that alter the immune system and inflammatory response. (Reijula et al. 2012, Roeder et al.)

Lipopolysaccharide (LPS), also known as endotoxin, is the most extensively studied bacterial structural component that alters the immune system. It occurs in the cell walls of Gram-negative bacteria and it is known to activate inflammatory events. Gram-negative bacteria proliferate in waste water so if, for example, floor drains begin to flood, the bacteria may occur in indoor air. (Reijula et al. 2012)

Lipoprotein occurs in the structures of fungi, Gram-positive bacteria and even in Gram-negative bacteria. Lipoprotein causes TLR2 activation, which results in substantial secretion of inflammation neurotransmittors and has a major impact on the development and onset of inflammatory events. (Reijula et al. 2012)

The DNA of bacteria and fungi contains unmethylated CpG sites, which can be identified with the help of TLR9 receptors in cells belonging to the immune system. Activation causes the production of inflammatory cytokines, thereby assisting the onset and development of inflammatory events. (Reijula et al. 2012)

2.2.1.4 Products of microbial metabolism

Products of microbial metabolism are microbial toxins and gaseous microbial metabolic products (microbial volatile organic compounds, MVOC). Microbial toxins are structural parts of fungi, yeast and bacteria or their metabolic products, which have harmful, toxic effects on organisms. Microbes, fragments of microbes and other particles transport microbial toxins into indoor air. They do not normally occur in gaseous form in indoor air. Several commonly occurring microbes that indicate moisture damage can produce toxic substances, although they have only been identified in very low concentrations in the indoor air of damaged buildings. (Reijula et al. 2012, Taubel et al. 2011)

Mycotoxins are harmful metabolic products of microfungi. Microfungi include mould and yeast fungi. Mycotoxins occur in mouldy foodstuffs and building materials with mould damage. The formation of mycotoxins requires a favourable substrate and conditions. Mycotoxins are transported into indoor air by fungal spores and fungal mycelia from mouldy substrates. Exposure to mycotoxins can occur by inhaling dust or the building blocks of toxic fungi detached from contaminated building material. Exposure to mycotoxins may also occur via the skin or digestive tract (Putus 2014, Reijula et al. 2012, Tuomi 2008).

MVOCs are microbial organic compounds that easily evaporate. MVOC is problematic as a concept because compounds can be liberated from microbial flora but also from sources such as building materials, foodstuffs, cleaning agents and tobacco smoke. The presence of MVOCs is therefore not an indication of the existence of microbial flora in structures, and MVOC measurements are not recommended for use as a means of detecting moisture and mould damage. (Salonen et al. 2014)

According to the Finnish Institute of Occupational Health's measurement register, MVOC concentrations are generally very low – clearly below 1 µg/m^3 – even on sites with moisture damage. This can be compared with the total quantity of VOCs (TVOC), which averages 75–88 µg/m^3 in offices and < 10 µg/m^3 for individual compounds. (Salonen et al. 2014)

2.2.2 Indoor air particles and industrial mineral fibres

Indoor air particles can be divided into respirable particulate matter, small particles and total suspended particulates depending on the particle size (Salonen et al. 2009). Total suspended particulates (TSP) refers to all airborne particles. The majority of TSP mass is coarse dust. Respirable particulate matter (PM10) refers to particles with an aerodynamic diameter of less than 10 micrometres, and small particulate matter (PM2.5) refers to particles of less than 2.5 micrometres. (Residential Health Guide 2008)

The total suspended particulates in indoor air are a result of indoor human activity and particles transferred indoors from outside, such as dust. The large particles in indoor air settle on the floor or other surfaces. (Residential Health Guide 2008)

Respirable particulate matter and small particulate matter are emitted by combustion reactions, energy generation, industry and traffic, as well as street dust, all of which originate from outdoors. Particles in indoor areas originate from tobacco smoke, house dust from food preparation and other indoor sources. Particles also pass into indoor areas from outdoor air. (Residential Health Guide 2008)

Industrial mineral fibres (also known as man-made vitreous fibres (MMVF)) are glass fibres (glass wool and continuous filament glass fibres), rock and slag wool, and ceramic fibres. Glass and mineral wool fibres occur most commonly in indoor air and they are collectively known as mineral wool fibres. Mineral wool is used in buildings for heat and sound insulation. Fibres may detach into indoor air when the mineral is installed. However, the fibres do not remain in the air for long: they quickly settle on surfaces. Regular cleaning has a greater impact on the quantity of fibres than ventilation. (Reijula et al. 2012)
The presence of fibres indoors can be evaluated by analysing the dust that has accumulated on surfaces (Kovanen et al. 2006, Salonen 2009).

2.2.3 Volatile organic compounds and formaldehyde

Volatile organic compounds (VOCs) include aromatic hydrocarbons, aldehydes, halogenated compounds, esters and alcohols (Residential Health Guide 2008). The largest sources of VOCs are construction and decoration materials. However, they can also

enter indoor air from substances such as detergents and even microbial flora. Emissions due to building materials may originate from solvents, raw material residues or the reaction and degradation products of the manufacturing process (Organisation for Respiratory Health in Finland 2015).

Several different VOCs from indoor air have been analysed. They can be divided into four different groups based on their boiling points as shown in Table 1. The boiling point affects the compound's volatility. A higher boiling point slows down the evaporation of the compound, so compounds with lower boiling points evaporate from their materials more quickly. The removal of compounds from a building can be accelerated by raising the indoor temperature and boosting ventilation. (Residential Health Guide 2008)

Table 1. Grouping of VOCs. (Residential Health Guide 2008)

Abbreviation for the group	Group	Boiling point (°C)
VVOC	Very volatile organic compounds	> 0…50–100
VOC	Volatile organic compounds	50–100…240–260
SVOC	Semi-volatile organic compounds	240–260…380–400
POM	Particulate organic matter	> 380

The VOC emissions of several materials increase as their moisture increases or when they are heated (Organisation for Respiratory Health in Finland 2015, Residential Health Guide 2008). In dry conditions, several materials absorb impurities and act as "secondary sources" of impurities. There is little information available about the health risks of VOCs, particularly in small concentrations. (Residential Health Guide 2008)

The durations of VOC emissions from materials vary. Paints and varnishes cause short-term emissions. Longer-term sources may include low-quality PVC plastic floorings that liberate additives and auxiliary substances related to plasticisation. The concentration in indoor air is affected by the building's age, traffic, ventilation and nearby industry. Brand-new buildings have particularly high levels of VOC emissions, but these

usually normalise within six months. (Organisation for Respiratory Health in Finland 2015)

Almost all building materials liberate VOCs. However, the emissions from flawless materials decrease significantly over time. Approximately half of a building's VOC emissions are caused by building materials, while the other half is accounted for by the users' materials, such as furniture, textiles and detergents (Valvira 2011). Naturally, the proportions vary depending on the users' habits and the building's purpose of use. Table 2 shows the most common sources of VOCs.

Table 2. Most typical sources of VOC gas emissions (Salonen 2011)

Compound group Most common individual compounds	**Examples of possible emissions**
Aromatic hydrocarbons	
Toluene, xylenes and trimethylbenzenes	Paints, adhesives, exhaust fumes, solvents, wall coatings, polyurethanes, cleaning agents, computers and printers
Benzene	Smoking, synthetic fibres, paints, adhesives, exhaust fumes, solvents, cleaning agents, computers and printers
Ethylbenzene	Exhaust fumes, petrol, smoking, insulators, printers, computers, photo-copiers and linoleum
Alcohols	
1-Butanol	Solvents, cleaning agents, paints, adhesives, filler materials, plaster, cosmetics and fibreboards
2-Ethyl-1-hexanol	Plastic floorings, adhesives, printers and photocopiers
Phenol	Solvents, cleaning agents, paints, adhesives, filler materials, plaster, computers, smoking and PVC equipment
Aliphatic hydrocarbons	
Dodecane, nonane, pentadecane, tetradecane and undecane	Paints, adhesives, petrol, combustion sources, sealants, photocopiers, computers, linoleum and cosmetics
Hexadecane and tridecane	Paints, adhesives, petrol, combustion sources, sealants, photocopiers, linoleum, cosmetics and wood extracts
Octane	Adhesives, exhaust fumes, solvents, polyurethane, printed wood products, cleaning agents, photocopiers and linoleum
Aldehydes	
Nonanal, octanal and pentanal	Wood products, chipboard, wallpapers, floor polishes, fragrances, linole-um, moist mineral wool and computers
Benzaldehyde	Exhaust fumes, chipboard, fibreboard, dyes, fragrances, computers, photocopiers and linoleum
2-Furfural	Filler materials, concrete, paints, linoleum, PVC flooring, adhesives, fibreboards and mineral wool
Glycols and glycol ethers	
1,2-Propanediol	Water-based paints, PVC flooring, adhesives, cork, filler materials, waterproofing, plaster, waxes and detergents
1-Methoxy-2-propanol	Adhesives, water-based paints and varnishes, and plasticisers
2-(2-Butoxyethoxy)ethanol	Cleaning agents, detergents, paints, dyes, inks and putties
Terpenes (isoprenoids)	
3-Carene	Wood and wood-based materials, fragrances, paints, solvents and clean-ing agents
Limonene, alpha-pinene	Wood and wood-based materials, fragrances, paints, solvents, cleaning agents, cosmetics and computers
Silicon compounds	
Decamethylcyclopentasiloxane	Cosmetics, caulk, moisture insulation, dirt-repellent textile coatings and plaster
Organic acids	
Hexanoic acid	Linoleum, resins, solvent-based paints, wood extracts and chipboard
Acetic acid	Sealant masses, putties, linoleum and adhesives
Pentanoic acid	Linoleum, resins and wood extracts
Esters	
2-(2-Butoxyethoxy)ethyl acetate and n-butyl acetate	Plastics, fibres, paints, varnishes, adhesives, cosmetics and putties
TXIB	Plastic floorings, floor adhesives, plasticisers, wallpapers, paints and artificial leather products

Formaldehyde is a colourless gas with a pungent, stifling odour. (Finnish Institute of Occupational Health 2015) Formaldehyde is liberated into indoor air from urea-formaldehyde resin, which is usually used as an adhesive in products such as chipboard. Varnishes, paints, coatings and carpets may also contain formaldehyde. (Residential Health Guide 2008) The temperature of the indoor air also increases the concentration of formaldehyde (Virta 2001).

2.2.4 Other impurities in indoor air

Carbon dioxide is produced by the complete combustion of carbonaceous compounds. Carbon dioxide in indoor air is formed almost entirely by respiration and it can be considered an indicator of impurities originating from humans in the indoor air. A high concentration of carbon dioxide indicates ineffective ventilation. Excessive concentrations of carbon dioxide indoors make the indoor air feel stuffy and may cause headaches and fatigue. (Residential Health Guide 2008)

Carbon monoxide is produced by the incomplete combustion of carbonaceous compounds. Carbon monoxide concentrations should be monitored continuously using meters based on infrared radiation or electrochemical cells that can raise an alert when a reference value is surpassed. The Finnish Public Health Act defines a maximum carbon monoxide concentration of 6.9 ppm, which corresponds to 8 milligrams per cubic metre. (Residential Health Guide 2008) The formation of carbon monoxide is not a problem if the building does not have a fireplace or wood-burning oven. In detached houses, high concentrations of carbon monoxide may become a problem and could even be life-threatening.

The presence of styrene is often connected to the incomplete reaction of various components of polyester resin. Ordinary concentrations of styrene are not very high – only approximately µg$/m^3$. Styrene has a distinctive, pungent odour that can be detected at concentrations of over 75 µg$/m^3$. At higher concentrations (over 500 µg$/m^3$), styrene can cause symptoms of irritation and disrupt the function of the nervous system. (Residential Health Guide 2008)

Ammonia is an inorganic gaseous compound. Moisture in structures contributes to the formation of ammonia via the hydrolysis of proteins (Virta 2001). Ammonia is liberated from paints, varnishes, construction materials, cleaning agents and animals. Ammonia has an easily identifiable, pungent odour but there is considerable variation in the threshold for detecting the smell – between 100 µg$/m^3$ and 37,000 µg$/m^3$ (Virta 2001).

Ammonia causes irritation of the eyes and mucous membranes. (Finnish Society of Indoor Air Quality and Climate 2015)

2.3 Health effects of impurities in indoor air

Studies have shown that moisture damage to buildings gives rise to several different health hazards but the mechanisms by which harm arises are not yet fully known. Odours and symptoms may reveal poor indoor air quality. (Ministry of the Environment 2013)

Section 1 of the Public Health Act defines a health hazard as conditions that cause disease or symptoms of disease. The definition also includes exposure to substances or conditions that are hazardous to health in such a way that the occurrence of a disease or symptoms is possible. Such situations include premises where people may be exposed to cells originating from microbial flora or the metabolic products thereof. According to present understanding, health hazards do not usually arise if the conditions correspond to the guidelines. (Residential Health Guide 2008) However, a lack of reference values and comprehensive research data lead to incomplete guidelines, so there may be problems in indoor air even if no identified values are surpassed.

2.3.1 Microbes and their metabolic products

Indoor air always contains small quantities of microbes. These ordinary microbes in indoor air do not cause any health hazards. However, harmful microbes form in damp structures, which then release microbes into the indoor air and thereby into people's respiratory systems. (Residential Health Guide 2008)

The microbial flora of a building refers to the growth of fungi, yeast or bacteria on surfaces or in structures such that it can be observed with the naked eye or verified with the help of microbiological analysis. Microbial flora in the home in areas such as indoor surfaces, thermal insulation, structures or areas where outdoor air passes inside can be considered health hazards as referred to in the Public Health Act. (Residential Health Guide 2008)

Species of fungi that may cause symptoms include certain *Aspergillus* and *Penicillium* species that are typically found in buildings with moisture damage. They are allergenic

and are capable of producing toxins. The most typical and most extensively studied fungi are *A. versicolor*, which produces toxins, and pathogenic *Aspergillus fumigatus*, which is known to readily cause symptoms in allergy-prone people (Reijula et al. 2012, Kurup et al. 2000, Greenberget 2002). In addition, *Aspergillus fumigatus* is known to cause severe diseases if the fungus is able to breed in an exposed person's lungs. (Reijula et al. 2012)

Penicillium concentrations have been shown to correlate with irritation and symptoms of asthma. Cases of allergies and asthma have been documented following exposure in working and residential environments. *Penicillium* can cause a direct infection in the organ system but this is rare and is usually associated with immunodeficiency. (Putus 2014)

Aspergillus fumigatus often causes immediate IgE-mediated hypersensitivity and allergic diseases. 23 per cent of patients referred for a study on occupational diseases due to exposure to moisture damage had mould allergies, and most of them were specifically allergic to *Aspergillus*. The study (Garret et al. 1998) shows that exposure to *Aspergillus* is a significant risk factor for asthma. Exposure to this fungus can cause a direct infection in the organ system if the fungus grows in areas such as the bronchus, sinus, bone or a wound from surgery (Rippon 1998). The most severe forms of *Aspergillus* infection may be fatal despite treatment. However, the identification of individual spores on mucous membranes is not grounds for an *Aspergillus* diagnosis: an invasive disease requires the identification of a mycelium or indication of flora in a tissue sample. Small-scale epidemics have occurred in Finland in hospitals with moisture damage. Some variants of *Aspergillus* produce alfatoxins, which can cause cancer, and tremorgens, which are neurotoxins that cause conditions such as tremors, muscle twitches and spasms. (Putus 2014)

Chaetomium is allergenic but any health hazards are most likely to be due to the effects of toxins. *Chaetomium* produces various toxins. The toxins may be carcinogenic or teratogenic (causing birth defects), and *Chaetomium* is also toxic to the lung tissue (Ammann 2005). Its toxins are highly heat-stable so they are difficult to remove from textiles and household items. According to guidelines issued by the Ministry of Social Af-

fairs and Health, moisture-damaged structures in which significant amounts of *Chaetomium* flora have been identified should be demolished. (Putus 2014)

Fungi in the *Fusarium* genus are allergenic and produce toxins. The fungi cause diseases such as asthma and may cause direct infections in areas such as the sinuses and skin. As they are rare, their presence in indoor air should be considered particularly serious. (Putus 2014)

Stachybotrys chartarum is allergenic and can produce several different toxins. Some of the toxins can cause damage to the liver, kidneys, nerves, skin and lungs. In the worst case, a large concentration of *Stachybotrys* spores in the air is associated with severe bleeding disorders; in the Cleveland case (Etzel et al. 1998, Dearborn et al. 2002), this caused the deaths of several neonatal infants. (Putus 2014)

The adverse health effects of Actinobacteria have been known since the 19th century. At that stage, they were known to cause infections – in this case, actinomycotic infections. Nowadays, they are known to cause pneumonitis, which is also known as allergic alveolitis. They are also known to cause vasculitis (inflammation of the blood vessels). Actinobacteria have a high potential for causing cell damage in comparison with many fungi, and the effect has been shown to increase with simultaneous exposure to mould fungi. Some microbes are able to cause such rapid cell necrosis in the lungs that there is no time for the formation of intermediate substances indicating inflammation. Actinobacteria have been observed to possess different properties depending on the substrate. For example, certain types of chipboard have been shown to change Actinobacteria in such a way that the harmful response of their cells becomes stronger. (Putus 2014) Particularly strong responses were obtained from microbes growing on certain types of construction panel manufactured from recycled material (Murtoniemi et al. 2003 and 2005).

The adverse health effects of mycotoxins in indoor air are difficult to assess because microfungi that have the potential to produce toxins are not always toxic – the toxicity depends on the growth conditions, temperature, other microbes and the substrate. The same microbe may be toxic in the laboratory but not necessarily in a building. (Putus 2014)

Mycotoxins are classified in several different ways, none of which is comprehensive or clear. Different microbes can produce the same toxin, and one genus of microbes may produce several different toxins. One toxin may have several different mechanisms of action. The characteristics of the exposed person, such as age, nutrition, smoking, diseases and medication, can affect how a mycotoxin disease – mycotoxicosis – occurs. The severity and duration of exposure also affect which diseases will occur in the exposed person. A long delay between exposure and the onset of diseases such as cancer can make it more difficult to detect causal connections. (Putus 2014)

The significance of the MVOCs liberated from moisture-damaged buildings in terms of the occupants' symptoms have been evaluated by studies. The compounds have been shown to cause symptoms of irritation at high concentrations that are not usually present in the indoor environment (Reijula et al. 2012). Based on the studies, it can be stated that current knowledge shows it is unlikely that MVOCs – with the exception of formaldehyde – cause occupants to experience symptoms in indoor environmental conditions (Pasanen et al. 1998, Korpi 2001, Wolkoff and Nielsen 2001).

2.3.2 Volatile organic compounds and formaldehyde

There are hundreds of VOCs but their health effects are not precisely known. Even one individual compound may be harmful (Organisation for Respiratory Health in Finland 2015). The most common health problems include symptoms of irritation in the eyes and mucous membranes, and headaches. The unpleasant odours caused by VOCs can affect factors such as job satisfaction.

The symptoms caused by formaldehyde are irritation of the eyes and upper respiratory tract. Formaldehyde's odour detection threshold is approximately 35 $\mu g/m^3$ but the threshold at which it causes irritation varies from person to person. The most sensitive people experience irritation at concentrations of 5–10 $\mu g/m^3$. In addition to formaldehyde, other aldehydes may be present in indoor air, but their threshold for causing irritation is approximately 100 times higher. (Residential Health Guide 2008) When the formaldehyde concentration of inhaled air increases, headaches, nausea and fatigue may occur (Finnish Society of Indoor Air Quality and Climate 2015).

2.3.3 Indoor air particles and industrial mineral fibres

Organic compounds and mineral wool fibres mixed in with dust are particularly harmful to health. They mainly cause symptoms of irritation, which can be caused simply by skin contact. (Residential Health Guide 2008)

Small particulate matter (PM2.5) is presumed to be more harmful to health when it travels deeper into the respiratory tract. Small particulate matter from outdoor air has been shown to intensify symptoms among children and asthmatics, and even to increase mortality from respiratory and heart diseases. (Residential Health Guide 2008)

Industrial mineral wool fibres cause building occupants to experience symptoms of irritation to the eyes and skin. Threshold values for fibres present in indoor air should not be used to evaluate risk because fibres that have settled on surfaces have been shown to be more significant causes of symptoms. However, mineral wool fibres have not been found to cause diseases or allergies (Organisation for Respiratory Health in Finland 2015).

2.4 Investigating an indoor air quality problem

2.4.1 Process for resolving indoor air quality problems

Indoor air quality problems in buildings are often complex and investigation requires cooperation between professionals in several fields. Problems are caused by factors such as moisture and mould damage, inadequate or defective ventilation (stuffy air and draughts), excessively hot or cold indoor air, material emissions, dry indoor air, dust and dirt (Salonen et al. 2014).

The quality of the indoor climate is affected by heating, ventilation and air conditioning equipment, building technology, the execution of construction work, the materials used, and the usage and maintenance of the building (RT 07-10946).

When investigating indoor environmental problems, the environment should be assessed as a whole when making the indoor climate and environment (ABC model)

(Lappalainen et al. 2009, Salonen et al. 2014, Finnish Institute of Occupational Health 2015). This includes the following:

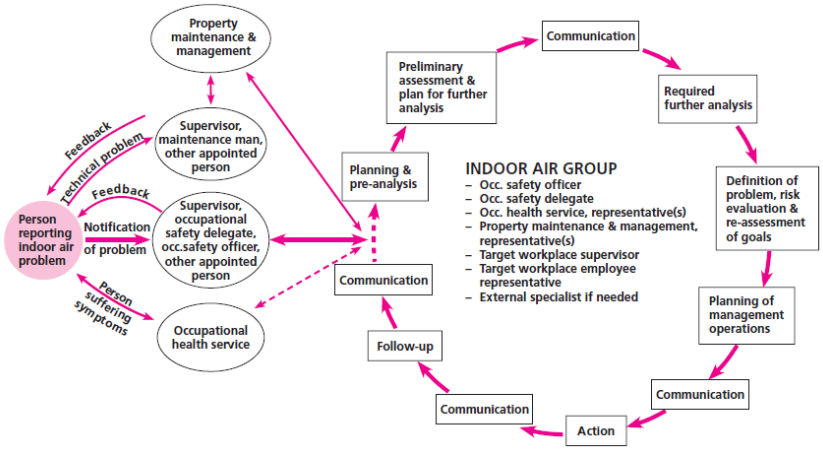
A) Technical factors relating to the building and services, and indoor climate conditions
B) The state of health and experiences of the occupants of the premises
C) Operating methods related to the indoor environment

In addition to investigating the building technology, reports from occupants should be taken into consideration, although occupants' assessments of the condition of the building are not as reliable as those of professionals. They are based on sensory assessments, but they may serve an illustrative purpose.

A working group at the Finnish Institute of Occupational Health (Lahtinen et al. 2008) has developed an operating model for resolving indoor air quality problems. The operating model is presented in Figure 1. The operating model for resolving indoor air quality problems is based on the actions of a multi-professional indoor air group. The operating model focuses on existing problems while also including preventive measures. Being prepared for problems makes it easier to solve them.
A representative of each group of users in the building is invited to join the indoor air group. The group usually includes representatives of the employer and the employees. In addition, the group should include labour protection and occupational health care representatives. If necessary, experts are invited to speak at meetings of the indoor air group. (Salonen et al. 2014)

Organisations that own several properties may have a permanent, centralised indoor air group that handles a coordinated response to indoor air quality problems. Additionally, a separate working group could be set up for separate problem sites if necessary. Experience has shown that the effectiveness of a working group increases significantly if the working group is permanent. The permanence of the group also improves its readiness to take preventive measures against indoor air quality problems. (Salonen et al. 2014)

Figure 1. Operating model for resolving indoor air quality problems (Lahtinen et al. 2008)



2.4.2 Condition survey of a building with moisture and mould damage

The aim of surveying the condition of a building with moisture and mould damage is to identify the causes of the moisture and mould damage. The survey should identify the causes and extent to a sufficient degree of certainty. Alternative methods for resolving the problem can be proposed on the basis of the survey and measurement results. The starting point for the condition survey is usually one of the following:

- A sudden, identified moisture stress such as a leaking pipe
- A known incident of moisture or mould damage
- The results of a microbial study
- A general suspicion, odour or symptoms
- A proactive investigation

(Environment Guide 1997)

Specifications are drafted in accordance with the applicable sections of the Residential Health Guide issued by the Ministry of Social Affairs and Health and the Ministry of the Environment's Environment Guide number 28, Condition survey of a building with moisture and mould damage.

When investigating moisture and mould damage, it is important to define the meaning of significant moisture and mould damage in terms of the occupants' health. According to Reijula et al (2012), major moisture and mould damage is a non-negligible structural flaw that makes it likely that occupants will be harmfully exposed to chemical, physical and biological impurities released from moisture-damaged structures, and that can be considered grounds for urgent repairs to reduce or eliminate exposure.

The use of mould-detecting sniffer dogs is based on the dog's strong sense of smell. With good training, dogs can smell specific moulds and wood-decay fungi in building materials. However, the Finnish Institute of Occupational Health does not recommend using dogs as the primary method for investigating mould damage. Dogs sometimes raise false alarms of the presence of mould. For example, they may smell odours from the soil. These do not necessarily indicate poor-quality materials but they can affect the quality of indoor air. Detections made by dogs always require additional investigation to clarify the condition of the structures. (Salonen et al. 2014)

2.4.3 Technical building surveys

Technical building surveys are conducted on specific structures based on the results of background studies. The background information may include mapping of risk structures, descriptions of structure types and sensory assessments. The physical functionality of the structures is investigated, along with their condition and effect on indoor air quality. Surveys enable a determination of the extent of damage and are used to identify the causes and damage mechanisms. It is also necessary to determine the air connection from the damaged structures to occupied premises. If necessary, structural openings can be made to enable an investigation of the technical functionality of structural layers in the event of moisture and to observe the visibly damaged areas. When openings are made, it is also possible to take moisture measurements and material samples, and to conduct microbiological examinations on these. By investigating whether structures are air-tight, it is possible to evaluate the effect of the structural damage on the quality of indoor air. (Salonen et al. 2014)

2.4.4 Studies of symptoms of occupants

Indoor air quality problems often arise when occupants suspect that their symptoms are due to poor indoor air quality or as the result of a doctor's suspicion based on the patient's medical history and clinical examination. The occupational health care service should investigate whether the workplace contains anything that could decrease the quality of indoor air and could be associated with the symptoms. A targeted workplace survey may be necessary. The occupational health care service is also responsible for evaluating the health implications of any harm that is identified. However, when doing this, the physician should have access to a technical building assessment provided by an expert in indoor air quality. If the report identifies mould and moisture damage in the workplace and the employee may have been exposed to it, there are grounds for demanding that the damage be rectified. However, it is not possible to know whether there is mould and moisture damage in the building or other indoor air quality problems based solely on the patient's description of symptoms. (Salonen et al. 2014)

Occupational disease studies are carried out if there is reason to suspect that something in the workplace is the primary factor in the disease. Accident and occupational disease legislation stipulates that, in the aforementioned cases, the disease is subject to compensation payable for occupational diseases. However, this requires a two-step causal relationship to be demonstrated. Firstly, it must be shown that the workplace contains a factor that can, on a general level, cause a disease. It must also be demonstrated that it was specifically this factor that caused the disease in the case in question. (Salonen et al. 2014)

2.4.4.1 Majvik II recommendation

The Majvik II recommendation is a joint declaration by indoor air quality experts on identifying, studying and treating patients suffering from conditions related to indoor air. Almost 40 experts have participated in creating it. According to the recommendation, moisture damage in buildings leads to microbe problems. Moisture-damage microbes represent the key exposure risk. Other exposure factors include ticks, mites, insulation wool fibres, chemicals, toxins, asbestos, inadequate ventilation, thermal conditions, draught, etc.

The Majvik II recommendations list matters that can indicate moisture damage, things that can indicate exposure to moisture-damage microbes, and useful questions that residents should ask when they suspect moisture damage. Table 3 shows the matters listed by Putus (2014).

Table 3. Guidelines of the Majvik II recommendations

Matters indicating moisture damage
• Visible damage: microbial flora, patches of moisture, swelling of the surface material, dark areas, detachment of coatings, large amounts of calcareous mildew
• Visible leaks from waterproofing (opened seams, unsealed ducts), detachment of floor coverings and serration of seams
• Stuffiness, abnormal odours, cellar-like or mouldy odour
• Condensation of moisture on windows or other surfaces
• Water meter turning when no water is being consumed, water needs to be added to the heating system
• People reporting symptoms that disappear or reduce in severity when elsewhere or that can otherwise be connected to the building
Matters that indicate exposure to moisture damage microbes
• Symptoms of irritation: nasal congestion, runny nose, persistent cough, coughing at night, throat irritation, shortness of breath, wheezing, eye symptoms, hoarseness, symptoms in the conjunctiva of the eyes
• Respiratory symptoms
• General symptoms: fatigue, headache, high temperature, fever, nausea, joint ache, muscle ache
Useful questions that residents should ask when they suspect moisture damage.
• Medical history of the symptoms and details of exposure: symptoms, general symptoms, recurring infections and the rate of recovery from such infections
• Previously diagnosed infections and atopy background
• Smoking, other exposures at work and at home
• When the symptoms began, time-based link to moisture damage
• Changes in the symptoms during holidays and trips
• Symptoms in other buildings with moisture damage
• Other people's symptoms in the same environment, in the workplace, etc.
• Do the symptoms get worse at work? Which day of the week are the symptoms at their worst? Changes in the severity and extent of symptoms over time

• Are the symptoms related to a specific work location, work phase?
• Do other co-workers complain of similar symptoms in the same work or work location?
• The patient's own understanding of the causes of the symptoms – a questionnaire is used for this purpose
• Impact on operating capacity, need for medication

2.4.4.2 Örebro symptom questionnaire

Indoor climate questionnaires are more precise than building occupant questionnaires. They aim to identify the indoor climate conditions and symptoms occurring in building occupants. The Örebro questionnaire is the most common symptom questionnaire. The questionnaire should be conducted with at least ten people and it should be done with all users of the premises or as a random sample. (Finnish Society of Indoor Air Quality and Climate 2015)

When interpreting the results of the Örebro questionnaire, take note if there is significant variation in the occupants' own impressions of the conditions. Even in ordinary work environments, 20–30 per cent of employees reported recurring harm due to the indoor climate. Almost 20 per cent reported weekly symptoms. For these reasons, a threshold of more than 20 per cent of respondents reporting symptoms has been adopted to define harm due to indoor air. However, for some symptoms, the threshold is too high. (Finnish Society of Indoor Air Quality and Climate 2015)

The Örebro questionnaire, also known as the MM-40 form, was developed solely for indoor air quality problems and it should not be used in contexts where production emissions are present. The MM-40 form consists of the following parts (Finnish Society of Indoor Air Quality and Climate 2015):

- Personal details
- Background information
- Harmful factors in the working environment
    - Draught
    - Temperature
    - Air quality
    - Other factors
- Work arrangements
- Prior diseases

- Symptoms associated with indoor air
  - General symptoms
  - Symptoms of the mucus membranes
  - Symptoms of the skin
- Further information

2.4.5 Measuring chemical impurities

Measurements of chemical impurities in indoor air are used to investigate the causes of health and odour problems, diseases or symptoms. Before measurement, material studies and odour observations should be used to clarify which compounds are present in the indoor air. In addition, the external and internal conditions of the room should be examined, including ventilation and the chemicals used.

Standardised methods should always be used to measure compounds whenever such methods exist. In other cases, methods that have proven to be reliable can be used. When the measurements are taken, the room should be under conditions that are as normal as possible to ensure that the values represent the situation when the room is in use. (Residential Health Guide 2008)

An air sample is collected from the centre of the room being studied at a height of approximately 1.1 metres. It is taken in a room that best represents the occurrence of the impurity being studied. Insofar as is possible, a reference sample should always be taken from corresponding premises. These may be premises that are in the same building and are used for the same purpose where the impurity is not known to occur. If it is suspected that outdoor air is passing into indoor air, a sample of the outdoor air should also be taken. The measurement times and collectors are specific to each compound. The pumps and measurement devices used must always be calibrated according to the manufacturer's instructions. Air flows are inspected with the help of a bubble calibrator, rotameter or dry gas meter. All of the conditions in the room at the time of measurement must be taken into consideration, as well as any sources of impurities that could affect the measurements. (Residential Health Guide 2008)

In the separation process, the air sample can be collected using an active or passive method. The active method can take from a few minutes to several hours, while the passive method can take from a few hours to several days. The most common collection

method uses Tenax TA adsorbent. It has a large collection area, it withstands moisture and the collected compounds can be transferred to a gas chromatograph (GC) (Saarela 1998). It should be noted that every adsorbent only reports results of TVOC concentrations in its own collection area. Often, there is a problem with small-molecule compounds remaining outside the collection area. In some cases, Tenax GR adsorbent or sensory assessment can be used to detect these. However, these methods are not suitable for all compounds. Unsuitable compounds include formaldehyde, acetaldehyde, acetic acid, amines, β-glucan, some aromatic hydrocarbons and many biocides. (Virta 2001)

VOCs should be determined using the ISO/DIS 16000-6 and ISO 16017-2:2003 standards. Direct-reading VOC meters have the problem of high detection thresholds. VOCs can be collected from the air using a short-term or long-term method. Long-term sampling can take up to several weeks. The sample is collected using the passive method. Resampling reduces the error caused by changes in conditions. (Residential Health Guide 2008)

Measurements of VOCs and sensory assessments of odours do not correlate with each other, so odour panels are recommended (Virta 2001). Gaseous emission rates can be increased temporarily by raising the temperature and boosting ventilation. Measurements are made when a specific compound or source is suspected to be harmful. Measurements often involve searching for indicator compounds whose presence is a sign of moisture damage.

When evaluating the quality of indoor air, it is not sufficient to determine the TVOC concentration because there are so many different VOCs and TVOC measurements do not provide data on the relative proportions of compounds or data on individual compounds. However, an elevated TVOC concentration (more than 600 $\mu g/m^3$) indicates an unusually large quantity of chemical substances, and further investigation is required. (Virta 2001) The National Building Code of Finland (RakMK-21503 2011) does not specify upper limits for TVOC concentrations. The Indoor Air Classification (2008) only provides a reference value for TVOC emissions from materials: in material class M1, these may not exceed 0.2 mg/m^2 h.

Measurements of VOCs are conducted using direct-reading instruments or a separation process. Direct-reading instruments include flame ionisation detectors (FID), photo-ionisation detectors (PID) and photo-acoustic detectors (PAS). The devices are easy to use and measurements can be taken over 24 hours. One drawback is that the devices only provide information on the TVOC concentration with a high detection threshold in the range 50–300 $\mu g/m^3$. Direct-reading instruments also only detect the worst problems. (Virta 2001)

Measurements of styrene concentrations are recommended when the air has a pungent odour typical of styrene. The styrene concentration study can be carried out using an activated carbon tube with a collected air sample of 100–200 litres. The sample is extracted into carbon disulphide and analysed using gas chromatography. A flame ionisation detector is used as the detector. The device does not function with concentrations below 0.5 micrograms per cubic metre. The styrene concentration can also be measured using Tenax adsorbent in connection with TVOC measurements. Styrene can also be measured using less accurate methods directly on-site but the health authorities do not accept results from these devices. (Residential Health Guide 2008)

The threshold for action when the total volatile organic compounds (TVOC) are calculated using the toluene response is 400 $\mu g/m^3$, and the threshold for action for each individual VOC is 50 $\mu g/m^3$. In addition, thresholds for action have been determined for a few compounds as shown in Table 4. (Residential Health Decree 2015)

Table 4. Thresholds for action for certain VOCs. (Residential Health Decree 2015)

Compound	**Threshold for action**
2,2,4-Trimethyl-1,3-pentanediol di-isobutyrate (TBIX)	10 $\mu g/m^3$
2-Ethyl-1-hexanol (2EH)	10 $\mu g/m^3$
Naphthalene	No odour is permitted, 10 $\mu g/m^3$
Styrene	40 $\mu g/m^3$

Formaldehyde measurement is carried out by liquid chromatography or using the chromotropic acid method. When using a passive collector, the collection time is 2–24 hours. The detector tube for formaldehyde measurements is an indicator that discolours in proportion to the formaldehyde concentration. (Virta 2001) The National Building Code of Finland (RakMK-21503 2011) and the Residential Health Decree (2015) specify a maximum reference value of 50 µg/m^3 for formaldehyde. In addition, the Residential Health Decree stipulates that the short-term (30-minute) average measurement of the formaldehyde concentration must not exceed 100 µg/m^3. In office buildings, a measurement of over 15 µg/m^3 is considered an elevated value that indicates abnormal sources of indoor air (Salonen 2009). The Indoor Air Classification (2008) only defines an emissions limit for class M1, set at 0.05 mg/m^2 h.

The concentration of ammonia in indoor air is measured using an ion-selective electrode or photometry. When a sample is taken, the air is bubbled into a sulphuric acid solution. Sampling takes eight hours and the air flow rate is approximately one litre per minute. The sample is delivered to a laboratory where it is analysed. (Virta 2001) The reference value for the concentration of ammonia in indoor air is 20 µg/m^3 (RakMK-21503 2011). The Indoor Air Classification (2008) sets an emissions limit of 0.03 mg/m^2 h for materials in class M1.

The concentration of carbon monoxide may be determined using an electrochemical cell or an infrared analyser. For carbon monoxide, the ventilation equipment and source of emissions are set up so as to give the maximum concentration. (Virta 2001) Direct detector tubes enable an accuracy of 25 per cent (Ruotsalainen et al. 1997). The maximum reference value for the carbon monoxide concentration as stated in the Building Code of Finland (RakMK-21503 2011) is 8 mg/m^3.

It is recommended that carbon dioxide concentrations be monitored for several hours or days using a continuously operating, registering devices based on methods such as absorption of infrared radiation (SFS5412) or an electrochemical cell (Residential Health Guide 2008). Before the measurement, people must be in the residence for a sufficiently

long time (hours) and the windows must be closed. In a room with an air replacement rate of 0.3 litres per hour, it can take up to 6 hours to balance out the concentrations. If the carbon dioxide concentration exceeds 1,500 ppm – even momentarily – it can be stated that the room has inadequate ventilation (Ruotsalainen et al. 1997). In industrial workplaces, the limit for carbon dioxide concentrations being considered a health hazard is 5,000 ppm (Ruotsalainen et al. 1997). With sufficient ventilation, the concentration should be less than 500 ppm (Virta 2001). According to the Indoor Air Classification, the limit for class S1 is 750 ppm. (Indoor Air Classification 2008)

2.4.6 Measuring particulates and industrial fibres

The quantity of particulate matter in indoor air can be measured in several different ways. Portable, easy-to-use equipment measures various properties of particles in a short time. An aerosol spectrometer can be used to measure the total distribution of particulate matter and the total number of particles can be measured with CPC apparatus. The mass size distribution can be studied using the impactor process (Pekkanen and Timonen 2001). Dust samples can also be examined using a scanning electron microscope to enable conclusions to be drawn on the basis of the original forms of particles. (Virta 2001) The average concentration of small particulate matter (PM2.5) in indoor air over 24 hours must not exceed 25 $\mu g/m^3$ (Residential Health Decree 2015).

The concentration of respirable particulate matter is measured in accordance with the EN 12341 standard. Cyclone is used as a pre-separator during collection, and the particles accumulate in a filter, which is selected according to the intended use. It usually takes 18–24 hours to collect a sample, and the air flow must be 4–20 litres per minute. The sample is weighed using a microbalance, and a static eliminator should be used to ensure accurate measurement results. (Residential Health Guide 2008) According to the Indoor Climate Classification (2008), the 24-hour average value of the concentration of respirable particulate matter (PM10) in indoor air must not exceed 50 $\mu g/m^3$ (Residential Health Decree 2015).

Total suspended particulates are estimated in accordance with SFS3860 (Using the filter method to measure the dust concentration in the air in a workplace). The samples are collected on a cellulose acetate filter, which is weighed before and after sampling. To

ensure that results are reliable, several cubic metres of air should be collected. (Residential Health Guide 2008)

The quantity of dust accumulating on surfaces can be measured by vacuuming up an area of a specified size and determining its mass. The sample can be used to determine the organic and inorganic material or mineral wool fibres. The mass of dust can be obtained by weighing the vacuumed material, and the mass can be used to calculate a quantity that measures the amount of dust. The quantity of mineral wool fibre is measured on the basis of measurements of deposits. During measurement, a collection container with a known surface area is placed in the area and covered with an adhesive material such as Vaseline. The sample is collected for 7 days, after which the quantity of fibres is calculated using an optical phase-contrast microscope. The result is expressed as a number of fibres per unit of surface area and time (generally fibres/cm^2). (Residential Health Guide 2008) The threshold for taking action in relation to industrial mineral wool fibres is 0.2 fibres/cm^3 (Residential Health Decree 2015)

2.4.7 Microbiological studies

Microbiological methods are used to identify and locate any unusual microbial flora. Microbiological methods require laboratory analysis and they can be used to directly indicate whether the examined structure is mouldy and whether there is a harmful amount of moisture in the structure. Microbial sampling and analysis must be based on the laboratory's own quality assurance system (Residential Health Guide 2009). Microbial samples do not need to be taken if moisture damage is evident. In this case, the rectification process should begin immediately (Environment Guide 1997).

Using culture methods, samples of mould fungi or bacteria can be collected from the air, surfaces or materials. The method enables the concentration and species to be determined. Bacterial cultures take from a few days to two weeks to develop, and fungal cultures develop in 7 days. The culture medium, growth conditions, activity of the microbial flora and the conditions when the sample was taken all affect the outcome of the culture. Using the culture method with dried flora provides uncertain results. (Virta 2001)

In the direct spore-counting method, the samples are viewed using a light microscope, scanning electron microscope or epifluorescence microscope. The method is usually used to examine Actinobacteria. The advantage of the method is that results are obtained rapidly and it can also be used for dried flora, although it cannot be used to distinguish living flora from dead flora. The use of the method when examining indoor air is limited by the lack of guidelines and standards and the poor availability of reference material (Pasanen 1999). The method's detection thresholds are high so it is challenging to use this method for indoor sites. In addition, the method requires considerable experience and professional expertise. (Virta 2001)

The recommended collector for impactor sampling is a 2- or 6-stage impactor. Other collection methods can be used providing that the volume of the air sample is known. The impactor samples pass through nozzles onto Petri dishes. As an example, when the Andersen 6-stage impactor is used, the volume flow rate is 28.3 l/min, the diameter of the plate is 9 cm and the volume is 25 ml. The sampling time is approximately 10 minutes and the sample is taken at a height of 1–1.5 m. After sampling, the plates and conditions are recorded in the log and the samples are delivered to the laboratory. Significant conditions include the weather, the number of people and animals, and the actions taken during measurement, which may affect the result. (Residential Health Guide 2008)

According to the Residential Health Decree (2015), the threshold for action is considered to have been surpassed in the event of irreparable moisture or rot damage involving the presence of microbial flora – confirmed by sensory assessment and analysis if necessary – on the building's indoor surfaces, internal structure or thermal insulation providing that the thermal insulation is not in contact with the ground or outdoor air.

Toxin measurements measure toxic compounds arising in the form of metabolic products and cell wall structures of fungi or bacteria, including mycotoxins and endo- and exotoxins (Virta 2001). Even in buildings with moisture damage, the toxin concentrations in indoor air are so low that direct measurement from indoor air is very labour-intensive and expensive. These concentrations can be estimated by theoretical means on the basis of the toxin concentrations in house dust and mould spores. Buildings with moisture damage are estimated to have concentrations of up to 10 ng/m^3. In office envi-

ronments with mechanical ventilation, the concentrations are generally below 0.1 ng/m^3 (Reijula et al. 2012).

Determining MVOC concentrations is highly problematic. A lack of standards and guidelines makes the method complicated to use (Pasanen 1999, 2001). A further problem is that the microbiological source of VOCs cannot always be confirmed because emissions from sources such as building materials contain the same compounds. With the exception of a few cases, it has not been possible to link the presence of MVOCs in indoor air to moisture and mould damage. (Salonen 2014)

2.5 Indoor air quality problems and the presence of impurities in a hospital environment

2.5.1 Most common indoor air quality problems in hospitals and causes of these

The majority of Finland's central hospitals were built between 1950 and 1980. The ventilation used at that time does not meet modern standards. In addition, errors in design, construction and use have led to major moisture damage in parts of the hospitals. This moisture damage is often also associated with a significant mould problem. (Reijula 2005)

According to Reijula (2005), the indoor air quality problems in hospitals are often caused by moisture and mould damage. In addition, the ventilation ducts in hospital buildings often release industrial mineral wool fibres that affect the quality of the indoor air. The need for repairs to hospitals can be classified into three categories:

- Class 1 – No repairs necessary
- Class 2 – Further investigation required
- Class 3 – Immediate repairs necessary

In Reijula's study (2005), the most common reasons for immediate repairs being necessary were problems in wet areas. Problems occurred in 80 per cent of the areas examined in the hospital. The problem was due to old-fashioned water insulation that used

glass fibre laminates. Other frequent reasons arising in the study were moisture damage to intermediate floors, base floor structures or outer walls. Damage to the outer walls was caused by factors such as insulation becoming wet from condensed moisture due to a lack of airing space. (Reijula 2005) Table 5 shows the problems necessitating immediate repairs as identified in Reijula's study (2005). The "Occurrence" section of Table 5 shows the letter corresponding to the hospital in which the observation was made. The letters A–J describe the hospitals that were studied, numbering 11 in total.

Table 5. Evaluation principles for determining a need for immediate repairs (class 3). Reijula (2005)

Evaluation principle	Occurrence
Moisture in the base floor	ABD
Contaminated material in the outer walls, wetness of the outer wall due to a lack of protection during repair work	CDFJ
Contaminated material in intermediate floors, moisture and mould damage to intermediate floors	DGH
Balcony waterproofing failed	ABD
Floor coatings damaged by moisture in structures	ABD
Lack of waterproofing in wash facilities with plasterboard structures, signs of moisture damage in wash facilities, lack of waterproofing in humid areas and/or cement mosaic tiles used for flooring	ACEFGHIJ
Cellar-like odour on the premises	G
Leaking roof	CDFJ
Water leaking in from windows	I
Waterproofing of the courtyard deck leaking	E
Drain leaking or similar problem	E
Technical systems (HVAC, electricity, automation) at the end of their life cycle	F

2.5.2 Indoor air quality in hospitals

The quality of indoor air is more critical in hospitals than other indoor environments; more microbiological factors are present in hospital environments than in other public buildings and patients are more susceptible to symptoms caused by indoor air than healthy people. Managing the indoor environments of hospitals is challenging because hospitals have a large number of different areas, each with its own hygiene requirements. For all hospital users, it is highly important that the ventilation systems produce fresh air and extract hazardous emissions. (Hellgren 2012)

According to a Finnish study (Reijula 2005), up to 15 per cent of the floor area of hospitals had an immediate need for repairs due to water damage. For patient wards, this proportion increased to up to 24 per cent. There was a total of 62,725 m^2. premises in need of immediate repairs. The majority of the premises – 63 per cent – were in good condition. Table 6 shows the repair requirements grouped by premises type.

Table 6. Repair requirements grouped by premises type (Reijula 2005).

Premises type	Floor area	No repairs necessary – class 1		Further investigation needed – class 2		Immediate repairs necessary – class 3	
	m^2	m^2	%	m^2	%	m^2	%
Wards	151,722	80,498	53	34,666	23	36,558	24
Laboratories	39,877	31,823	80	5,775	14	2,279	6
Reception rooms and X-ray rooms	137,520	90,699	66	38,061	28	8,760	6
Operating theatres	38,815	31,198	80	4,700	12	2,917	8
Offices	160,844	138,999	86	9,634	6	12,211	8
Total	416,841	261,280	63	92,836	22	62,725	15

The quality of the indoor air in hospital buildings is essentially dependent on the functioning of ventilation. Cleaning the ventilation systems in many hospitals, the materials used to insulate ducts are damaged and they release industrial fibres into the supply air. In addition, the pressure ratios are incorrect. External moisture stresses have been too much for some ventilation systems and this has caused users of the buildings to be exposed to microbes.

The ventilation systems used in hospitals have little or no ventilation technology that is specifically designed for hospitals. Hospital ventilation systems often require industrial-grade systems but they have been implemented using basic technology. Some of the hospitals built in the 1950s and 1960s have not been comprehensively renovated at any stage, which leads to obsolete technology that does not meet modern requirements. Old-

er systems built before 1975 do not have features such as heat recovery, so they use energy very inefficiently. (Reijula 2005)

Specifications are drafted in accordance with the applicable sections of the Residential Health Guide issued by the Ministry of Social Affairs and Health and the Ministry of the Environment's Environment Guide number 28, Condition survey of a building with moisture and mould damage.

2.6 Maintenance and repairs related to the quality of indoor air in hospital buildings

2.6.1 Ventilation equipment

Depending on the condition of hospital buildings, the functionality and maintenance of ventilation play an important role. Modernising ventilation systems by installing new technology would dramatically improve the quality of indoor air but is, unfortunately, very expensive. However, maintaining systems – even old systems – increases their reliability and improves air quality. The importance of preventive maintenance is highlighted in areas such as ensuring the functionality of fans. In the worst cases, a fan fault could shut down ventilation in an operating theatre or the pressure ratio in the theatre could be disrupted, enabling contaminants to find their way into the operating theatre. Problems have even arisen with new ventilation equipment – for example, with electric motors – so it is also important to maintain new equipment. (Reijula 2005)

Reijula's (2005) report highlighted the importance of the flow of information. "Inherited information" that had existed within the organisation for 20 years should be transferred to new employees. Unfortunately, maintenance and repair work often has to be assigned to external companies, with competitive tendering taking place every 1–2 years.

An electronic service log would be an advisable way of facilitating the supervision and documentation of the work. However, it should be possible to use the service log to specify which actions are taken, as well as the frequency and means by which they are carried out. Good examples include things that must be inspected and maintained, the

frequency of filter changes, air quality measurements, inspecting the functionality of fume hoods and cupboards, and checking the pressure ratios. (Reijula 2005)

Cleaning ventilation systems is a very important maintenance measure. There have been many severe deficiencies in this area, and it has not even been carried out in accordance with regulations in every hospital. According to a decree by the Ministry of the Interior (number 802), hospital ventilation systems should be cleaned every five years. However, the ducts are often difficult to clean. Design errors have made cleaning complex or even impossible. According to Reijula (2005), the most typical problems with cleaning are as follows:

- Bad cleaning hatches
- Insufficient number of hatches in channels and vertical ducts
- Inaccessible channels
- Lack of instructions
- 24-hour operation of the hospital
- Tight spaces on wards
- Dirty ceiling spaces

The filtration level for supply air has been increased in all hospitals. The filtration class of the filters usually corresponds to the level required for the premises. In some cases, it may even be unnecessarily good to the extent that it provides no actual benefit. The cleanliness of ducts, condition of supply air chambers and unfiltered, leaking air flows affect the required level of filtration. The quality and adequacy of filters is not a problem in existing hospitals. More problems are caused by insufficient cooling, leading to windows and doors being kept open and unfiltered, leaking air accessing other areas. (Reijula 2005)

2.6.2 Repairs to structures

Any structural repairs required should always be specified by an expert qualified in matters related to indoor air. Building technology studies are allocated on the basis of background information, such as descriptions of the structure type, sensory assessments and risk structure analysis. Studies are used to specify the scope and causes of problems.

Based on these, the repair methods considered necessary are presented to the indoor air group (Salonen et al. 2014).

The following are potential structural repairs related to indoor air quality:

- Repairing old traces of moisture damage
- Sealing and repairing drains
- Repairing damp areas
- Sealing the spaces between window and wall structures
- Repairs around windows
- Sealing expansion joints and ducts
- Removing mineral wools from suspended ceiling panels
- Eliminating areas where mineral wool is exposed
- Removing excess items and decorative objects
- Changing floor coverings
- Repairing damaged floor coverings

2.6.3 Special features of hospital repairs

The project to develop the national hospital property portfolio (VALSAI) has investigated the status of hospital properties. VALSAI released a report entitled “Developing the hospital repair process” (Koski 2008), which highlighted several problems associated with renovations. These include the following:

- The premises were designed for old operating processes and flexibility is poor Workplaces are cramped and lack ergonomics
- The development of medical science has changed the structure of hospitals, and hospitals have become modularised into entirely new parts.
- The design of Finnish hospitals has not striven for a modular approach or standard solutions.
- Insufficient attention has been paid to property maintenance and repair needs. An overall plan of the repairs does not exist and attention has only been paid to the details.
- The ability to connect cost implications with plans for the premises has been lacking. As a consequence, premises have been poorly designed, leading to higher operating costs.

When renovating hospitals, it is important to keep in mind that medical care will not be carried out in the same way in the future. This should be taken into consideration when designing hospitals in terms of matters such as the adaptability of premises. Renovating ageing hospital buildings is a demanding challenge for designers, builders and contractors. (Koski 2008)

The production planning of hospital renovations is demanding in comparison with residential buildings, particularly in terms of logistics. Perhaps the most important feature is that renovations must be carried out while the hospital is in operation. Although a ward may be emptied for the duration of major renovation work, the work will affect the surrounding areas – where patients are being treated – in many ways. The areas above and below must also be taken into account. Access routes and routes for transferring materials are logistical problems because they must not disrupt the operations of other wards in the hospital. Various types of outage in technical systems also require careful planning because water or power outages could impact wards for several months if the functionality of these systems is vital to the wards. (Koski 2008)

In terms of the functionality of the hospital, the flow of information plays a major role. Many people will be involved in the renovation work and it will affect a very large number of people belonging to different organisations. Information must flow as planned and it must be certain of reaching the relevant personnel to ensure that the efficiency of renovations is optimal and the minimum amount of disruption is caused to the hospital's activities. For this reason, it is advisable to agree upon communication practices and select contact people for the various parties involved. (Koski 2008)

The VALSAI project approached risk management for hospital renovations from two angles: safeguarding the foundations of the hospital's essential activities and minimising the disruption caused by the work. (Koski 2008) The matters considered in risk management are shown in Table 7.

Table 7. Matters considered in risk management (Koski 2008)

Foundations for essential activities	Minimising disruption
Electricity	Noise and vibration
Water	Dust
Heat	Asbestos
Ventilation	Microbes
Access routes	
Telephone and IT systems	
Drains	
Information security	
Security against crime	
Hospital gases and piping	
Building automation system	

A challenging aspect of hospital renovation is that hospitals' activities cannot be discontinued for the duration of the renovation – operational continuity must be assured while the renovation is underway. However, it is often impossible to carry out more extensive renovations while the hospital is operating, so the functions in question must be transferred elsewhere for the duration of the renovation. (Koski 2008)

3 Study material and methods

Material for the study was collected in two different ways: using emailed questionnaires and follow-up interviews, and using the study reports written on the case site, Tyks' Hospital U.

3.1 Emailed questionnaires

Emailed questionnaires were used with the aim of obtaining information about as many of the most common and most severe indoor air quality problems in hospitals as possible. The questionnaire analysed good, cost-effective repair methods and surveyed hospitals' investigation practices in relation to indoor air quality problems with the aim of identifying the best practices.

The questionnaire initially requests basic information about the building, such as its age, size and number of floors. It then asks what types of symptom employees have experienced, what types of study and repair have been conducted in relation to indoor air quality, and what the effects of the repairs were. Follow-up questions requested information about the price and quality of repairs and studies. In addition, respondents were asked how indoor air quality problems are managed and what costs had been incurred due to indoor air quality problems. The questionnaire also aimed to investigate the functionality of various air purifiers.

The indoor air quality questionnaire was prepared in Finnish and English versions, which differed only in minor considerations. The Finnish questionnaire (Appendix 1) was sent to ten different university or central hospitals. The English questionnaire (Appendix 2) was sent via IFHE-EU to more than ten European Union countries and responses were requested from at least three different hospitals in each country.

The research method is benchmarking. Based on the responses received, the study attempts to identify good operating practices and discover which operating models may have caused problems. Based on the responses, the study aims to build an understanding of the most common and most severe indoor air quality problems in hospitals in Finland and other European countries.

3.2 Interviews

Two follow-up interviews were conducted as part of this study in addition to the emailed questionnaires. The purpose of the interviews was to search for more detailed information about the most common indoor air quality problems that emerged in the emailed questionnaires, as well as the effectiveness of the repairs that had been carried out. A further aim was to study operating methods in matters related to hospitals' indoor air quality and the effectiveness of such methods in more depth.

The interview questions (Appendix 3) were used as a template for the interviews. In addition, further questions were posed about the topics that arose in the interviews.

The interviews were conducted in autumn 2015. The interviewees were Mikko Hollmén, the Real Estate Manager at Kuopio University Hospital, and Tapio Rautiainen, the Maintenance Manager at the Hospital District of Helsinki and Uusimaa.

3.3 Case study: Hospital U

The case study site was the maternity ward on floor 1 of Hospital U at Turku University Hospital. The site was analysed on the basis of study and planning reports provided by Tyks. The reports were commissioned by external parties. The reports fell into the following three categories:

- Occupational health survey
- Building condition surveys
- Contract programme

The reports are used as the basis for describing Tyks' activities in relation to indoor air quality problems and for analysing the effectiveness of the measures taken. The Hospital U case is an example of how indoor air quality problems have been studied and resolved in hospitals. The floor plan of the ward is shown in Appendix 4.

4 Research results and interpretation

4.1 Emailed questionnaires

4.1.1 Finnish hospitals

The emailed questionnaire was considered difficult and several hospitals did not respond or were only able to respond to some of the questions. Some of the responses were estimates, so they could not be used to make precise statistics. Five hospitals in different parts of Finland responded to the questionnaire. The hospitals are identified by the numbers 1–5.

Experiences were garnered from the properties stated by the central hospitals where indoor air quality problems had been identified. The responses concerned floor areas ranging from 8,000 to 120,000 square metres, numbers of floors ranging from 4 to 13, and age groups ranging from 30 to 64. The U-value of the hospitals was not known in the vast majority of cases. Mould or moisture damage had occurred on all five of the

sites with varying severity classes. Extraneous odours had been present in all of the hospitals – continuously in two of them and occasionally in three of them.

The occurrence of symptoms was consistent on all sites – all of the symptoms described in the questionnaire had occurred in all of the hospitals. Only hospital number 5 said that asthma, nasal symptoms and shortness of breath had not occurred.

In all five hospitals, sensory assessments had been carried out, air samples had been taken and structural openings had been made. Some of the hospitals stated only that extensive indoor air quality analysis had been conducted. Two of the hospitals were unable to say anything about the usefulness of the study, and there was no consensus among the other hospitals.

Repairs related to indoor air quality problems had been carried out in all five hospitals. All of the hospitals had removed or replaced plastic floor coverings and had repaired seals. Four hospitals stated that they had repaired or cleaned their ventilation systems. In addition, the responses included various individual repairs that not many hospitals were said to have conducted. The repairs were deemed to have helped either a little or a lot in terms of indoor air quality problems. None of the hospitals said that repairs had not helped to ease problems.

Separate air purifiers based on recirculation had been in use in four hospitals. In three of these hospitals, the benefit was considered to depend on the case and was variable. One hospital considered air purifiers to have caused more harm than good. Air purifiers that use ultraviolet light or hydrogen peroxide for the purpose of eliminating mould had been in use in only two of the hospitals. In one of the cases, the functionality was variable, while in the other case, the device was considered useless.

There were no consistent responses regarding the cost-effectiveness of repairs. All of the hospitals had differing opinions on the most effective repairs. Individual responses included changing the flooring, eliminating leaks and cold bridges, sealing, comprehensive structural renovation and thorough cleaning of ventilation ducts, sealing and removing old-fashioned wool-based noise-reducers. Hospital 4 suggested that compartmentalisation is a cheap and effective fix for the short term but not for the long term. It was also stated that each repair was specific to the case in point.

Three of the five hospitals were able to identify their largest indoor air quality problems. In all of these, the VOC emissions from plastic floorings were among the largest problems. Hospital 4 also stated that inadequate ventilation and broken pipes were problems. The intention was to rectify the problems by changing the flooring. Hospital 5 did not

specify this measure but stated that the indoor air quality group makes decisions on the necessary measures.

Based on the responses, management of indoor air quality problems had been carried out by an indoor air quality group in four hospitals. Two hospitals responded that inspections had been performed by using building occupants as indicators, and the emergence of symptoms represented grounds for taking action.

In the main, the respondents were unable to accurately answer questions designed to collect statistical data, and in some cases they could not answer at all. Some of the responses were entirely estimated because there had been no monitoring of the matter in question. As responses were only obtained from five hospitals, the responses would not have been statistically very significant. The need for repairs due to indoor air quality problems was estimated to be between 5 per cent and 100 per cent.

The proportion suffering symptoms caused by indoor air quality problems was estimated to be between 10 per cent and 30 per cent. The number of people suffering work-related diseases identified over the last year was estimated to be no more than a couple, although some respondents were not even able to estimate the number. Occupational health care providers were expected to have more information on statistics on symptoms and work-related diseases, and the respondents did not have access to these statistics.

Only hospital 1 knew the costs incurred due to indoor air quality problems: the annual costs were less than EUR 5 per square metre. The other four hospitals did not have a precise figure for the cost. These hospitals estimated their annual costs at between EUR 1 and EUR 25 per square metre. Hospitals 3 and 4 felt that the costs were difficult to distinguish from other costs and that they consist of several different aspects.

Finnish hospitals are clearly aware of indoor air quality problems. One reflection of this is the existence of indoor air quality working groups. Setting up an indoor air quality working group is a good way to resolve problems with indoor air quality, as it enables problems to be investigated thoroughly. Hospitals were also able to state which repairs had been the most cost-effective. A lack of statistics and monitoring proved problematic. If there is no accurate monitoring of the effects of repairs on people's symptoms and the costs of repairs, the cost-effectiveness cannot be analysed with any certainty. However, it can be challenging to monitor costs as repairs related to indoor air quality are often part of other repairs. In these cases, a procedure should be agreed upon to obtain the best possible estimate of the costs. One obvious problem was the flow of information or combination of information between the Finnish Institute of Occupational Health and the hospitals. Several hospitals stated that the Finnish Institute of Occupa-

tional Health keeps records of symptoms. Multi-professionalism is a good thing but the overview becomes less detailed if information does not flow and is not combined.

4.1.2 Foreign hospitals

The questionnaire was considered very difficult and it was difficult to obtain responses. In total, eight responses to the questionnaire were received, and in several of these cases, the respondents had not been able to answer all of the questions. For this reason, the questionnaire only has minor statistical significance. Responses were received from Belgium, Italy, France, Denmark and Switzerland.

In three hospitals, there had been no symptoms caused by indoor air, or there was no record of such symptoms. All of the other hospitals reported headaches and eye irritation. In addition, there were individual mentions of asthma, rashes, coughing and high temperature.

In terms of the largest problem related to indoor air quality, inadequate ventilation and the consequent high temperature received by far the most mentions. In addition, three hospitals listed mould as a severe problem and one mentioned formaldehyde. Other impurities in the indoor air or moisture damage were not listed as major problems. The intention was to resolve the problems almost exclusively by improving ventilation. The hospitals that had discovered impurities also intended to add filters.

With regard to measurements related to indoor air quality, there were two types of response. Some focused on the physical properties of the air, such as temperature, humidity, oxygen or carbon dioxide concentration and air flows. Only three of the hospitals said that they had taken microbial measurements. One hospital stated that it does not take any measurements in patient rooms or offices. There was no consensus on the value for money of measurements. One hospital used a building monitoring system (BMS), which records values for heat, humidity, carbon dioxide, noise and air volumes automatically every 10 minutes.

Almost all of the repairs that had been conducted were related to ventilation. In some of the ventilation renovations, the purpose was to add cooling, thereby enabling a more comfortable working environment. The remainder of the ventilation renovations aimed to control the movement of impurities. In these cases, the hospitals had added filters to reduce impurities. The renovations that involved adding filters were considered to have improved the air quality significantly, while the other cases had varying effects on the air quality. None of the respondents were able to say which repairs would have been the most effective. Several responses stressed the importance of planning. Investments

should be made in planning before the construction phase in new hospitals so as to ensure functionality and adequate ventilation.

The number of people experiencing symptoms was generally quite low, and there were cases where the respondent was unable to give a number. In one hospital, symptoms were experienced by 15–20 per cent of people, while other responses stated a figure below 1 per cent. The hospitals had no information to speak of in relation to work-related diseases. Only two hospitals were able to give an estimate of the number and two hospitals stated that they have no work-related diseases due to indoor air. The number of people falling ill each year was estimated to be no more than a few.

Compared with Finnish hospitals, the number of people suffering from indoor air quality problems was lower in other countries involved in the study. According to the answers obtained from Finland, the number of people experiencing symptoms was estimated to be at least 10 per cent, while hospitals in other countries reported a rate of less than 1 per cent. Either people do not suffer from indoor air quality problems as severely abroad, they are not known or the hospitals under comparison were in better condition than Finnish hospitals. The largest difference was in the understanding of indoor air problems. In foreign hospitals, the problem is often considered to be due solely to inadequate ventilation or high temperatures. In Finland, problems included mould and moisture damage, material emissions and other impurities. On the basis of the questionnaire, it is not possible to state whether foreign hospitals experience lower levels of impurities and mould in their indoor air or whether this is not considered a problem. In Finnish hospitals, heat was not mentioned as a problem – this may be due to the climate or the fact that it is not perceived as a problem.

4.2 Interviews

4.2.1 Kuopio University Hospital

At Kuopio University Hospital, a separate indoor air quality working group coordinates matters related to indoor air quality. The working group decides on studies and surveys to be carried out, and monitors the execution of these. The working group can also decide upon repairs, except in cases where an urgent response is needed – the property management unit takes action in these cases. It consists of representatives from several different professional groups. The group strives to keep the same members from year to year. The indoor air quality working group includes:

- The occupational safety manager (employer's representative)
- The labour protection representative (employees' representative)

- An occupational health physician and/or nurse
- 3 building technology professionals and 1 building services professional (property management representatives)

The largest indoor air quality problems are caused by VOCs and industrial mineral fibres. However, the harm caused by fibres had been brought under control proactively. Sweeping the ventilation ducts, changing and cleaning the filters, and selecting the right materials has helped to prevent problems caused by fibres. At the moment, the largest problem in Kuopio University Hospital is the liberation of VOCs from plastic floorings. Problems are also caused by old wet areas with plasterboard walls and no waterproofing.

20–30 studies and measurements related to indoor air quality have been carried out annually. Studies are always performed when problems are suspected. Technical sensory assessments of structures are carried out first, along with rapid measurements of factors such as dust. More precise measurements are then taken if necessary. In some cases, more studies should be conducted to enable problems to be located with more accuracy and avoid unnecessary repairs.

The indoor air quality group decides when to arrange questionnaires related to symptoms. The Örebro survey has only been conducted a couple of times. Other, smaller surveys have been done in greater numbers. The surveys are carried out by the occupational health care service, which is tasked with monitoring these in addition to the indoor air quality working group.

It is difficult to say which means of repair is most effective because repairs differ from one project to the next. Planning for repairs should always give careful consideration to how far under the surface existing structures can be removed and to what extent the repair is actually necessary. Sealant repairs are effective and prevent impurities from entering working premises. Sealant should be added in every direction – for example, to the floor and to the ceiling.

Compartmentalisation is among the bad repair solutions. This functions as a temporary correction, but it is often forgotten and the problem returns in a more severe form some time later. The fire-blocking masses used in renovations between fire compartments have also caused problems. They do not always remain airtight and impurities can pass through them.

The success of repairs is monitored passively. After repairs, the organisation waits to see whether anyone in the premises complains of poor indoor air quality. No separate confirmation questionnaires are carried out in relation to symptoms. Changes related to ventilation are measured retrospectively by means such as measuring air volumes. The temperature is also monitored after repairs if necessary. No studies are conducted to monitor VOCs, microbes or fibres after the repairs to verify the functionality of the repairs.

Air purifiers based on recirculation, UV light and hydrogen peroxide – designed for installation in the home – are in use. The functionality of these varies, and may depend on the model. The functionality of air purifiers is not verified using any measurements: they are assessed on the basis of experience. Air purifiers have been found to help with problems related to stuffy air, high temperatures and symptoms caused by VOCs.

Separate funding has been budgeted for repairs relating to indoor air quality. This does not include additional investments that must be made. Fairly minor indoor air quality problems may give rise to major investments because it is often worth renovating other things in conjunction with repairs related to indoor air quality. The recent trend has been for hospitals to increase in area and costs to decrease.

The indoor air quality working group communicates on matters related to indoor air quality problems and repairs. An information event is held before studies begin. The number of participants in such events depends on the scope of the problem. One downside to communication may be an increase in fear. Employees whose workplaces are located closest to the repair area but not actually within it may begin to question whether the indoor air in their room is safe.

The interviewee felt that their hospital has a director committed to handling indoor air quality matters well. As a consequence, funding is in place. It was felt that the attitude towards this matter is good, which improves the potential for handling indoor air problems.

4.2.2 Hospital District of Helsinki and Uusimaa

In the Hospital District of Helsinki and Uusimaa, matters related to indoor air quality are coordinated by indoor environment working groups, which are mainly property-specific. The working group's operating process begins with a kick-off meeting where the situation is assessed on the basis of the initial data and plans are drawn up for additional investigations. After this, the working group executes the plan. When the additional investigations are complete, the problem is defined, the risk is evaluated and the

objectives are specified in detail. The objectives are then used to prepare a repair plan. After this, the repair can begin. Everything is documented and every project is monitored until the problem is eliminated. Communications are a key focus throughout the operating process. The indoor environment working group consists of the following parties:

- The occupational health and safety manager
- The labour protection representative
- Occupational health care
- HUS Facilities Centre and HUS-Kiinteistöt Oy
- Indoor air experts
- A supervisor from the target location
- A representative of HUS Desiko
- An external expert if necessary

In addition, HUS has an indoor environment steering working group that manages the indoor environment working groups. This consists of the maintenance manager, the property manager, the managers of groups of departments and senior doctors. The steering working group monitors factors such as the costs of indoor air quality problems and the activities of the indoor environment working groups.

HUS has prepared clear operating guidelines for detecting indoor environmental problems. The guidelines are one A4 page long. The guidelines request the person who identifies a problem or his/her supervisor to report the problem to the 24-hour fault reporting service. A caretaker from HUS-Kiinteistöt inspects the problem and reports to the unit's supervisor on his/her visit and any actions taken. The supervisor informs the personnel and verifies whether the cleaning/tidiness guidelines have been complied with in the workplace. If the problem is not resolved, the unit's supervisor reports the problem to the technical building manager, who inspects the problem and submits an inspection form to the unit's supervisor. The supervisor is responsible for informing the labour protection manager and representative, as well as the director responsible for the issue. The occupational health care service visits the workplace if necessary and decides on how to proceed with the unit's supervisor. A report on the visit is prepared, including the occupational health care service's assessment of potential health hazards. If the problem is found to be extensive or complex, the case will be referred to the indoor environment working group for consideration.

The largest problems are caused by outer walls getting wet, pressure differences, broken drains, leaking roofs and old-fashioned construction methods that would nowadays be

considered construction defects. In the Meilahti area of Helsinki, problems are also caused by difficult soil conditions where it is difficult to channel rainwater.

The success of repairs has only been actively monitored for a few years, so no statistical data is yet available on the most effective repairs. However, the interviewee mentioned compartmentalisation as one repair for which no positive experiences could be recalled. Sealant repairs were also considered weak. Nowadays, every repair is discussed in monitoring meetings of the indoor environment working group. After repairs are completed, a symptom survey is conducted to track changes in symptoms.

There have been varying experiences with the use of separate air purifiers. The devices are based on filtration technology. Some devices have offered ozonation features but using these in hospitals was forbidden. No differences were noticed between the devices, regardless of the manufacturer. According to protocol, purifiers can be requested and an indoor air expert determines whether they are necessary. Units can also order purifiers independently – in this case, the unit is liable for the rental costs. Good experiences have been obtained with air purifiers in areas that have a major need for repairs and that are awaiting the commencement of repairs. In such cases, purifiers have helped occupants to "survive" until the repair. Purifiers have also been good on wards adjacent to areas where repairs are underway. In some cases, symptoms have clearly decreased when purifiers were used.

The costs incurred by HUS due to indoor environmental problems amount to several million euros annually. Studying and analysing the indoor air quality accounts for approximately EUR 200,000 of this, which is less than 10 per cent. The costs of using indoor air purifiers also run into hundreds of thousands of euros. HUS is responsible for approximately 950,000 square metres of premises, so indoor air costs amount to a few euros per square metre.

HUS has prepared guidelines for unit supervisors concerning communications on projects related to indoor air quality problems. When projects commence, awareness of the problem must be communicated, along with the fact that the required action is being taken, as well as the handling of the indoor environment group. During the investigation phase, up-to-date information must be communicated regarding which studies are being conducted and where they are being conducted. The unit's supervisor also holds an information event regarding the arrangement of the indoor climate survey. When an overview of the problem is known, the results of the studies are communicated, along with the health implications of the evaluation, the objectives of corrective measures, a preliminary timetable and any applicable substitute premises. Communications on repair plans should include at least the commencement, objectives and plans in broad terms.

During the repair process, the supervisor must ensure that up-to-date information is provided as regards the progress of the repairs. After this, a detailed monitoring and follow-up plan is communicated, as well as any applicable long-term monitoring.

4.3 Case study: Hospital U

4.3.1 Indoor air quality survey

An extensive indoor air quality survey was last conducted at Turku's Hospital U by the West Coast Institute of Occupational Health in April 2013. Responses were received from a total of 530 employees who had worked in the premises of Hospital U within the previous 3 months. An additional 124 responses were received from people who had responded to the previous survey, which was carried out in 2011, although they no longer worked at Hospital U. Hospital U is divided into three sections: A, B and C.

According to the occupational health survey, the responses concerning section A (206 responses) mentioned stuffy, dry air and inadequate ventilation, as well as a draught. One third of the respondents had experienced varying or excessively low temperatures, a mouldy or cellar-like odour and other unpleasant odours, and discernible dust or dirt. Half of the respondents experienced symptoms of irritation of the mucous membranes as work-related symptoms, while one third experienced fatigue, headaches and skin-related symptoms. On the basis of these matters, the Institute of Occupational Health concluded that there was a clear indoor climate problem, and deficiencies in ventilation and temperature regulation "come into question" as causes of the problem. The conclusions also mentioned that the mouldy or cellar-odour and the symptoms affecting mucous membranes indicated moisture-microbial damage, while the dry air combined with the mucous membrane symptoms could indicate mineral fibres or material emissions. The responses were itemised by floor within the building and the conclusion had been drawn that the results on floor 2 indicated moisture damage and that this was also possible on other floors.

Respondents in section B (185 responses) also experienced generally stuffy and dry air, as well as inadequate ventilation. Draughts, fluctuating or excessively low temperatures, a mouldy or cellar-like odour and other unpleasant odours, and discernible dust or dirt were also experienced more than in the reference material. The symptoms that were experienced more than in the reference material were irritation of the mucous membranes, fatigue, cough and skin-related symptoms. Approximately half of the respondents experienced symptoms related to the mucous membranes. The responses were analysed for each floor separately and they led the Institute of Occupational Health to conclude that the responses on floors 3 and 6 indicate moisture-microbe damage and that

respondents on floors 2, 5, 7, 9 and 12 did not report a cellar-like odour any more than normal.

In relation to the responses from section C (139 responses), the Institute of Occupational Health noted that the response profiles were similar to those in sections A and B, and that the results from floor 3 indicated moisture-microbe damage.

Following the survey, the occupational health care provider concluded that the results indicated moisture-microbe damage, most likely on floors 2, 3 and 6, but with possible damage on other floors. Hazards caused by mineral fibre and/or material emissions were possible in all parts of the hospital and on every floor. The recommendation was to pay close attention to the level of cleaning and the ability of premises to be cleaned. Special cleaning sites: behind machines and equipment. Inadequate ventilation and stuffy indoor air may explain the headaches and lack of concentration reported by occupants, but these do not pose a specific risk of disease.

4.3.2 Indoor air analysis 2013

An indoor air analysis was commissioned in Hospital U in January 2013 to be conducted in the maternity ward on floor 1. In conjunction with the analysis, the surface moisture was measured, along with moisture in floorings beneath incisions, smoke signal tests were conducted to identify the pressure ratios and microbial tests were conducted from structural openings. Surface moisture measurements were conducted using a probe moisture meter based on electrical conductivity and the result is for illustrative purposes only. The microbial cultures required for the material studies were commissioned from the University of Turku's Aerobiology Unit.

According to preliminary information received from occupants, the following symptoms had been experienced on the ward: eye-related symptoms, symptoms of the mucous membranes, throat-related symptoms, skin-related symptoms, headaches, dizziness, sinus pressure, cough, breathing difficulties, oxygen depletion, loss of voice and nosebleeds. Occupants had found the office, recovery room, anaesthesia storage room, caesarian section operating theatre 1 and delivery rooms 1, 3, 5, 8 and 9 to be particularly problematic. A cellar-like odour was detected in delivery rooms 3 and 9, the entrance to delivery room 3, washroom 1128 and hallway 1130.

Tracer tests showed that air was flowing into the room via the pipe shafts in the outer corners of the delivery rooms and the connections between outer walls and partition walls. Air leakage was observed in the lower and upper edges of the window frames and in the ducts for earthing cables. The observations were repeated in almost every room.

Based on structural openings made in other wards, air leakage was observed to occur at least partially via the insulation space of the outer wall. It was known that air leakages via the insulation space could transport impurities, such as microbes and mineral wool fibres. It was proposed that the pipe shafts, curtain boxes and suspended ceilings in every room be opened and made airtight. In conjunction with this opening, it would be possible to locate and repair any leaking pipes, as well as the damage caused by these. In addition, the other aforementioned air leakage sites should be sealed.

The studies carried out in delivery rooms 1–5 and 7–11 led to findings that indicated possible moisture damage in five of the rooms. Elevated moisture values identified using surface moisture metres were found in rooms 1, 2, 8 and 9 or in the walls and floors of the adjoining wet rooms.

The bathroom adjoining room 1 was found to have elevated moisture values in the lower part of the shower wall, in the floor in the shower cubicle, and in the corner backing onto the corridor. Elevated moisture values were also found in the back wall on the corridor side, where an incision measurement was also taken from under the plastic flooring. The incision measurement identified elevated moisture values and a microbial odour under the flooring. A control measurement was taken approximately one metre from the previous measurement. The control did not identify an elevated moisture content.

In office room 1107A, between rooms 1 and 2, detachment of the partition walls and plaster was found, indicating moisture. It was recommended that the ceiling panel structure and the plaster on the walls and ceiling be replaced, although the material sample that was taken did not contain microbial flora.

When room 2 was examined, elevated surface moisture values were found in the shower area in the vicinity of the shower, and the plastic flooring had become detached from its base on the floor and the skirting areas of the wall. Room 2 also has the largest washing space, and the tiles at the bottom of the wall were found to have come loose from their adhesive bases.

According to preliminary information, a cellar-like odour was detected in room 3 in the entrance and next to the outer wall. The same findings were made at the time of testing. Next to the entrance is auxiliary room 1128, which had been repaired approximately one year previously, according to the information received. The plastic flooring in the auxiliary room and connecting washing space (room 1129) had been replaced up to half-way up the skirting area. The plaster on the partition wall between the entrance and the auxiliary room was found to be detached at the lower edge of the wall and, in the same loca-

tion, the plastic flooring was found to be detached from its base. The surface moisture meter did not detect elevated values. A hole was made in the skirting area of the flooring and an incision was made at the point where it had become detached from its base. In both locations, a strong microbial odour was released from beneath the flooring and moisture measurements showed elevated moisture values. Material samples were taken from the plaster on the partition wall and from the plastic flooring and plaster on the floor. The samples taken from the plaster on the partition walls revealed substantial Actinomyces growth, as well as moderate amounts of fungi from the *Aspergillus* genus. Cultures made using the samples taken from the floor found only small amounts of growth indicating moisture damage, and they did not indicate active microbial flora.

Elevated surface moisture concentrations were found in the vicinities of the floor drains in rooms 8 and 9, and in room 9, plaster was found to have detached in some places from a concrete beam. Occupants had found room 9 to contain a cellar-like odour. The plastic flooring on the floor of auxiliary room 1133A, which is connected to rooms 7 and 8, had detached from its base near the shower drain but the surface moisture levels were not elevated. The moisture values for auxiliary room 1133B were elevated and the floor was observed to become wet despite the presence of a shower cubicle.

At the time of the study, delivery room 12 and its associated washroom, 1137B, were out of service for repair due to moisture damage. In the corridor outside the washroom, elevated surface moisture values were observed. An incision test was conducted on the plastic flooring, and moisture was also found under the flooring. Samples were taken from the damp area of the plastic flooring as well as from the plaster on the floor, and a culture test found no active microbial flora.

The former delivery room 6, which nowadays acts as a staff room, contains a floor drain that floods frequently, according to the information provided. At the time of the study, the moisture values for the floor, obtained using a surface meter, were not elevated. No significant room-specific observations were made in the other delivery rooms besides the findings that applied to every room.

The tap in the sink in kitchen 1159 did not have a watertight attachment to the sink. Moisture had entered the cupboard below the sink via the tap connection and visible fungal growth was observed on the internal surfaces of the cupboard. Air leakage was observed in the patients' kitchen (room 1164) but there were no other problems.

The plastic flooring in operating theatre 1 was electrically conductive, so no results could be obtained using a surface moisture meter. However, the skirting areas of the flooring had detached from their bases in several places. No observations were made in

operating theatre 2 to indicate moisture damage. No observations were made to indicate moisture damage in the recovery room, which had been considered a highly problematic area.

The washroom connected to patient room 1144 has been converted into a storage room and the floor drain in the room was dry at the time the study was conducted, so the room had a strong drain-like odour. The plastic flooring had also become detached from its base. Traces of moisture were observed in patient room 1151, and in the adjoining washroom (room 1158), the plastic flooring and the tiles on the lower edge of the wall had become detached from their base. The same had happened in patient room 1165 and its washroom, room 1168.

In the office (room 1175), the floor plaster and painted surface were peeling off near the sink. The same was observed in room 1178, behind the office. However, the moisture values of these areas were not elevated when measured using a surface moisture meter. The medication room (room 1169), which is connected to the office, had previously been a toilet. The drain, which had previously been in use, was now plugged. The plastic flooring was slightly detached from its base but the surface moisture values were not elevated. The sterilisation room (room 1184) next to the office contained a water pipe and drain that were no longer in use but that had not been properly plugged. Around the drain, the flooring seams were flawed and the water trap of the floor drain was empty.

Based on the aforementioned findings, the study report recommended the following additional investigations:

- Inspect all pipe casings and curtain boxes during the next renovation
- Investigate potential moisture damage to the partition walls and ceiling of office room 1107A between delivery rooms 1 and 2
- Measure moisture using drill-hole and incision measurements in the wet rooms (1112, 1106B, 1128, 1129, 1133A, 1133B, 1168)
- Measure moisture in the areas next to the floor drains in delivery rooms 8 and 9, and in the floor in delivery room 1, from which a material sample should also be taken
- Investigate the reason for the flooding of the floor drain in staff room 1120
- Open the suspended ceilings throughout the ward in conjunction with the next renovation
- Investigate the condition of the floor of medication room 1169 next to the office by means including material sampling
- Inspect the electrical switchboards and other technical facilities
- Inspect the stairwells

- Clarify the functionality of the ventilation system

In addition to these additional investigations, the report recommended the following short-term measures:

- Open, inspect and seal all of the curtain boxes and pipe shafts in the ward so they are airtight
- Seal other identified air leakages so they are airtight
- Renovate the wet rooms Remove the surfaces all the way down to the concrete surface and dry them if necessary Install new coverings in accordance with current guidelines (1112, 1106AB, 1117, 1128, 1129, 1133AB, 1158, 1168). In addition, a strip of at least one metre should be repaired around the rooms being renovated.
- Repair the moisture damage in room 1107A between delivery rooms 1 and 2
- Convert the washrooms into storage rooms
- Replace areas of plaster that are becoming detached (1175, 1178, 1160)
- Repair the broken tile in the sterilisation room and plug the drain
- Repair the boxes in front of the pipe shafts in the corridors
- Renew the paint and plaster that is peeling off in waiting room 1140

4.3.3 Analysing the routes by which impurities enter indoor air

In December 2014 and January 2015, an analysis was carried out of the routes by which impurities enter the indoor air in Hospital U. The analysis involved studying the movement of air flows using smoke signal tests, and the pressure ratios on the premises were investigated using differential pressure gauges. The temperature and relative humidity of the premises was measured for one week. Additionally, a mineral wool study was conducted to analyse dust that had settled on surfaces using gel tape experiments.

During the follow-up measurements, the temperature remained between 20.5 °C and 23.4 °C in the maternity ward on floor 1. The temperature of the outdoor air when the study was conducted was between -2 °C and +6 °C. The room temperatures of the premises were found to be appropriate in view of the building's intended use. The relative humidities measured inside the rooms were 21–34 RH per cent, which is normal for the season.

The tracer study revealed several sections in the outer wall that were not airtight. Leaks were identified in the connections between the outer wall and the floor, the connections between the outer wall and the windows, and around radiator brackets and electrical

channels. Tracer experiments carried out in pipe conduits revealed air connections between floors in some places. There was also considerable variation in pressure ratios. The change in pressure ratios from overpressure to underpressure was found to be a possible route by which impurities within structures could move indoors.

In delivery room 1, the radiator pipe ducts were not airtight. Leaks were also observed in a crack in the chimney structures on the premises. The leaks were identified using tracer experiments.

Delivery room 3 was out of use due to the occurrence of severe symptoms. The floor tiles were found to be detached from their base around the floor drain and also in some places next to the outer wall. The concrete partition wall between the room and the stairwell was insulated with plaster-covered cork insulation, on top of which is a wood-framed panel wall. The connection between the floor's skirting rise and the panel wall is open in the bottom part of the wall, and it was possible to observe loose pieces of filler or plaster through the gap. There is a similar wall structure in room 12.

Mineral wool experiments were conducted in delivery room 3 on the terminal device of the ventilation supply duct and in delivery room 4 on the dust that had settled on surfaces. The result of the experiment in delivery room 4 was less than 0.1 fibres/cm^2. The result does not indicate that mineral wool is responsible for symptoms in the area. In delivery room 3, the accumulation of mineral fibres in the supply air duct was 27.8 fibres/cm^2. An ordinary fibre accumulation in supply air ducts that are in use is 10–30 fibres/cm^2. This result is within the ordinary range but close to the upper limit.

A follow-up measurement of the pressure ratio in delivery room 1 was taken as part of the analysis. The room remained overpressured throughout almost the entire monitoring period. The report warned that major fluctuations in pressure ratios could pump impurities into rooms. In the case of delivery room 1, however, this does not seem likely.

4.3.4 Renovations in 2015

The project programme completed on 30 March 2015 includes changes to the delivery rooms. The intention is to renovate rooms 1, 2, 5, 7, 8, 9, 11 and 12 one at a time. Additionally, the washroom connected to rooms 7 and 8 will be overhauled. The project includes replacing the suspended ceilings, painting the walls, making the outer walls airtight, and ventilation and electrical work.

4.3.5 Analysis

Based on the reports, it can be stated that the replacement of the plastic flooring in auxiliary room 1128 and washroom 1129 was a failure. It is uncertain whether the concrete was still damp when the covering was applied or whether it became wet again. Before coverings are applied, moisture measurements should be taken and the point from which moisture has entered the structure should be identified to enable the transport of moisture to be prevented with appropriate corrective measures. Before coverings are applied, checks should be conducted to ensure that the concrete base is dry enough to receive the covering.

As regards room 12 and the associated washroom, 1137B, renovation had been initiated without sufficient investigation. In conjunction with the indoor air quality survey, moisture was also observed to have accessed the corridor. It would be a good idea to renovate the corridor at the same time as the other renovations to ensure that the problem is eliminated entirely. Before any repairs take place, confirmation of the extent of the problem must be obtained to ensure that no additional repairs are needed. Delivery room 12 was scheduled for renovation again in conjunction with the overhauls of the other rooms.

Only one of the microbial samples contained active microbial flora. The sample was taken from the wall of auxiliary room 1128 in delivery room 3. The other samples were taken from the corridor facing delivery room 12, which is scheduled for renovation, and from the partition wall in office 1107A next to delivery room 1. Other premises that were considered problematic and in which observations were made indicating moisture damage were the office and the surrounding rooms, operating theatre 1 and delivery rooms 8 and 9. It was not possible to conduct incision measurements in the floors of rooms 8 and 9 because the floors are tiled. It would have been possible to take measurements in operating theatre 1, the ward office and auxiliary room 1133AB but, for some reason, it was recommended that they be taken later. If material samples are being taken in any case, they should be taken on the first visit to provide a more comprehensive overview of the extent of the problem.

The result of the microbial samples appears to be relevant with regard to the actions taken. The sample from the partition wall of the office and delivery room 1 was negative, and one of the samples from the auxiliary room in delivery room 3 was positive. However, the structures of both rooms were on the short-term action list and they were scheduled to be overhauled, as were the other wet rooms in which no samples were taken. The cost-effectiveness of cultivating material samples can be questioned if they result in the same corrective measure in any case.

The cork panel structure in delivery rooms 3 and 12 has likely been a very bad solution. The most severe symptoms were experienced in these rooms and the first repairs were also targeted to these rooms. The renovation of delivery room 12 was already underway when the indoor air quality analysis was conducted in 2013. At this stage, the cork structure was not yet under suspicion. However, this was identified during the 2015 analysis and presumed to be one of the causes of the problem. There are no measurements or surveys of the renovation of the structure or subsequent symptoms experienced by occupants that could have been used to confirm that the structure was the cause of indoor air quality problems.

In 2015, slightly elevated deposits of mineral wool fibre were found in the ventilation duct in delivery room 3. No comparable measurements were taken on the ward in a room with fewer reported occurrences of symptoms. A fibre deposit test was carried out in delivery room 4 and the fibre quantities were found to be small. However, these cannot be compared with other measurements so it is not possible to assess the connection between mineral wool fibres and the onset of symptoms.

The surface moisture levels measured on and beneath plastic flooring were elevated in several rooms, and damage indicating moisture was observed in several places on the flooring. Microbial studies were carried out randomly but measurements of VOC emissions were not recommended. The 2013 report simply stated that damp plastic flooring could liberate VOCs but it was not deemed necessary to take action. A study of VOC emissions could have identified further explanations for the onset of symptoms. However, if the plastic flooring was due to be changed in any case, the VOC analysis would not have affected the renovation.

The airtight sealing of structures was found to be poor in almost every room, and air was able to flow into the intermediate space in the outer wall between the floors and rooms. Between 2013 and 2015, some of the problems had become less severe but not all of the problem sites with insufficient airtight sealing had been successfully repaired. There was no correlation between the level of sealing and the rooms where the worst symptoms were experienced.

The correlation of symptoms with the identified damage was imperfect. In each of the rooms that had caused the most symptoms, something was identified that could have caused an indoor air quality problem. The worst problems and active fungal growth were found in or nearby a room that was considered bad. However, observations indicating moisture damage were also made in rooms that were not considered particularly problematic.

5 Conclusions

The study revealed that the greatest single problem with the process for handling indoor air quality problems is monitoring. Monitoring should take account of both the effectiveness of repairs and the costs. The effectiveness of repairs could be monitored by taking measurements and conducting surveys of building occupants' symptoms after repairs are completed. If these active measures become too expensive, it is also possible to create statistics passively. If occupants stop complaining of symptoms after a repair – or if the number of complaints decreases substantially – the repair can be considered a success. Statistics can be created on successful repairs and the costs incurred in them to enable an analysis of the most functional and cost-effective repairs. Monitoring costs also provides a better overview of the financial scale of the problems and enables annual changes to be tracked.

Indoor air quality working groups are a good way of determining and monitoring indoor air quality problems. The mix of professions within the group makes it more qualified to act. The quality of monitoring and statistics can be improved by combining information more actively between different members of the working group. The data offered by different sub-areas should be continuously combined and statistics created to ensure that an overview of problems and the associated changes is known and readily available.

Clear operating models for resolving indoor air quality problems facilitate the identification of problems and accelerate resolution. The study revealed that HUS uses very clear and simple operating instructions for reporting observations of indoor air quality problems. Maintaining a clear approach is a good way of ensuring that problems are also brought to the attention of the indoor air quality working group. The indoor air quality working group should also have consistent operating instructions to ensure progress throughout the process of resolving problems. Communication between the indoor air quality working group and the personnel is important, as is communication between the indoor air quality working group and the parties involved in the repair process. As hospitals usually remain in use while repairs take place, communication must be efficient to ensure that the repair does not disrupt the hospital's activities or vice versa. Communication plays a key role in indoor air quality problems and it is important to establish a clear operating practice for communication between different parties in different phases of the process.

Increasing the extent of collaboration between hospitals and hospital districts when resolving indoor air quality problems would benefit all of the parties. Good practices

could be shared. A consistent operating model, monitoring and statistics would enable comparisons between different hospitals and would generate additional information for all parties regarding the effectiveness of repairs. This would also allow new repair methods to be compared with old ones, as well as enabling analysis of the functionality of stand-alone air purifiers or other corresponding devices. It would also not be necessary for each individual hospital to make the same mistakes – these could be avoided by learning from the experiences of other hospitals.

Increasing the number of comprehensive studies undertaken as part of the process to resolve indoor air quality problems would reduce the number of flawed or unnecessary repairs. Follow-up studies could clarify whether impurities have been eliminated from the indoor air in a particular location. If preliminary studies are used as the basis for making decisions on the necessity of repairs, it would be good to carry out a follow-up study to verify that the repair has eliminated the problem in question. Otherwise, it will not be certain whether the problem was the impurity that was originally measured or whether a different problem was eliminated by the repair. However, if the data obtained from preliminary studies leads to repairs being targeted in such a way that occupants' symptoms disappear, the repair can be considered successful from the perspective of symptoms. The effectiveness of repairs can therefore be verified based on the occurrence of symptoms or based on tests, depending on whether the aim was to eliminate symptoms or ensure that the indoor air does not contain impurities known to be hazardous. When indoor air quality problems are resolved, it should not be forgotten that measurements are only part of the resolution process and no single measurement result can be used as the basis for wide-reaching conclusions.

There was an identifiable difference in perspective between the study participants from Finland and some of the other countries. The presence of impurities in indoor air and the physical properties of air were considered the largest indoor air problem in different countries. The differences in perspective could be due to the climate, the condition of buildings or cultural differences. On the basis of this study, it can be concluded that inadequate ventilation and insufficient planning are considered the greatest problems. It can be stated that monitoring of indoor air quality problems and the related costs is also poor in foreign hospitals. This study does not enable a comprehensive comparison between different countries because the responses were based on the subjective views of a handful of people and on different monitoring methods. The optimal scenario would be for consistent monitoring and statistical methods to be used in the EU so as to enable a more extensive analysis of the effectiveness of repairs.

Foreign respondents mentioned some methods that are used for improving indoor air quality or related monitoring and that could be introduced in Finland: investing more in

the design of newly-built hospitals and the BMS system, which enables the physical properties of the indoor climate in hospitals to be monitored in real time.

Further studies should focus on evaluating the effectiveness of repairs on the basis of several measurements and more detailed surveys of symptoms, along with comparison of these data and an attempt to identify correlations. It would also be advisable to study the development of processes to resolve indoor air quality problems, as well as the management and monitoring of costs. In the same context, it would also be good to study how the costs of indoor air problems arise and how they should be itemised, as well as how they could be distinguished from other costs.

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7 List of appendices

Indoor Air Quality (IAQ) in Hospitals – Survey

This is a study commissioned by the Association of Finnish Hospital Engineering. The aim is to identify the most common causes of indoor air quality problems and the best methods for studying and rectifying these problems in Finland's university hospitals.

The study will be conducted as part of a master's thesis at Aalto University (Helsinki), department of civil engineering.

Questions 1–11 are open-ended questions that aim to obtain information about what action is taken to address indoor air quality problems in Finnish hospitals. A further aim is to identify the most severe and most common indoor air quality problems, as well as the best means of resolving them.

Questions 12–15 aim to collect statistics about the status of indoor air quality problems in Finnish hospitals.

I would be grateful if you could send your response to mikko.narvanen@aalto.fi by 18 September 2015.

Thank you for participating.

Sincerely,
Mikko Närvänen
Aalto University

Respondent:

RESPONSE FORM

Title:

Hospital:

Email:

Building characteristics (Choose a hospital building where you have had IAQ problems):

Building age____ Number of floors____ Gross area _____

Building frame material Concrete / Steel / Other: _____

U-value of the building:_____

Has there been mould or moisture damage? Major / Minor / None

Have there been any unpleasant odours? All the time / Sometimes / No

Has a blower door test been conducted? If yes, what was the result?_____

1. What IAQ-related symptoms have employees experienced?

   Fatigue Headache Cough Irritation of eyes Asthma

   Fever Rash Nasal congestion Shortness of breath Other

2. What IAQ measurements have been taken and what method was used?

3. Which measures provide the best value for money?

4. What IAQ-related repairs have been carried out?

5. Has there been an improvement after repairs? (In measured levels or in symptoms)

   Major / Minor / No change / Got worse

6. Have you procured room-specific air purifiers based on air circulation?

   no / yes: what are your experiences regarding how well these work?

7. Are any other room- or ward-specific devices in use in your hospital with the aim of purifying the air based on eliminating microbes or mould in indoor air using solutions such as hydrogen peroxide or UV light?

   no / yes, make and model_____. What are your experiences regarding how well these work?

8. Which were the most cost-effective repairs?

9. What are the most severe IAQ problems? What is causing them?

10. How are/were problems intended to be solved?

11. How do you control IAQ? What methods are used to monitor IAQ?

12. How much of the floor area is specified as requiring repairs because of IAQ problems? (Patient rooms and offices)

13. How many employees have IAQ-related symptoms? (Total and percentage)

14. How many employees have been diagnosed with work-related illnesses due to indoor air quality problems in the last year?

15. What are the estimated annual costs of IAQ problems per square metre?

Indoor Air Quality (IAQ) in Hospitals – Questionnaire

This is a study commissioned by the International Federation of Hospital Engineering Europe and the Association of Finnish Hospital Engineering. The purpose is to find out about the most common IAQ problems in hospitals in Europe and the best methods for measurements and repairs. The study will be conducted as part of a master's thesis at Aalto University (Helsinki), department of civil engineering.

Questions 1–9 are open-ended questions. Their purpose is to describe how IAQ is managed in hospitals, the focuses of measurements and repairs, and the effects on health in as much detail as possible to identify the most common problems and the problems that are most difficult to resolve. The aim is to identify common factors in countries in Europe, identify effective ways of controlling IAQ and finding the best solutions to IAQ-related problems.

Questions 10–15 are more exact questions that aim to collect statistics.

This study focuses on patient rooms and offices in buildings with fully mechanical air conditioning.

I would be grateful if you could send your response to mikko.narvanen@aalto.fi by 24 August.

Thank you for participating.

Sincerely,
Mikko Närvänen
Aalto University

Respondent:

RESPONSE FORM

Title:

Employer:

Country:

Email:

Building characteristics (choose a hospital building where you have had IAQ problems or define the total gross area that your response concerns. The building should be large and have fully mechanical air conditioning.):

Building age____ Number of floors____ Gross area _____

Building frame material Concrete / Steel / Other: _____

Is the building insulated? Y/N U-value of the building:_____

Has there been mould or moisture damage? Major / Minor / None

Have there been any unpleasant odours? (Abnormal odours) All the time / Sometimes / No

Has a blower door test been conducted? If yes, what was the result?

1. What IAQ-related symptoms have employees experienced? (Circle if the symptom occurs. Underline the most common one.)

   Fatigue Headache Cough Irritation of eyes Asthma

   Fever Rash Nasal congestion Shortness of breath Other

2. What IAQ measurements have been taken and what method was used?

3. Which measures provide the best value for money?

4. What IAQ-related repairs have been carried out?

5. Has there been an improvement after repairs? (In measured levels or in symptoms)

   Major / Minor / No change / Got worse

6. Which were the most cost-effective repairs?

7. What are the most severe IAQ problems? What is causing them?

8. How are/were problems intended to be solved?

9. How do you control IAQ in hospitals? What methods are used to monitor IAQ?

10. How much of the floor area is specified as requiring repairs because of IAQ problems? (Patient rooms and offices; Total and percentage)

11. How many employees have IAQ-related symptoms? (Total and percentage)

12. Are you aware that any employees have contracted occupational diseases because of IAQ? If yes, how many cases within a year?

13. What are the standards and guidelines for measured pollutant levels in hospitals in your country? (Particles, VOC, formaldehyde, MMVF, bacteria and fungi)

14. Are there any limits for levels of pollutants in legislation in your country?

15. What are the estimated annual costs of IAQ problems per square metre?

Interview questions

- How are indoor air quality issues coordinated/managed?
    - How has responsibility been allocated?
- What are the greatest problems related to indoor air quality?
- What types of research have been conducted and what results have been obtained?
- How often are symptom surveys carried out?
    - Who monitors these and how are they monitored?
- Were the completed repairs successful?
    - How was the success of the repairs monitored?
    - What has been the most effective repair method?
- Do you use air purifiers? (Air recirculation, UV, hydrogen peroxide)
    - What type?
    - How have they functioned?
    - How has the functionality been verified?
- What are the costs related to indoor air quality problems?
- How are indoor air quality issues communicated?
- Other