Perceived indoor environment and probability of abnormal indoor air exposure in health care workplaces

Katja Tähtinen
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A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Engineering. https://aalto.zoom.us/j/68069357832, Meeting ID: 680 6935 7832, on 7 of October 2020 at 12.

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Aalto University publication series
DOCTORAL DISSERTATIONS 125/2020

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ISBN 978-952-64-0006-8 (printed)
ISSN 1799-4934 (printed)
ISSN 1799-4942 (pdf)

Images: Katja Tähtinen

Unigrafia Oy
Helsinki 2020

Finland
Abstract

An abnormal indoor air (IA) exposure probability assessment is often needed to identify indoor environmental (IE) risks and their extent in office-type workplaces. The assessment and categorisation of the probability of abnormal IA exposure is used as part of a workplace’s health significance assessment. There is little research on this method or how its results are associated with employees’ IE-related complaints, symptoms, group-level health information, and perceived psychosocial work environment. The aim of this study was to assess the prevalence of IE-related symptoms, complaints, perceived psychosocial work environment; and the association between the probability of abnormal IA exposure categories and IE-related symptoms, complaints, perceived psychosocial work environment and group-level health information on employees in health care workplaces. The study provides new reference material to interpret IE questionnaire results at these workplaces.

Data I were collected from workplaces (office, school, health care) using the MM-40 based IE questionnaire and consisted of 28 826 employees’ responses. Data II–III comprised an assessment of the probability of abnormal IA exposure in 27 investigated hospital buildings, IE questionnaire responses of 2669 employees, and health information on employee health. Data were collected in 2011–2017. Health care employees more often reported IE-related symptoms and complaints than office or school employees. There was no statistical association between abnormal IA exposure and the employees’ perceived IE-related complaints, symptoms, health information and perceived psychosocial work environment. However, there was a link between employees’ perceived mould odour and detected mould damage. The results showed an association between ventilation deficiencies and perceived IE. When there are multiple sources of impurities in the IA and deficient ventilation in premises, many environmental factors may affect symptoms and complaints.

Therefore, it is important to thoroughly follow the building technology and IAQ investigation process to evaluate the factors that may influence the IE. Regardless of the probability of abnormal IA exposure category, employees’ experience of the IE may vary. There was no association between the probability categories of abnormal IA exposure and the occupational health services’ group-level health information. The IE questionnaire results only partly predicted the building-related problems and conversely, the probability of abnormal IA exposure was only partly associated with perceived IE. Organisational and individual factors may also influence perceived IE. Therefore, possible IE-problems should be evaluated multi-professionally. Most of the common IA impurity sources and their impact on IA can be identified, and the method of assessing the probability of abnormal IA exposure provides a holistic picture of the factors’ impact on IE.

Keywords indoor environment, exposure, indoor air, questionnaire, building technology, health care workplaces
This work was supported by grants from the Organisation for Respiratory Health in Finland and the Confederation of Finnish Construction Industries RT. The Finnish Society of Indoor Air Quality and Climate, The Finnish Environment Fund, and the Foundation for Aalto University Science and Technology also provided financial support for a conference visit abroad. The Finnish Institute of Occupational Health (FIOH) offered research material and support for this dissertation. I would like to express my gratitude to the funders for supporting this dissertation and my conference visit abroad, as well as FIOH for all its support.

Assistant Professor Heidi Salonen supervised my postgraduate studies and dissertation research. I am deeply grateful to her for her positive, cheerful and forward-looking support throughout my journey. I am also extremely grateful to my supervisor, co-author and colleague Sanna Lappalainen, PhD, for her proficiency, all our discussions, and for giving me the opportunity to work at FIOH. I also wish to thank Sanna for having confidence in me, and for her never-failing support. I also warmly thank my supervisor, co-author and colleague, Docent Kirsi Karvala, MD, PhD, for her wisdom, encouragement, gracious collaboration and analytical advice during this work. I am enormously grateful that you were all always there for me when I needed your support.

I wish to express my appreciation to the reviewers, Associate Professor Pawel Wargocki and Professor Ulla Haverinen-Shaughnessy, for their invaluable comments for improving my manuscript, as well as Alice Lehtinen, for her kind and high-quality revision of my English language.

I offer my sincere thanks to my co-authors and colleagues: Marjaana Lahtinen, PhD, for her support and our discussions; Kari Salmi, MSc, for his indispensable help; Jouko Remes, MSc, for his expert supervision; Professor Kari Reijula, MD, PhD, for his guidance; and Veli-Matti Pietarinen, MSc, for working on many excellent projects with me. My great team in FIOH provided me with knowledge and an inspiring scientific atmosphere in which to work. I thank all my current and former colleagues and teachers for their support and for bringing me such joy in my work over the years.

My warmest thanks go to my colleagues and dear friends Leena Aalto, Pia Sirola and Taina Kinnari for all their help, encouragement and discussions, and for being there for me during both the setbacks and the successes. I am lucky to have your friendship. My dear friends Heli, Sanna, Yessica and Sanna P. – thank you, for all our talks and laughs, for sharing all my ups and downs, and for
believing in me for all these years. I am eternally grateful to all my friends, who have brought me joy and showed me all the sides of life.

Finally, I owe my dearest thanks to my family, Pirjo and Pauli and my brother Jari; thank you for always being interested in my studies and dissertation work, which ended up taking almost five years. Thank you for the priceless, endless support you have always offered me.

Above all, I thank my loving husband Henrik for helping me with everything! When I lost faith in myself and my work you always believed in me, said all the right words, offered me positive solutions and love. You always make me smile. Thank you for being beside me! The light of my days and the loves of my life, Kajsa and Laura – everything would be meaningless without you, my lovely, precious children! Thank you for generating so much humour and happiness during this process.

Hämeenlinna, 7 October 2020
Katja Tähtinen
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List of Abbreviations and Symbols

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>E₁H</td>
<td>2-Ethyl-1-hexanol</td>
</tr>
<tr>
<td>FIOH</td>
<td>Finnish Institute of Occupational Health</td>
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<tr>
<td>IA</td>
<td>indoor air</td>
</tr>
<tr>
<td>IAQ</td>
<td>indoor air quality</td>
</tr>
<tr>
<td>IE</td>
<td>indoor environment</td>
</tr>
<tr>
<td>IOM</td>
<td>Institute of Medicine (US) Committee on Damp Indoor Spaces and Health</td>
</tr>
<tr>
<td>MMVF</td>
<td>man-made vitreous fibres</td>
</tr>
<tr>
<td>OHS</td>
<td>occupational health services</td>
</tr>
<tr>
<td>P</td>
<td>percentile</td>
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<tr>
<td>p</td>
<td>statistically significant level</td>
</tr>
<tr>
<td>Pa</td>
<td>pascal</td>
</tr>
<tr>
<td>PAH</td>
<td>polycyclic aromatic hydrocarbons</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity</td>
</tr>
<tr>
<td>TXIB</td>
<td>2,2,4-Trimethyl-1,3-pentanediol di-isobutyrate</td>
</tr>
<tr>
<td>TVOC</td>
<td>total volatile organic compounds</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compounds</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their numerals.


Author’s Contribution

**Publication 1:** Perceived Indoor Air Quality and Psychosocial Work Environment in Office, School and Health Care Environments in Finland

The author carried out the data preparation with Kari Salmi and Jouko Remes from the FIOH. The author was responsible for the conceptualisation, original draft preparation, methodology, visualisation, writing and editing of the paper and the management of the study. The author was also involved in the statistical analyses. Jouko Remes was responsible for the methodology, data preparation, and statistical and formal analyses. Kari Salmi was involved in the data curation, formal analyses and review, and commented the paper. Marjaana Lahtinen from FIOH participated in writing the paper, contributed to the conceptualisation, and participated in the scientific discussion and provided comments. Kirsi Karvala from FIOH and Kari Reijula from FIOH and the University of Helsinki contributed to the conceptualisation, participated in the scientific discussion and provided comments.

**Publication 2:** Association between Four-level Categorisation of Indoor Exposure and Perceived Indoor Air Quality

The author managed and carried out the building and indoor air investigations and collected the other information and data used in this research with Veli-Matti Pietarinen from FIOH. The author was responsible for the collection and preparation of the data, the conceptualisation, original draft preparation, methodology, visualisation, writing and editing of the paper, the statistical analyses, and managing the study. Jouko Remes from FIOH supervised and contributed to the methodology, data preparation and the statistical and formal analyses. Kirsi Karvala and Sanna Lappalainen from FIOH, and Heidi Salonen from Aalto University supervised and contributed to the conceptualisation and scientific discussion, provided comments and participated in writing the paper.

**Publication 3:** Probability of Abnormal Indoor Air Exposure Categories Compared with Occupants’ Symptoms, Health Information, and Psychosocial Work Environment

The author managed and carried out the building and indoor air investigations and collected the other information and data used in this research with Veli-Matti Pietarinen from FIOH. The author was responsible for the collection and preparation of the data, the conceptualisation, original draft preparation, methodology, visualisation, writing and editing of the paper, statistical
analyses, and managing the study. Jouko Remes from FIOH supervised and contributed to the methodology and data preparation, and conducted the statistical and formal analyses. Kirsi Karvala and Sanna Lappalainen from FIOH and Heidi Salonen from Aalto University supervised, contributed to the conceptualisation and scientific discussion and provided comments, and participated in writing the paper.
1. Introduction

1.1 Background of the study

The good indoor environment (IE) has a significant impact on a person’s well-being. A good, high-quality IE supports and promotes the work-related well-being of employees. According to reviews by Ghaffarianhoseini and colleagues (2018) and Dovjak and Kukec (2019), IE-related problems have been reported for decades and are internationally quite common in non-industrial workplaces. When IE-related issues exist, employees may perceive non-specific symptoms and complaints related to their workplace and building. When IE-related issues are prolonged or cannot be solved, they may evolve into IE-related problems. IE-related problems commonly influence many employees at workplaces as well as those striving to solve the problem.

At workplaces, employees’ perceived IE is influenced by the physical environment (physical, chemical and biological factors) (SCHER, 2007), the psychosocial environment (job strain, organisational factors e.g.) (Lahtinen et al., 1998; Bakke et al., 2007; Finell et al., 2017; Carrer & Wolkoff, 2018) and individual factors (gender, age, illnesses, personal tendency to develop allergies and allergy history) (Jaakkola, 1998; Kim et al., 2013; Magnavita, 2015; Ghaffarianhoseini et al., 2018).

Employees working in buildings with IE-related problems may perceive symptoms due to the indoor air quality (IAQ), temperature, acoustics, noise and lightning. IE can be influenced by thermal factors such as temperature and humidity (Seppänen & Fisk, 2004; Bluyssen, 2010), ventilation (Sundell et al., 2011), factors of noise (Bluyssen et al., 2011) and lightning (Bluyssen, 2010); chemical and biological factors through different emissions and particles from materials (SCHER, 2007), indoor activities (Sundell et al., 2011), and outdoor air (SCHER, 2007; WHO, 2009).

Studies have shown an increased risk of certain respiratory symptoms and illnesses in moisture-damaged workplaces and residential buildings (Bornehag et al., 2001; WHO, 2009; Mendell et al., 2011). A link has also been found between the need to repair buildings and perceived symptoms in health care workplaces (Hellgren et al., 2008). In addition, in most cases the physical, chemical and biological factors in a building have a simultaneous influence.
According to a review by Ghaffarianhoseini and colleagues (2018), the most common symptoms linked to IE-related problems are eye, nose, throat and skin irritation and, coughing, fatigue, headaches, and general symptoms. These symptoms can vary greatly. Many previous studies have assessed the relationship between single factors of exposure and occupants’ and employees’ IE-related complaints and symptoms in domestic and public environments (Bornehag et al., 2004; Sauni et al., 2015), in offices (Salonen et al., 2009c) and in health care environments (Rautiainen et al., 2016). In addition, a study by Hellgren (2012) classified hospital buildings as either moisture damaged or undamaged. In this study, the classification of buildings into two categories may be too approximate to describe the multidimensional technical problems that may affect employees’ IA exposure in buildings.

Therefore, many other exposures that have not been identified or investigated may leave room for interpretation in terms of the comprehensive picture of building technology, IE and IE exposure. In addition, building investigations have often been affected by or even based on the observations of the users of the premises, rather than being conducted by teams of multidisciplinary researchers (Mendell & Kumangai, 2017). Moreover, investigations conducted as part of research have shown to be more reliable than surveys conducted by the users of the premises themselves (Mendell & Kumangai, 2017). Observations based on studies in a building alone do not provide a reliable picture of the factors affecting IE, and hidden damage can remain unsolved (Mendell & Kumagai, 2017). Therefore, studies should consider the investigations of the building technology (e.g. structures, building hygrothermal behaviour, ventilation) and the potential impact of many factors on IE, as well as their causes and associations with perceived IE.

Many factors may affect the association between perceived symptoms, the experience of IE and the psychosocial work environment. Examples of these are, individual factors, physical IE, chemical and biological factors and psychosocial factors (Lahtinen et al., 2004b; Runeson & Norbäck, 2005; Runeson et al., 2006; Bakke et al., 2007; Hellgren et al., 2008; Brauer & Mikkelsen, 2010; Miskulin et al., 2014; Azuma et al., 2017). Earlier studies have mainly focused on employees’ self-reported symptoms and the psychosocial work environment at workplaces, and some studies have presented information on buildings either with or without IE-related problems (or a single IA impurity source or concentration) (Lahtinen et al., 2004b; Runeson & Norbäck, 2005; Runeson et al., 2006; Bakke et al., 2007; Brauer & Mikkelsen, 2010; Miskulin et al., 2014; Azuma et al., 2017). These studies have often lacked detailed, comprehensive building technology (e.g. structures, building and structures hygrothermal behaviour, ventilation) investigations. This leaves more room for interpretation regarding the association between a building, its condition, impurity sources and IE, and the chain of symptoms and psychosocial work environment in IE-related problem cases.

According to the Finnish Occupational Safety Act (Finnish Ministry of Social Affairs and Health, 2002), an employer must assess the health impacts and risks of the workplace to employees’ health. Exposure to environmental risks
(biological, chemical, physical and psychosocial) may have impacts on human health, and the aim of risk evaluation is to prevent, diminish and eliminate these risks (SCHER, 2007). The extent of their impacts depends on different pollutants, exposure time and exposure dose, as well as human individual characteristics (Dovjak & Kukec, 2019).

Assessing the significance of exposure for employees’ health is considered challenging, especially in non-industrial work environments such as offices or similar workplaces. In these environments, IA pollutants are generally not related to known production processes or their emissions, but to, for example, a building’s technology and its condition, materials, maintenance, and indoor activities (Bluyessen, 2010). The recommended limit values (of, for example, microbiological, volatile organic compounds (VOC) and some particles) are not health-based; they are guidelines that strive to minimise health risks and protect the health of the general public or employees (WHO, 2009; Finnish Ministry of Social Affairs and Health, 2015). Thus, assessing the significance of exposures for employees’ health is difficult because there are no health-based limit values for most of the pollutants in office-type environments.

Further, according to the Finnish Occupational Health Act, occupational health service (OHS) must assess the health significance of the IA risks to employees’ health. Comprehensive and holistic information on IA exposure is needed to evaluate the significance of IA exposure to employees’ health (Carrer & Wolkoff, 2018). The IA exposure assessment plays a key role in evaluating the health risks associated with IE, due to the lack of health-based limit values in non-industrial work environments (Carrer & Wolkoff, 2018).

In Finland, employers may use FIOH’s method to assess the probability of abnormal IA exposure in workplaces (Lappalainen et al., 2017). The main early criteria of the method was presented in a Working group on moisture damage of the Ministry of Social Affairs and Health in 2009. The method left too much room for interpretation and was not exact enough from the perspective of structural and building technology.

This lack of certain methodologies in the early model inspired me to add building technology aspects to this method. Moreover, the improvement of the method (Lappalainen et al., 2017) inspired us at FIOH to further study it and its results concerning perceived IE, employees’ group-level health information and IA group (multiprofessional expert team) information. The preliminary work to improve the method was carried out by FIOH and was officially published in 2016 and updated in 2017 in Finland (Lappalainen et al., 2017). The aim of the method is to assess the probability of abnormal IA exposure, and to provide a clear picture of all the impurity sources and factors affecting the IE of a building and premises (which sources, their extent, where and how much, evaluation of the impacts on IA). The research material used in this dissertation is from FIOH’s development and research projects in health care workplaces in 2012–2014.

To assess the probability of abnormal IA exposure, a building should be investigated according to the latest guidelines for building structures, technology and IE investigations. When national guidelines are followed, the required scope
and depth of the building technology and IE investigation are achieved. This can also lead to the building and its systems not requiring wider investigations. In these cases, the necessity of the investigations are thoroughly evaluated. Every building is different and needs investigations of varying scope and depth.

The results of the method for assessing the probability of abnormal IA exposure may be used as part of OHS’ health risk assessment. Although FIOH published the preliminary method for evaluating exposure earlier (Lappalainen et al., 2017), there is little research on the method and how its results regarding the probability of abnormal IA exposure assessment are associated with employees’ IE-related complaints, symptoms, group-level health information, and psychosocial work environment. The focus of this dissertation is on health care workplaces.

1.2 Objectives and scope

The main aim of this dissertation was to assess (a) the prevalence of IE-related symptoms and reported complaints, (b) how the psychosocial work environment is perceived and (c) whether the probability of abnormal IA exposure categories (a comprehensive method categorising the results of building technology and IE investigations) are associated with IE-related complaints, symptoms, psychosocial work environment and employees’ group-level health information, and (d) whether ventilation deficiencies are associated with IE-related complaints and symptoms in health care workplaces. This adds information on the use of the method as part of the IE-related problem-solving process in cases when the IA group needs to assess the urgency of the measures and the OHS needs to assess the significance of the probability of abnormal IA exposure for users of the premises.

Another aim was to provide new reference material for interpreting IE questionnaire results in health care workplaces.

This main study consists of three separate parts (Sub-studies I-III) with the following purposes:

1. To assess the prevalence of IE-related symptoms, complaints and perceived psychosocial work environment of employees in health care workplaces in Finland (Sub-study I).

2. To assess the association between the probability of abnormal IA exposure categories and employees’ IE-related complaints in health care workplaces (Sub-study II).

3. To assess the association between ventilation system deficiencies and perceived IE-related symptoms (Sub-study III) and complaints (Sub-study II) in health care workplaces.

4. To evaluate the association between the probability of abnormal IA exposure categories and employees’ IE-related symptoms, psychosocial
work environment and group-level health information in health care workplaces (Sub-study III).

In this dissertation, the focus was on group-level comparisons of the categories of probability of abnormal IA exposure and IE questionnaire results (Sub-studies II–III). Another aim was to study the prevalence of perceived IE in health care workplaces and produce reference data on a level that is acceptable for the purposes of interpreting IE questionnaire results in practice (Sub-study I). Group-level comparisons were chosen because IE-related problems at the workplace are most often solved using group-level information.

Sometimes the distribution of the susceptibility and its determinants is also the subject of the study, and previous research has shown that human individual factors also affect employees' perceived IE and are a part of the contributing variables of perceived IE (Magnavita, 2015). In the process of solving IE-related problems, individual factors (health information such as illnesses, asthma, allergy) are surveyed by occupational health services but IE questionnaire results are not interpreted at the individual level at the workplace. Thus, individual factors were not studied as confounding variables in this dissertation.

In this dissertation, the focus was on the most common factors (IAQ impurity sources such as moisture and mould, total VOC (TVOC) and VOC, man-made vitreous fibres (MMVF) sources, ventilation impurity sources and ventilation adequacy, IA temperature and humidity, odours, IA pressure differences between outdoor and indoor air or between different spaces, air leakages between spaces or through or from structures, impurity sources from activities) influencing IE and their effects on employees' IE-related complaints, symptoms and health.

House dust mites, viruses, endotoxins and mycotoxins and other special impurities such as environmental tobacco smoke and individual chemical compounds were not studied. The aim of the building technology and IE investigations was to detect the main impurity sources in the IA, not to measure all the IA concentrations. For this reason, the IAQ measurements were not extensively addressed in building investigations.

Also, noise, light, acoustics, ergonomics, space arrangements, layouts and interior components of IE are not addressed in this dissertation. The characteristics that have an impact on the usability of work environments (such as lighting, materials, safety, layout, acoustic, guiding signs, colours, perceived IAQ) were investigated in the same FIOH’s research and development projects and the results are addressed in the publication by Aalto et al. (2017).

1.3 Dissertation structure

This dissertation consists of three publications and their summaries. The summary consists of six independent chapters, the first of which is the introduction.

In Chapter 2, I use the literature review to illustrate the theoretical background of the research. In Chapter 3, I present the research material and methods. Chapter 4 presents the results of the study. In Chapter 5, I review the
research results, assess the reliability and validity of the study, propose some future uses, and address future research needs. In Chapter 6, I present a summary of the findings and the conclusions.

The original publications are attached to the dissertation.
2. Literature review

2.1 Indoor environment-related problems in non-industrial workplaces

IE consist of many elements, such as IAQ with thermal conditions (indoor climate), sound environment, lighting conditions, and space arrangements. IE-related issues may become IE-related problems when situations are prolonged or the issues cannot be solved for some reason (for example, the IE-related issues cannot be identified or there is no consensus on the reasons or solutions). IE-related problems have been reported for decades and are internationally quite common in non-industrial workplaces (Redlich et al., 1997; Dovjak & Kukec, 2019). IE-related problems are mostly related to indoor climate and to a person’s experience of IE and its potential impact on human symptoms and complaints. IE-related complaints and symptoms are commonly non-specific and decrease when an employee leaves the workplace or building (Ghaffarianhoseini et al., 2018; Dovjak & Kukec, 2019). A building-related group of non-specific symptoms is called sick building syndrome (SBS) (WHO, 1983; Ghaffarianhoseini et al., 2018). The World Health Organisation (WHO) presented the concept of SBS in 1983 (WHO, 1983). The SBS phenomenon occurs when 20% of the users of a building are worried about health problems and the problem is observed for more than two weeks (Ghaffarianhoseini et al., 2018). However, although a human may feel sick, a building cannot be sick or healthy in the same sense. Therefore, the use of the term of SBS is difficult and debatable.

IE is influenced by chemical, biological and physical factors (SCHER, 2007), such as building and interior materials, structural and building technology, outdoor air, soil, weather conditions, indoor activities, machines, people themselves, and property maintenance and cleaning. Generally, the IE of a building is simultaneously influenced by many factors.

Buildings and the factors influencing IE, as well as their relationship with the symptoms and the IE-related complaints of the employees of the premises, have long been studied (Mendell et al., 2011; Ghaffarianhoseini et al., 2018; Dovjak & Kukec, 2019). It is known that perceived IE is influenced by the type of building (Mendell et al., 2006; Hellgren et al., 2008; Sakellaris et al., 2016), building related-factors (Bluyssen et al., 2011; Frontczak & Wargocki, 2011; Frontczak et al., 2012; Magnavita, 2015; Bluyssen, 2016; Sakellaris et al., 2016; Wolkoff,
2018), damage to the building, the extent of damage to materials (Haverinen et al., 2001; Mendell et al., 2011), building technology-related impurity sources in the IA, and impurity concentrations in the IA (Schneider, 2008; Salonen et al., 2009a; Nevalainen et al., 2015; Ghaffarianhoseini et al., 2018). It is also known that IE comfort influences satisfaction factors, depending on location (Ervasti et al., 2012) or country (Humphreys, 2005).

Perceived IE can also be affected by a variety of other factors, such as human individual factors (Kim et al., 2013; Magnavita, 2015; Wolkoff, 2018), psychosocial work environment (Lahtinen et al., 2004b; Marmot et al., 2006; Runeson et al., 2006; Bakke et al., 2007; Lahtinen et al., 2008; Carrer & Wolkoff, 2018; Finell & Seppälä, 2018) and practices for solving IE-related problems (Lahtinen et al., 2002).

One, several or even a combination of different environmental IE-related factors may cause health outcomes and symptoms, and the phenomenon consists of many different interactions between environmental factors and health (Jaakkola & Jaakkola, 2010) (Figure 1).

![Factors affecting perceived indoor environment](image1.png)

**Figure 1.** Applied overview of factors affecting indoor environment (IE) and their possible effects on work environment according to Jaakkola, 1998 and Ghaffarianhoseini et al., 2018.

According to Jaakkola and Jaakkola (2010), health outcomes can be divided into physical and psychosocial effects. Thus, the physical environment may cause physiological effects (physiological phenomena, illness) and the social environment may cause psychological effects (symptoms, perceptions) (Figure 1). A person’s individual factors also play a role in the effects of physiological and psychological processes (Jaakkola, 1998; Ghaffarianhoseini et al., 2018) (Figure 1).
2.2 Factors affecting indoor climate

2.2.1 Building technology

Building technology encompasses many interdependent aspects, which means that structures, building envelopes and ventilation systems interact (Seppänen & Fisk, 2004). Building technology influences IA through emissions from different building materials of different ages (Holøs et al., 2018). The concentrations of impurities in the IA are determined by several factors, including ventilation rate, types and rates of emissions from sources, and materials’ characteristics and their ability to emit or absorb compounds (SCHER, 2007; Holøs et al., 2018). Concentrations can vary in time and space (Zabiegala, 2006; Bluyssen 2010; Nevalainen et al., 2014). Too low ventilation rates increase the risk of concentrations from buildings' furniture and interior materials accumulating in the IA (Holøs et al., 2018). Too low ventilation rates may also increase the IA’s carbon dioxide (CO2) concentrations and cause the accumulation of moisture on/in building structures and materials (Seppänen & Fisk, 2004). Under normal conditions, properly designed and operating ventilation systems remove and control the amount of material emissions into the IA (Seppänen & Fisk, 2004; WHO, 2009; Ye et al., 2014). Moreover, through ventilation it is also possible to influence IA temperature, draught, the IA’s relative humidity (RH), and the number of impurities arising from activities in the building (WHO, 2009).

The ageing of building technology, inadequate maintenance, delayed refurbishment, and poor planning and construction can lead to damage of structures and materials (Annila et al., 2017). Errors in ventilation systems can lead to abnormal impurities and abnormal numbers of impurities in the IA (Seppänen & Fisk, 2004). Structures and materials can be damaged by excessive moisture and lead to mould damage to materials and the deterioration of different materials, and cause impurities in the IA (Vitanen et al., 2010). In buildings, such damage can be on top of structures and materials as well as inside them and inside structure layers. Hidden damage in different parts of structure layers is more common in structures facing the ground and on basement floors (Annila et al., 2017). However, increased moisture content in materials does not always lead to mould damage (Haverinen et al., 2001). Many of the bacterial and fungal species normally detected in the IA are the same as those detected in damp-damaged environments, but their concentrations may be higher and their species more diverse (Nevalainen et al., 2015). Some species also typically exist in water-damaged environments and indicate mould damage or abnormal mould sources in premises (SCHER, 2007). The size, age, location and interior material of the moisture damage may indicate exposure (Haverinen et al., 2001).

High negative IA pressure (15Pa) (Valvira, 2016) or pressure differences (-10-30Pa) (Vitanen et al., 2010) may cause air leakages from structures, structure joints or through structure materials, causing a possible spread of impurities (e.g. microbial, radon) with air flows into the IA (Airaksinen et al., 2004). Radon gas may diffuse through soil into buildings via structures and structural air
leakage paths. Indoor radon concentrations can be reduced by technical measures (SCHER, 2007).

Air leakages from outdoors to indoors, through structures, may also cause an increased risk of moisture damage in structure assemblies (Viitanen et al., 2010). Ventilation is one of the factors affecting changes in IA pressure across structures and between the outdoors and indoors (Seppänen & Fisk, 2004). Ventilation deficiencies and ventilation rates (Seppänen & Fisk, 2004; Sundell et al., 2011), impurities entering through ventilation systems (Viana et al., 2011), impurities in the ventilation system (Salonen et al., 2009a), and outdoor pollutants all influence IA. As early as 1985, the Finnish Ministry of the Environment mentioned the airtightness of structures in their regulations, but current, more detailed design guidelines and regulations have now been given for building airtightness in the 21st century (Finnish Ministry of the Environment, 2003a, 2007b, 2010).

Man-made vitreous fibres (MMVF) are a commonly used material in insulation and acoustic materials and are manufactured primarily from glass, rock and minerals (Dovjak & Kukec, 2019). In office-type environments, the number of MMVF on surfaces or their concentrations in IA are generally low (Harbison et al., 2015), and MMVF sources in the IA are often unsealed isolation materials (Harbison et al., 2015). Asbestos was commonly used (before the 1990s) in construction products for isolation and fireproofing (thermal insulation, adhesives, roofing, duct insulations, flooring) (WHO, 2017). In Finland, the use of asbestos has been forbidden in buildings and interior materials since 1993 (Finnish Government, 1992), but it may be released into the IA during various repair and demolition work (Harbison et al., 2015). Some older building materials may emit polycyclic aromatic hydrocarbons (PAH) and one common component of these is naphthalene and its odour in the IA (Zabiegala, 2006). The most common building materials contain naphthalene are older water-proofing materials in and on structures.

Building technology, planning and building, as well as their instructions, regulations and legislation have changed over the decades. Different attributes of structure and material types and ventilation system operation, together with the indoor and outdoor environment, influence building structures’ thermal and moisture behaviour. Use, maintenance and refurbishment vary in every building. Therefore, the impact of structures and materials on the IA is different and varies from building to building.

2.2.2 Other factors

Many factors in premises and the outdoor environment influence IA. Weather, traffic, industry, and nature have an effect on outdoor air quality. Outdoor air enters the indoors through open windows and doors and ventilation systems that use outdoor air (Sundell et al., 2011), and by penetrating the building envelope (Airaksinen et al., 2004; Viana et al., 2011). Particles from the outdoor air may be present in the IA (SCHER, 2007). According to previous studies, printing and copying activities in offices (Kowalska et al., 2015), human activities in offices, homes and schools (Sundell et al., 2011; Nevalainen et al., 2015),
operations inside premises in offices, homes, schools (Sundell et al., 2011) and hospitals (Rautiainen et al., 2018), and cleaning products (Nazaroff & Weschler, 2004) and cleaning in offices and laboratories (Viana et al., 2011) may increase the number of impurities and the amount of emissions and concentrations in the IA. It is estimated that 10–20% of the IA’s total VOC concentrations come from consumer products (SCHER, 2007). The concentrations and number of impurity sources depend on many different things, such as building technology, the use of the premises, the number of users of the premises and the size and layout of the premises, materials and machines, maintenance and cleaning, the geographical location of the building, the weather, and outdoor air.

### 2.2.3 Factors affecting indoor climate in health care environments

In health care environments, VOC (Rautiainen et al., 2018) and other compound (Dascalaki et al., 2008) concentrations in the IA are strongly related to the health care activities in hospitals and hospital operating rooms. Exposure to cleaning agents, and to disinfection, laboratory, alcohol-based and antiseptic products and anaesthetics gases is common in hospitals (Dascalaki et al., 2008; Malo & Chan-Yeung, 2009; Donnay et al., 2011; Bessonneau et al., 2013). It is generally known that room temperature deviation effects the IA’s relative humidity and perceived IA. Both too high or too low room temperature, and low or high IA relative humidity may increase perceived symptoms and complaints (Seppänen & Fisk, 2004; Ghaffarianhoseini et al., 2018).

The building’s condition (Annila et al., 2017), characteristics and age (Missia et al., 2010) may also influence IAQ. Finnish public health care buildings are old (Reijula, 2005; Hellgren, 2012; Reijula et al., 2012; Leskelä et al., 2016). According to Reijula et al. (2012), the majority of health care buildings (measured by floor area) were built in 1940–1989, after which health care building construction began to decline until the 2010s in Finland. In addition to older building property, new hospital buildings were constructed and completed, and older buildings were renovated in many hospital districts in Finland in the 2010s. The latest survey of the Finnish Association of Civil Engineers (2019) shows that the amount of public buildings (measured by floor area) has not reached the same level as in the peak years (1980–1989), and the renovation needs of public buildings are high and estimated to increase in the future in Finland. In addition, the prevalence of significant moisture and mould damage is estimated to be 20%–26% in the floor areas of health care institutions in Finland (Reijula et al., 2012). In comparison, in schools, the estimated prevalence of significant mould and moisture damage is 12%–18%, and in offices 2.5%–25% of the floor area (Reijula et al., 2012). However, it should be noted that the building inspections of this study (Reijula et al., 2012) may not be comparable, and data may also be based on observations rather than on detailed building investigations.

### 2.3 Perceived indoor environment

In the case of IE-related problems, several non-specific symptoms such as upper- and lower respiratory, mucosal membrane and skin symptoms, and a
A combination of general symptoms may be related to a building and its IE. These kinds of core symptoms are concentration difficulties; fatigue; headaches; irritation of the skin, eyes, throat and nose; coughing; hoarseness; wheezing; and shortness of breath (Redlich et al., 1997; Dovjak & Kukec, 2019). More common symptoms and health effects are related to physical, chemical and biological agents (SCHER, 2007) as follows:

**Physical.** Sundell et al.’s (2011) review showed that too low ventilation rates may cause general symptoms in office environments. Too low ventilation rates increase the risk of concentrations from building, furniture and interior materials accumulating in the indoor air and the accumulation of excessive (over thresholds) CO₂ and moisture on/in building structures and materials (Seppänen & Fisk, 2004). In addition, Wargocki and Wyon (2017) stated in their study that too high or too low IA temperatures are perceived as unpleasant and may cause health symptoms in occupants of offices and school environments. It is known that high IA temperature with low outdoor air RH may cause low RH into the IA, especially in office-type buildings, and this is associated with sensory irritation (Wolkoff et al., 2006; SCHER, 2007).

**Chemical.** It has been suggested that inhaled chemicals may cause sensory irritation (Wolkoff et al., 2006; SCHER, 2007). Generally, chemicals may cause odours in the IA, but typically the threshold values for irritation symptoms are higher than the corresponding odour thresholds in non-industrial workplaces, and the typical VOC concentrations (except e.g. formaldehyde) may not explain the reported complaints in non-industrial workplaces (Wolkoff et al., 2006; Salonen et al., 2009b). Naphthalene can irritate the skin, eyes and the respiratory tract (USEPA, 2003). Particles such as outdoor air particles are associated with respiratory and cardiovascular effects. Studies suggest that MMVF and may be associated with skin, eye and respiratory irritation in offices (Schneider, 2008) and in hospitals (Hellgren et al., 2011). Asbestos was used in building materials and coverings before 1993 and typically only occurs in IE during the demolition of building structures or systems. All types of asbestos cause lung cancer (fibrosis of the lungs) (WHO, 2017).

**Biological.** Biological agents, such as moulds, are associated with respiratory symptoms, coughing, upper respiratory tract symptoms and health effects such as asthma in different type of environments (public and domestic buildings) (IOM, 2004; SCHER, 2007; WHO, 2009; Mendell et al., 2011; Karvala, 2012; Quansah et al., 2012). There is also evidence that observed IA mould and moisture damage in buildings pose an increased health risk (Mendell & Kumagai, 2017). It has been proposed that the extent of mould and moisture damage is relative to the most prevalent respiratory symptoms among adults (Mendell & Kumagai, 2017). Moreover, ventilation operation and differences between indoor and outdoor air pressure have been estimated to play a role in the migration of impurities from structures to the IA in studies of residential houses (Haverinen et al., 2001; Airaksinen et al., 2004) and laboratory simulation tests (Lappalainen et al., 2015).

Table 1 presents some of the common factors influencing IE and common IE-related complaints and symptoms.
<table>
<thead>
<tr>
<th>Factor or impurity source</th>
<th>Typical impact on indoor air and impurity / pollution</th>
<th>General or building-related complaints and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>High ventilation rate</td>
<td>- air movement (draught) (Sundell et al., 2011)</td>
<td>- complaints of draught, too low indoor air temperature, (Sundell et al., 2011; Ghaffarianhoseini et al., 2018).</td>
</tr>
<tr>
<td></td>
<td>- air movement in ventilation machinery (Bluyssen et al., 2011)</td>
<td>- general symptoms (WHO, 2009)</td>
</tr>
<tr>
<td></td>
<td>- may increase accumulation of indoor air CO₂ concentrations (from human) and may increase accumulation of RH in the IA (Seppänen &amp; Fisk, 2004)</td>
<td>- noise (Bluyssen et al., 2011)</td>
</tr>
<tr>
<td>Low ventilation rate</td>
<td>- may increase accumulation of VOCs (from materials or activities in the premises) (SCHER, 2007)</td>
<td>- complaints of perceived air IAQ (Seppänen &amp; Fisk, 2004; WHO, 2009)</td>
</tr>
<tr>
<td></td>
<td>- may increase accumulation of VOCs (from materials or activities in the premises) (SCHER, 2007)</td>
<td>- irritation, fatigue, headache (SCHER, 2007; Annesi-Maesano et al., 2013; Ghaffarianhoseini et al., 2018)</td>
</tr>
<tr>
<td></td>
<td>- biological impurity concentration in the IA (moisture and mould contamination in ventilation system) (WHO, 2009)</td>
<td>- general symptoms (WHO, 2009; Sundell et al., 2011)</td>
</tr>
<tr>
<td>Ventilation impurities</td>
<td>- may increase number of particles and amount of dust (from building site, outdoor air) (Sundell et al., 2011)</td>
<td>- particles: respiratory symptoms and cardiovascular effects (SCHER, 2007)</td>
</tr>
<tr>
<td></td>
<td>- MMVF (from acoustic isolation) (Salonen et al., 2009a)</td>
<td>- MMVF: irritation of skin, eyes, throat and respiratory tract (Hellgren et al., 2008; Schneider, 2008)</td>
</tr>
<tr>
<td></td>
<td>- biological impurity concentration in the IA (moisture and mould contamination in ventilation system) (WHO, 2009)</td>
<td>- mould: respiratory and allergic symptoms, asthma (IOM, 2004; WHO, 2009; Karvala, 2012; Quansah et al., 2012)</td>
</tr>
<tr>
<td>High room temperature</td>
<td>- may cause low RH in the IA (Seppänen &amp; Fisk, 2004)</td>
<td>- complaints of poor indoor air quality (Seppänen &amp; Fisk, 2004)</td>
</tr>
<tr>
<td>Building and interior materials, furniture</td>
<td>- may increase several chemical concentrations and their combinations and particles (e.g. VOC, PAH, asbestos, MMVF) (SCHER, 2007)</td>
<td>- skin, nose and eye symptoms (Wolkoff et al., 2006; SCHER, 2007; Wargocki &amp; Wyon, 2017)</td>
</tr>
<tr>
<td></td>
<td>- biological impurities (e.g. from moisture and mould damaged materials) (WHO, 2009)</td>
<td>- mould: respiratory and allergic symptoms, asthma (IOM, 2004; WHO, 2009; Karvala, 2012; Quansah et al., 2012)</td>
</tr>
<tr>
<td>Operations and activities in premises</td>
<td>- several chemical concentrations and their combinations (machines, cleaning, maintenance, textiles, hygiene products, disinfection and other hospital and, pharmacy products) (Nazaroff &amp; Weschler, 2004; Viana et al., 2011; Kowalska et al., 2015)</td>
<td>- mould: respiratory and allergic symptoms, asthma (IOM, 2004; WHO, 2009; Karvala, 2012; Quansah et al., 2012)</td>
</tr>
<tr>
<td></td>
<td>- dust and dirt (window opening, activities in premises) (Sundell et al., 2011)</td>
<td>- PAH (naphthalene): irritation of eyes, skin, respiratory tract (USEPA, 2003)</td>
</tr>
<tr>
<td>Outdoor and soil</td>
<td>- particles (outdoor air, pollen, biological agents, traffic, wood burning) (SCHER, 2007)</td>
<td>- chemical concentrations: sensory irritation, asthma symptoms (SCHER, 2007)</td>
</tr>
<tr>
<td></td>
<td>- chemical and biological impurities (traffic, wood burning, possible biological impurities from soil) (SCHER, 2007)</td>
<td>- MMVF: irritation of skin, eyes, throat and respiratory tract (Hellgren et al., 2008; Schneider, 2008)</td>
</tr>
<tr>
<td></td>
<td>- chemicals (SCHER, 2007)</td>
<td>- mould: respiratory and allergic symptoms, asthma (IOM, 2004; WHO, 2009; Karvala, 2012; Quansah et al., 2012)</td>
</tr>
</tbody>
</table>

IA=indoor air
RH=relative humidity
2.3.1 Prevalence of indoor environment-related symptoms in health care environments

Various IE-related irritation symptoms such as on the skin of the hands, (24%–25%); other skin symptoms, (35%–40%) (Aarnio et al., 2005); upper respiratory symptoms, (over 50%); headaches, fatigue, (21%–43%); feeling heavy-headed, (26%); hoarse throat, (17%–37%); and coughing, (8%–30%) are common among health care employees (Hellgren & Reijula, 2006; Hellgren et al., 2008; Magnavita et al., 2011; Rautiainen et al., 2018).

These symptoms are common among hospital employees all over the world. In a study (Loupa et al., 2017) of a Greek hospital’s employees, 56% reported fatigue, 42% heavy-headedness and 33% headaches, which differs from the results of Finnish studies (Reijula & Sundman-Digert, 2004; Aarnio et al., 2005; Hellgren et al., 2008). This difference may be related to differences in climate conditions (Loupa et al., 2017). Hospital employees in Slovenia also more often perceived fatigue and irritation symptoms, (30% of respondents) (Kalender Smajlović et al., 2019). In a study of hospital employees in Taiwan, the most often reported symptoms were nasal symptoms (66% of respondents), ocular symptoms (53%), and fatigue (30%) (Chang et al., 2015). Moreover, research on nurses in Iran found that the prevalence of building-related symptoms was over 86%, and that the most common complaints were headaches, fatigue and dryness of the hands (Keyvani et al., 2017).

A recent Finnish study (Rautiainen et al., 2018) of hospital employees found that employees reported symptoms 2.5 times more often than in previous studies (Reijula & Sundman-Digert, 2004; Hellgren et al., 2008). A Finnish follow-up study also suggested that IE-related symptoms increased among hospital employees in 1999–2005 (Aarnio et al., 2005).

In comparison, in offices, the most prevalent symptoms were fatigue (10% of respondents), irritated or runny nose (9%) and irritation of the eyes and itching scalp or ears (6%) (Andersson, 1998). In an Italian study reveal 32% of office employees reported IE-related symptoms (Magnavita, 2015). In Finnish offices, the most prevalent weekly symptoms related to IE were irritated/runny nose (20% of respondents), irritation of the eyes (17%), fatigue (16%), irritation of the skin on the hands (15%) and a hoarse throat (14%) (Reijula & Sundman-Digert, 2004). The studies were conducted more than 10 years apart and the former two studies were Nordic whereas the latter was from southern Europe, which may also have affected the results. However, based on the results of earlier studies, hospital employees seem to have a higher prevalence of IA- and building-related symptoms than office employees.

Public health care buildings are old in Finland (Reijula, 2005; Hellgren, 2012; Reijula et al., 2012; Leskelä et al., 2016) and they are estimated to have a prevalence of 20% to 26% of significant moisture and mould damage in their floor areas (Reijula et al., 2012). Thus, generally the type, age and condition of the
building may influence perceived IE-related symptoms (Mendell et al., 2006; Hellgren et al., 2008; Brauer & Mikkelsen, 2010; Sakellaris et al., 2016). The more extensive the moisture and mould damage in the premises, the more common respiratory symptoms are (Mendell & Kumagai, 2017). An association has also been found between respiratory symptoms and mould damage (Cox-Ganser et al., 2009) as well as between the condition of a building and its ventilation system and perceived symptoms (Hellgren et al., 2008). On the other hand, employees in undamaged buildings have also had IE-related symptoms (Reijula & Sundman-Digert, 2004; Bakke et al., 2007; Rautiainen et al., 2018).

Early studies show that MMVF sources in ventilation systems are in relation to IA-related symptoms and can cause skin and upper respiratory irritation among users of the premises (Schneider, 2008; Salonen et al., 2009a; Hellgren et al., 2011). Symptoms of the same type can also be caused by, for example, dry air and high IA temperature (Wolkoff, 2018).

Different irritation symptoms among healthcare employees may appear partly due to hospital work involving several chemical products and hand-washing (Aarnio et al., 2005). A literature review by Norbäck (2009) also shows that individual factors such as gender, atopy and smoking habits are associated with building-related symptoms. A study of Italian public and private companies showed that 2%–25% of the explanatory variables of perceived IE were related to individual factors (Magnavita, 2015). Further, 75% of the explanatory factors of IE-related complaints remained unclear (Magnavita, 2015).

2.3.2 Prevalence of indoor environment-related complaints in health care environments

A follow-up study of health care employees in Finland (1995–2001) showed that IE-related complaints of stuffy air, odour, dry air, and high room temperature were increasingly perceived over the years (Aarnio et al., 2005). More common IE-related complaints (stuffy air 40%–44%, dry air 35%–46% and unpleasant odour 26%–44%) among hospital employees were also common in subsequent studies in Finland in 2008 and in Greece in 2017 (Hellgren et al., 2008; Loupa et al., 2017).

Deficiencies in ventilation are associated with poor IAQ (Seppänen & Fisk, 2004; Norbäck & Nordström, 2008; Hellgren et al., 2011; Turunen et al., 2014; Haverinen-Shaughnessy et al., 2015; Loupa et al., 2017). Generally, in hospitals mechanical ventilation is efficient (Dascalaki et al., 2008; Rautiainen et al., 2018), but health care employees are still exposed to poor IAQ as a result of the various chemicals and their mixtures used in hospital work and cleaning (Dascalaki et al., 2008; Donnay et al., 2011). However, the measured IA concentrations of chemicals in hospital studies have been low (Bessonneau et al., 2013; Rautiainen et al., 2018).

In the 1990s, Andersson (1998) reported that the most prevalent IE-related complaints in office environments were dry air (20%), stuffy air (10%) and dust/or dirt (10%). Respectively, in 2004, Reijula and Sundman-Digert reported results regarding 11 154 respondents in 122 non-industrial workplaces. In their study, the most prevalent IE-related complaints were dry air (35% of
respondents), stuffy air (34%), draught (22%), too high room temperature (17%), and unpleasant odours (17%). A study published in 2015 (Magnavita, 2015) on indoor climate comfort in Italian offices revealed that 65% of employees had made IE-related complaints. These studies are from different geographical locations and were conducted at different times, which may affect the results. However, earlier studies have shown that the prevalence of IE-related complaints in hospitals has been higher than that in offices. More women work in health care and female employees more often report symptoms than males and, it is suggested that this may be due to differences in experience of the psychosocial work environment (Runeson, 2006).

As public health care buildings are old (Reijula, 2005; Hellgren, 2012; Reijula et al., 2012; Leskelä et al., 2016) and the prevalence of significant moisture and mould damage is estimated to be 20%–26% of the floor areas in health care institutions in Finland (Reijula et al., 2012). Several earlier studies have found a connection between mould odour and moisture damage in homes (Reponen et al., 2010; Täubel et al., 2016; Mendell & Kumagai, 2017) and in schools (Cho et al., 2016; Park et al., 2004). Furthermore, odours may increase the reporting of symptoms (Wolkoff et al., 2006) and mould damage may increase users’ experience of stuffy air (Nordström, 1999).

Earlier studies have focused on some IA- and building-related factors and their association with building users’ complaints and symptoms. But it seems that more comprehensive studies of the most common impurity sources in building and ventilation systems that affect IA and employees’ symptoms and complaints, are rare.

2.3.3 Perceived psychosocial work environment

Jaakkola (1998) determined the IE in non-industrial workplaces and divided the five important determinants of health as follows: (i) outdoor sources, (ii) type of building, (iii) occupants and their activities, (iv) physical indoor sources and (v) heating, ventilation and air conditioning, as well as psychological and social factors. Building-related symptoms consist of several health outcomes and environmental determinants. Thus, one, several or even a combination of different environmental building-related factors may cause health outcomes and symptoms, and the phenomenon may consist of many different interactions between environmental factors and health (Jaakkola & Jaakkola, 2010). According to Jaakkola and Jaakkola (2010), health outcomes can be divided into physical and psychosocial effects. Thus, the physical environment may cause physiological effects (physiological phenomena, illnesses) in the physical environment and psychological effects (symptoms, perceptions) in the social environment (Figure 1). In addition, a person’s individual characteristics may play a role in the effects of physiological and psychological processes (Jaakkola, 1998; Ghaffarianhoseini et al., 2018) (Figure 1).

The psychosocial work environment includes areas of personal, work and organisational psychology and their interactions (Chmiel, 2000; Rugulies, 2019). In this context, the psychosocial work environment concerns psychosocial
working conditions such as workload, job content, work organisation and employees’ social relations in the work community.

The Örebro MM-40-based IE questionnaire is a widely used and established way of eliciting employees’ experiences of perceived IE and their psychosocial work environment (Andersson, 1998; Lahtinen et al., 2004b; Reijula & Sundman-Digert, 2004) (see Chapter 2, section 2.4.3). In simplified terms, the questionnaire screens the factors related to the work environment and the state of their interaction; for example, work stress and job satisfaction. These factors may explain certain employee attitudes and work behaviour (Leiter & Stright, 2009). Psychosocial stress may be defined as a disproportion between a person and the environmental psychosocial stress factors in the work environment that are related to job content or the organisation of work, the opportunities offered by work, the use of one’s own skills and learning, the opportunity to influence work or the work environment, job roles, social relationships, or organisational structures and culture (Leiter & Stright, 2009).

Several studies have examined the relation between employees’ reported IE-related complaints, symptoms and the psychosocial work environment of office employees (Lahtinen et al., 2004b; Runeson & Norbäck, 2005; Azuma et al., 2017) in the Swedish workforce (Runeson et al., 2006), the users of university buildings (Bakke et al., 2007), health care employees (Hellgren et al., 2008), employees of randomly selected workplaces (Brauer & Mikkelsen, 2010), and public institutions’ employees (Miskulin et al., 2014). Azuma and colleagues (2017) evaluated the seasonal characteristics of symptoms and the psychosocial work environment and reported job stressors as being related to general symptoms among office employees. Bakke and colleagues (2007) state that gender and the psychosocial and physical environment are related to symptoms among the users of university buildings. Brauer and Mikkelsen (2010) studied the role of the psychosocial work environment, at the individual level, to explain the differences between employees’ perceived IE. They found differences between employees in the same building, which indicated that some employees perceived problems in the IE even when no IE-related problems had been detected (Brauer & Mikkelsen, 2010). A Finnish study of the work population found the risk of experiencing the workplace as harmful to be higher among respondents who reported mould problems than among those who reported ventilation deficiencies at the workplace (Finell & Seppälä, 2018). In contrast, a cross-sectional study suggested that psychosocial work environment factors may cause building-related symptoms among public institutions’ employees (Miskulin et al., 2014). A Finnish study of hospital employees reported no significant association between psychosocial work environment, symptoms and a building needing repairs, except the experience of a heavy workload (Hellgren et al., 2008). No association was reported between heavy workload, general symptoms and a building needing repairs, but in this study the heavy workload explained the concentration difficulties and fatigue better than the building’s poor condition (Hellgren et al., 2008).

A study of Polish nurses showed that hospital work was moderately or highly demanding and that social support from co-workers was moderate (44%), which
may indicate difficulties in team work or organisation (Rotter et al., 2014). However, different studies of hospital employees have found that 76%–82% find their work interesting and stimulating and 67%–79% receive help from their fellow-workers (Hellgren et al., 2008; Stankovic et al., 2008; Loupa et al., 2017).

IE factors or combinations of factors may cause different types of symptoms and health issues in different individuals, depending on several of the mechanisms involved and personal susceptibility (Jaakkola & Jaakkola, 2010). In addition, good practices for and control in solving IE-related problems may influence employees’ IE-related complaints and symptoms (Lahtinen et al., 2002; Lahtinen et al., 2004a). Thus, when IE, psychosocial work environment, human individual characteristics, and good practices for managing IE-related problems are all connected, it may be impossible to determine the main reason and its impacts on the phenomenon. Moreover, several studies have highlighted the importance of psychosocial stressors, among other factors, when solving IE-related problems (Lahtinen et al., 2002; Lahtinen et al., 2004a; Lahtinen et al., 2004b; Runeson, 2006; Runeson et al., 2006; Magnavita, 2015; Carrer & Wolkoff, 2018; Finell & Nätti, 2019).

2.4 Methods for solving indoor environment-related problems

2.4.1 Multiprofessional process for solving indoor environment-related problems

The IE consists of many multiscientific elements, such as air quality, building technology, thermal conditions, sound environment, lighting conditions, and space arrangements. Therefore, the IE problem-solving process should consider (A) the building, building technology and IE conditions, (B) users’ experiences and health, and (C) good IE practices (Lappalainen et al., 2009). Multidisciplinary cooperation, a participatory and holistic approach to the problem-solving process, process-oriented work, and interactive and regular communication is important when solving IE-related problems (Lahtinen et al., 2004a; Lahtinen et al., 2008).

IE-related problem-solving requires the skills and work of many professionals (Lahtinen et al., 2004a; Reijula & Sundman-Digert, 2004; Lahtinen et al., 2008; Carrer & Wolkoff, 2018). Many people, from the employees who have observed the problem, to various experts and authorities are involved in handling the case (Lahtinen et al., 2004a; Lahtinen et al., 2008). To successfully solve the problem, cooperation needs to be structured and organised in a multiprofessional team (Lahtinen et al., 2004a; Reijula & Sundman-Digert, 2004; Lahtinen et al., 2008; Carrer & Wolkoff, 2018). In Finnish workplaces that are subject to both the Occupational Safety and Health Act (Finnish Ministry of Social Affairs and Health, 2002) and the Occupational Health Care Act (Finnish Ministry of Social Affairs and Health, 2001), there must be cooperation between authorities, employer, employee, and OHS. The participation of the users of the premises in the IA group is part of good practices (Lahtinen et al., 2008). Collaboration builds trust and there is less distrust if the employees are involved in the problem-solving process (Lahtinen et al., 2008). In addition, the more people involved in
the process and the decision-making, the more readily they will accept the solutions and decisions made (Lahtinen et al., 2008).

The role of the IA group is to serve as a forum for multidisciplinary cooperation (Lahtinen et al., 2008). The IA group organises and implements the problem-solving process in the workplace (Lahtinen et al., 2008). It brings multi-professional expertise to solving the IE-related problem, to improving the interaction between the various members, and to increasing the confidence of the users of the premises that the problem will be solved (Lahtinen et al., 2008).

Finnish legislation guides and obliges employers to prevent and solve workplace environmental problems (Finnish Ministry of Social Affairs and Health, 2002). Employers must ensure that the work environment does not harm employees' health and safety. According to the Occupational Safety and Health Act (Finnish Ministry of Social Affairs and Health, 2002), employers must analyse and identify the hazards and risk factors caused by work and eliminate or diminish the factors that are harmful to health in the work environment. The causes of IE-related problems and the condition of the building technology and IAQ must always be investigated by following the building and IE investigation process. If the employer does not have the necessary expertise to solve the problems, different experts (e.g. building health specialist, building condition specialist) must be used.

The role of OHS is important when employees have symptoms related to the IE. If the hazards cannot be eliminated, the employer must involve OHS to assess the significance of the hazards for the employee's health (Finnish Ministry of Social Affairs and Health, 2002). The law obliges the employer to continuously monitor the health and safety of the workplace (Finnish Ministry of Social Affairs and Health, 2002).

The building owner plays a key, active role in the IA group in gathering, analysing and providing information on the building, as well as conducting possible repairs and other various measures related to the condition of the building technology and its operation.

### 2.4.2 Phases of building, ventilation and indoor environment investigations

Suspicion of an IE-related problem usually arises from a notification by a user of the premises. Easily recognisable technical problems are handled by the building’s maintenance staff. If the problem is unclear or more than a maintenance deficiency, the building technology and IE investigation proceeds in a step-by-step manner (Pitkäranta, 2016; Lappalainen et al., 2017; Carrer & Wolkoff, 2018). Between the various phases, an assessment of the situation and decisions on possible measures and repairs and follow-up are made together with the building owner, building condition and health experts, health professionals, employer and occupational safety representatives, and the IA group (Lappalainen et al., 2017). The phases of building, ventilation and IE investigations are presented in more detail in Tables 3–5 in the Methods and Materials section (Chapter 2, Sections 2.3.1 and 3.2.2).
**Background information.** Existing material on IE-related problems in the building (including previous IE surveys and occupational health interviews, IE questionnaire results, results of earlier of building technology and IE investigations, and possible other research reports) are evaluated (Pitkäranta, 2016; Lappalainen et al., 2017). The building design documentation and any previous renovation and refurbishment documentation and maintenance history are reviewed for a technical risk assessment (Pitkäranta, 2016). The technical risk assessment assesses at least the likely risks of damage to the building and structures and the sources of impurities affecting the IA and the operation, purity and suitability of the ventilation system. In this phase, the building maintenance staff and IA group members are interviewed, or they provide information on the building technology and other factors of the IE-related problem. If necessary, IE questionnaires and OHS interviews are conducted to monitor the state of perceived IE and the psychosocial work environment (Lappalainen et al., 2017).

Preliminary studies focus on the suspected causes of the IE-related problem.

**Building technology and IE investigation plans.** The building technology and IE investigation plans are made on the basis of the information provided in Phase 1 (Pitkäranta, 2016; Lappalainen et al., 2017)). In addition, walkthroughs and preliminary studies are carried out (Pitkäranta, 2016; Lappalainen et al., 2017). Walkthroughs are a way of making observations regarding the building technology, materials and IE, and enable interviews of the users of the premises (Pitkäranta, 2016; Lappalainen et al., 2017). All this information is used for making an investigation plan (Pitkäranta, 2016). It is important to observe the structures and evaluate the hygrothermal behaviour of the structures with the help of building technology plans and on-site observations before drawing up investigation plans. After this, the structural openings and samples of the materials can be planned and the condition of the structures and materials and the extent of damage assessed (Singh et al., 2010; Singh et al., 2011; Pitkäranta, 2016; Annila et al., 2017)

The purpose of the investigations is to determine the causes of the IE-related problems, and, if necessary, the probability of abnormal IA exposure. They also provide information for repairs and other measures. The scope and depth of the investigations varies from case to case, depending on the nature and extent of the problem and the hypothesis of the causal agents of the problem. Often, several factors influence the IE-related problems, and the investigations should consider the function of the building technology as a whole in terms of structural and ventilation technology.

**Building technology and IE investigations.** Building technology and IE investigations follow the investigation plan (Pitkäranta, 2016). In cases of extensive IE-related problems or risks in building technology, based on technical risk assessment, the structures of the building and the sources of contamination of the structure and air paths to the IA should be examined (Pitkäranta, 2016). Investigations commonly include openings of high-risk structures, measurements of the structures and material sampling (Pitkäranta, 2016). Air leakages from or through structures are assessed (Pitkäranta, 2016). Many earlier studies have only made observations of visible damage and indicators of damage, and
have not detected hidden damages in structures (Mendell & Kumagai, 2017) nor verified structural damage by observation alone (Singh et al., 2011; Mendell & Kumagai, 2017). Indoor air measurements are often unable to verify structural damage and sources of impurities (Hyvärinen et al., 2001; Sokolowsky et al., 2017).

In addition, the efficiency and purity of the ventilation system are assessed and measured, and the system operation checked. Risk factors in building technology, such as old sewerage and plumbing systems and their joints, are taken into account. IAQ measurements are carried out when necessary. The operation and efficiency of the ventilation system, as well as indoor and outdoor air pressure differences, are investigated. IAQ is measured according to the preliminary study hypothesis and the background and walkthrough information.

Finland also has a method for categorising building technology and IE investigation results to enable the assessment of the probability of abnormal IA exposure (Lappalainen et al., 2017). The method can provide holistic and classified information for OHS professionals, employer and IA group. FIOH published the main criteria of this method in 2009 (Finnish Ministry of the Social Affairs and Health, 2009) and developed and extended it in 2016–2017 (Lappalainen et al., 2017). An accurate description of the content of the building technology and IE investigation process, and the pilot method (used in Sub-studies II-III) for the probability of abnormal IA exposure is provided in Chapter 3, Sections 3.2.1 and 3.2.2.

2.4.3 Questionnaire survey of perceived indoor environment

The MM-40 questionnaire is a widely used tool for monitoring the state of perceived IE during problem-solving and after IE-related repairs in a building. It is primarily intended for the use of health care professionals. Multiprofessional teams also usually benefit from using the questionnaire as part of the IE-related problem-solving process. The standardised (1989) MM-40 IE questionnaire is used in parallel with other methods to investigate IE in workplaces and is not the sole instrument in problem diagnosis (Andersson, 1998; Reijula & Sundman-Digert, 2004).

It has versions for offices, schools, day care centres, hospitals, and residential dwellings. The first reference data for offices and schools were published in Örebro University Hospital in 1990 (Andersson et al., 1990). The questionnaire has four parts, with questions on (i) the work environment, (ii) work arrangements, (iii) individual allergy history, and (iv) IE-related symptoms.

In Finland, FIOH published the office reference data in 2004 (Lahtinen et al., 2004b; Reijula & Sundman-Digert, 2004) and the hospital reference data in 2008 (Hellgren et al., 2008). Reijula and his colleagues (2004) stated that when the mean values of the questionnaire responses concerning IE-related complaints exceed 30% and those concerning symptoms exceed 20%, this indicates possible problems in a building and its ventilation systems. Hellgren and colleagues (2008) stated that their study results’ mean questionnaire values can be used to identify the needs for immediate repair of moisture and mould damage in health care buildings in Finland.
FIOH’s MM-40-based IE questionnaire was slightly modified in 2008 (Hellgren, 2012). In this modification a question about the smell of mould was added to the IE-related complaints, and questions about fever or chills, shortness and wheezing of breath, and muscular and joint pain were added to the symptoms (Hellgren, 2012). In addition, recurrent respiratory infections were added to the questions about allergy history (Hellgren, 2012). The additions to the questionnaire were based on the knowledge that hospital employees (20%) perceived mould odour in the workplace IE and an increasing number of cases of work-related asthma among hospital employees (Hellgren, 2012). The question about feeling heavy-headed was removed (Hellgren, 2012).

The questionnaire can be filled in online or manually on paper. It is important to inform the respondents of the questionnaire’s purpose and method, of the use of the results and of personal data protection. Participation is always voluntary. An accurate description of the content of the MM-40 questionnaire is described in Chapter 3: Methods, 3.2.3.

2.4.4 Occupational health service’s assessment of health risks related to indoor environment

The Scientific Committee on Health and Environmental Risks (SCHER) recommends evidence-based risk assessment. The extent of the effects is related to exposure dose, exposure time, different pollutants and their type, and individual and personal characteristics. Longer exposure times and increased user sensitivity may increase the risk of the negative health effects in the IE (Dovjak & Kukec, 2019). It is also estimated that the classification of pollutant emissions plays an important role in OHS exposure assessment (Karvala et al., 2010). According to SCHER (2007), risk assessment includes the identification of risks, a dose-response evaluation, an exposure assessment including the evaluation of the time of the exposure and the pollution levels of the exposure, and risk characterisation.

Considering the variability and complexity of the IE, data on risk assessments are scarcely available and are often insufficient in relation to the known number of impurities. There is always uncertainty related to risk estimates. However, the most common IA pollutants, such as radon, asbestos, mould, VOCs and particles, are well known. In addition, their most common effects and risks are known to the extent that measures to mitigate the problems are possible (SCHER, 2007).

The role of OHS is important when employees have IE-related symptoms (Hellgren, 2012; Magnavita, 2014; Carrer & Wolkoff, 2018). If the environmental hazards cannot be eliminated or efficiently controlled, the employer must obtain an OHS assessment of the significance of the hazards to the employee's health (Finnish Ministry of Social Affairs and Health, 2002). The Finnish Occupational Safety and Health Act (Finnish Ministry of Social Affairs and Health, 2002) obliges the employer to continuously monitor the health and safety of the workplace. The concept of the Finnish health significance assessment comes from this Act (Finnish Ministry of Social Affairs and Health, 2002) and the Occupational Health Care Act (Finnish Ministry of Social Affairs and Health,
The employer is responsible for ensuring that health experts and professionals are used to assess the risks to health, as provided for in the Occupational Health Care Act (Finnish Ministry of Social Affairs and Health, 2001).

SCHER (2007) states that when symptoms or complaints, illnesses or risks of illness are clearly related to unacceptable IA (e.g. lack of ventilation, excessive dirtiness, excessive microbial growth and dampness) no further detailed risk assessment is needed and risk management and corrective measures may be performed directly. In Finland, employers must broadly identify and assess the health and safety of work and working conditions. This means that the employer, with the help of OHS, should take into account workplace exposures, as well as workload and work arrangements, the health status of employees, and their ability to work.

A Working Group on Moisture Damage established and reported national guidelines for the risk assessment of mould problems (Finnish Ministry of the Social Affairs and Health, 2009). In mould problems, OHS assesses the health significance of the adverse effects, harms and hazards associated with the probability of abnormal IA exposure. Prior to assessing the health significance, the employer must investigate the probability of abnormal IA exposure under the guidance of an expert in building health, as the health significance of the problem cannot be assessed without exposure data.
3. Materials and methods

3.1 Study characteristics and materials

This dissertation is based on three Sub-studies and two individual sets of material. In Sub-study I, the data were collected from FIOH’s customer service’s IE questionnaire responses (N=28,826) from Finnish workplaces (N=455) from 2011–2012 and 2015–2017 (Table 2).

Sub-studies II–III used the results of two of FIOH’s research and development projects in two hospital districts from 2013 to 2014. In Sub-studies II–III, the material included IE questionnaire results (N=1,558) from workplaces, the building technology investigation results from 27 buildings (included 111 building floors), the probability of abnormal IA exposure assessment results from 95 floors or building sections, OHS group-level information on employees’ health (40 groups) and IA group’s information on the IE-related problem (43 groups) (Table 2 and Figure 1).

Table 2. Materials and main methods used in Sub-studies I–III. Section 3.2 contains a more accurate description of the methods and analyses.

<table>
<thead>
<tr>
<th>Method</th>
<th>Sub-study I</th>
<th>Sub-studies II-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>• IE(^1) questionnaires (MM-40 based (Lahtinen et al., 2004b; Reijula &amp; Sundman-Digert, 2004; Hellgren et al., 2008))</td>
<td>• 28,826 respondents</td>
<td>• 2,669 respondents</td>
</tr>
<tr>
<td></td>
<td>• 455 workplaces (office, school and health care workplaces in Finland)</td>
<td>• 1,558 selected respondents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• two hospital districts’ workplaces</td>
</tr>
<tr>
<td>• building structure, architecture, ventilation, repair and refurbishment plan survey, and possible earlier investigation report survey</td>
<td>• Information not available</td>
<td>• all available documents on two hospital districts’ 27 buildings</td>
</tr>
<tr>
<td>• walkthroughs of buildings (observations)</td>
<td>• Not performed</td>
<td>• in two hospital districts’ 27 buildings and on 111 floors</td>
</tr>
<tr>
<td>• investigation plans</td>
<td>• Not performed</td>
<td>• in two hospital districts’ 27 buildings and on 111 floors</td>
</tr>
<tr>
<td>• building structures, ventilation and IE investigations</td>
<td>• Not performed</td>
<td>• in two hospital districts’ 27 buildings and on 111 floors</td>
</tr>
<tr>
<td>• measurements in/on structures and surfaces</td>
<td>• Not performed</td>
<td>• in two hospital districts’ 27 buildings and on 111 floors</td>
</tr>
<tr>
<td>• IAQ and ventilation or ventilation system measurements (followed national instructions, measuring and sampling): material samples of microbes, PAH(^2), TVOC(^3), VOC(^4), asbestos, aldehydes, dusts,</td>
<td>• Not performed</td>
<td>• 432 items</td>
</tr>
</tbody>
</table>

35
In **Sub-study I**, the mean of the response rate for the IE questionnaire surveys was 77%, with a range of 43%–100%. The average age of the respondents was 47 and 70% of the respondents were women. The background information revealed that the workplaces either had suspected IE-related problems (n=16 902, 58.7%) or the questionnaire was only for monitoring the state of perceived IE after IE-related repairs or refurbishment, for example (n=4244, 14.7%). Information on the purpose of the questionnaire in the workplaces was not included (n=7680, 26.6%) in the data. The responses from workplaces only monitoring the state of perceived IE (n=4224) were analysed as a subgroup.

The workplaces in the data were mainly categorised according to work done in office (n=206, 57% of workplaces), school (n=122, 18%) and health care (n=127, 25%) workplaces. The study focused on the IE questionnaire responses regarding perceived weekly symptoms and IE-related complaints. The office workplaces were from government sectors (39%), the public sector (21%), the private sector (34%), and other sectors (6 %). The schools were from government sectors (4%), the public sector (93%), and other sectors (3%). The school workplaces included universities, elementary and high schools, and schools of
applied sciences. The health care workplaces were from government sectors (2%), the public sector (75%), the private sector (19%), and other sectors (4%).

In Sub-study II–III, the selected buildings were part of the hospital districts’ real estate group. According to the background information, some of the buildings had previous IE-related problems. All the hospital districts’ buildings in the same area were selected for the studies. The condition of the buildings was examined, and the results of the building technology and IE investigations were divided into four categories of probability of abnormal IA exposure:

1. unlikely probability of abnormal IA exposure,
2. possible probability of abnormal IA exposure,
3. likely probability of abnormal IA exposure, and
4. very likely probability of abnormal IA exposure (method described in Chapter 3, Section 3.2.2).

The hospital buildings were categorised as floors or building sections (Figure 2). The selected sections were in the same building, the building technology was the same, and the age of the building and possible earlier renovations or refurbishment timing and characteristics were also the same. For reasons of hygiene, the building technology investigations were not performed in operating rooms, hospital pharmacies or other high-purity classified premises, and so were not included in Sub-studies II–III. All the assessed building floors were hospital wards, which were confined to their own airspace by fire doors and other doors. Public entrances, corridors or other public spaces were not included in the assessed sections, but their possible influence on the hospital wards’ IA were estimated.

**Selection of the data**

1. **Definitions:**

   - Building floor
   - Building section (two or more floors with technically same circumstances)

**Figure 2.** Data selected for Sub-studies II–III included indoor environment (IE) questionnaire results, employees’ group-level health information and assessments of probability of abnormal indoor air (IA) exposure in work environments.
The reason for forming building sections was that the IE questionnaire groups had to include more than 20 respondents for the questionnaire results to be valid. The results regarding the probability of abnormal IA exposure in 40 building floors or sections were selected. Questionnaires were sent to 3608 employees, of whom 2669 responded, with a response rate of 74% and a range of 51%–93%. Eighty-eight per cent of the respondents were women and the average age was 42. The results of 40 IE questionnaire groups (n=1558) were selected for the studies (Figure 2). The selection focused on floors and building sections that had one IE questionnaire group with the assessed probability of abnormal IA exposure category and with group-level employees' health information (Figure 2). The employees did not know the results of the building technology investigation before answering the IE questionnaires, and FIOHs’ researchers did not know the results of the IE questionnaires before the building technology investigations.

The hospitals’ OHS provided group-level information on the employees’ health as follows: (i) case of new onset asthma or aggravation of existing asthma, (ii) having to change workroom because of IAQ and work environment-related symptoms, (iii) increased amount of employee visits to OHS due to IAQ-related problems, and (iv) increased sickness absences due to respiratory symptoms. The information covered a total of 43 floors and building sections, and 40 groups were combined with IE questionnaire group information and with a category of probability of abnormal IA exposure (Figure 2). The group-level health information did not include information on how many employees had IE-related symptoms and illness.

The multiprofessional IA groups of the hospitals (specialist in building technology, maintenance and management; occupational safety and health care specialist) also provided information on the estimated duration of the IE-related problem-solving work on every building floor or in every section. All the work premises selected for the studies were in use.

3.2 Methods

3.2.1 Building, ventilation and IE investigation process (Sub-studies II–III)

In Sub-studies II–III, the condition of all the 27 hospital buildings and their floors (111) were investigated systematically and carefully according to the building technology and the IE investigations instructions (made before 2014) (Tables 3–7). All the premises were investigated, except for the operating rooms, hospital pharmacy and other high-purity classified premises. The same group of researchers carried out all the building, ventilation and IE investigations. All the data were analysed by the same multiprofessional group of experts, which comprised researchers, a structural engineer, an occupational health physician, a microbiologist, and a ventilation and building health specialist.

Phase one’s investigation process included all the surveys and assessments of building technology background information (Table 3). The documentation on the architectural, ventilation and structural plans, earlier refurbishment and
repairs, and possible building, ventilation and IE investigation reports, and measurements report surveys were examined. All the information on the building maintenance was also studied.

Table 3. Building, ventilation and indoor environment (IE) information survey and assessment conducted in investigation process Phase 1.

<table>
<thead>
<tr>
<th>Building, ventilation and indoor environment investigation process</th>
<th>Phase 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure and architectural plan surveys, earlier refurbishment and renovation plan surveys</strong></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Surveys of architecture, structure and renovation plans and possible earlier investigation and measurement reports from throughout the building’s life cycle.</td>
</tr>
<tr>
<td>Information implication</td>
<td>Identification of potential risk structures and impurity sources in IA1.</td>
</tr>
</tbody>
</table>

| **Surveys of ventilation plan, investigation and measurement reports** | |
| Description | Ventilation plans from throughout the building’s life cycle. Earlier investigation and measurement reports. |
| Information implication | Identification of potential deficiencies and impurities of the system and the suitability and adequacy of the system for its current purpose. |

| **Maintenance staff interviews for collecting background information** | |
| Description | Building-related information through interview and completed short forms. |
| Information implication | Summarised information describing building service and maintenance. Identification of potential deficiencies and condition of building technology. |

The purpose of Phase 2’s premises walkthroughs was to make observations regarding the condition and operation of the building technology, the IE and the use of the premises (Table 4). The earlier information on the building was used for planning and performing walkthroughs and observations.

Table 4. Building walkthroughs and observations in premises in investigation process Phase 2.

<table>
<thead>
<tr>
<th>Building, ventilation and indoor environment investigation process</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Premises walkthroughs</strong></td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Walkthrough in premises and observations regarding condition of the structure, smells, ventilation systems operation, indoor air pressure, moisture detection, impurity sources in the IA1, temperature, indoor air humidity, cleaning and use of the premises. Observations regarding building envelope, water control systems and building surroundings</td>
</tr>
</tbody>
</table>
Materials and methods

<table>
<thead>
<tr>
<th>Analysis method</th>
<th>Comparing the information and the design data (from plans) and their analyses and estimating measurement needs and other investigations in the building and premises.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information implication</td>
<td>Identification of potential deficiencies and IA(^1) impurity sources, observations regarding abnormal IE(^2), plans for structure openings and detailed measurements. Information for investigation plans.</td>
</tr>
</tbody>
</table>

**Investigation plans**

<table>
<thead>
<tr>
<th>Description</th>
<th>Drawing up an investigation plan for investigating building structures, ventilation system and IE(^2).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidelines for analysing results and information</td>
<td>National instructions for investigating building technology and IA(^1) (Finnish Ministry of the Environment, 1997).</td>
</tr>
<tr>
<td>Information implication</td>
<td>The investigation plan supports the ordering of the investigations, the investigation work itself and the management of the work.</td>
</tr>
</tbody>
</table>

\(^1\) IA=indoor air  
\(^2\) IE=indoor environment

In Phase 3, the examinations and openings of high-risk structures followed the investigation plan. High-risk structures had been defined in earlier phases (Phase 1–2) of the process. Assessments of air leaks from or through damaged structures were based on the information from earlier phases (Phases 1–2) of the process. Clear, visible air leakage pathways were not verified by measurements (Table 5).

Table 5. Building technology and indoor environment (IE) investigations were conducted in building investigation process Phase 3.

<table>
<thead>
<tr>
<th>Building, ventilation and indoor environment investigation process Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examinations and openings of high-risk structures</strong></td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Guidelines for analysing results and information</td>
</tr>
<tr>
<td>Information implication</td>
</tr>
</tbody>
</table>

| Moisture- and mould-damage range and severity authentications              |
| Description                                                                | Based on the information from earlier Phases 1–2 of the investigation process, necessary moisture detection and measurements on/in structure and material sampling were conducted to verify the humidity and condition of the structure, insulation and materials. |
| Guidelines for analysing results and information                            | National instructions for investigating building structure and IA impurity sources (Finnish Ministry of the Environment, 1997; Finnish Ministry of Social Affairs and Health, 2009). |
| Information implication                                                     | Part of IA\(^6\) impurity source range and severity authentication. |

| Assessments of air leaks from or through damaged structures                 |
| Description                                                                | Information on structure and renovation plans and possible earlier investigation and measurement reports from throughout the building’s life cycle. Identification of potential risk structure with air leakage paths (structure material, tightness and joints, penetrations of structures, etc). Clear air leakage pathways can be detected by observation, and smoke and tracer marker measurements can also be used. |
Phase four, the ventilation assessment, was part of the IA impurity source range and severity authentication and verified ventilation adequacy and functioning. The effect of ventilation on the functioning of structures and IE was also assessed (Table 6).

### Table 6. Ventilation system effects on indoor environment (IE) and air pressure differences between indoors and outdoors assessed in investigation process Phase 4.

<table>
<thead>
<tr>
<th>Description</th>
<th>Assessments of ventilation systems’ effects on IA(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walkthroughs of premises and machine rooms. Observations regarding ventilation systems’ operation and purify, adequacy and IA(^1) pressure between indoor and outdoor air, impurity sources (MMVF(^2), dust, damaged materials) in the IA(^1) and use of premises. Comparison of information with design data (from plans) and the use of the premises, estimate of the condition and necessary measurements and sampling.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Assessments of air pressure differences between outdoors and IA(^1) or between different premises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessments are based on earlier Phases 1–3 of the investigation process results and the information on the use of the premises and ventilation system deficiencies and investigations, and the results of the IA(^1) pressure measurements.</td>
<td></td>
</tr>
</tbody>
</table>

Phase five, the needs for IE measurements and sampling, was based on all the information on the investigation results, observations and information gathered in the whole investigation process (Phases 1–4). Necessary IAQ measurements, RH, air temperature, air movement, and material sampling were conducted in the cases in which the impurity source or its density (even a rough estimation) was unclear or unknown, other investigation or observation results showed risks of IA impurity sources, or observations had been made of inadequate ventilation or abnormal IA RH, temperature or air movement (draught).
Table 7. Necessary indoor air quality (IAQ) measurements taken in investigation process Phase 5.

<table>
<thead>
<tr>
<th>Building, ventilation and indoor environment investigation process Phase 5</th>
<th>Assessments of IA(^1) impurities or pollutant sources in the buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Based on the all above information on the investigation results, observations and information gathered in the whole investigation process. Necessary IAQ measurements (PAH(^2), TVOC(^3), VOC(^4), 2E1H(^5), TBIX(^6), micro-organisms, air RH(^7), air temperature, MMVF(^8)) and material sampling (PAH(^3), TVOC(^4), VOC(^5), 2E1H(^5), TBIX(^6), micro-organisms, asbestos) in cases in which the impurity source was unclear or unknown, other investigation or observation results showed risks of IA impurity sources and inadequate ventilation.</td>
</tr>
<tr>
<td>Guidelines for analysing results and information</td>
<td>National authorities’ instructions (Finnish Ministry of Social Affairs and Health, 2009), FIOH(^9)’s reference values for IAQ for workplaces (Salonen et al., 2007; Salonen et al., 2009a; Salonen et al., 2009b).</td>
</tr>
<tr>
<td>Information implication</td>
<td>Part of verifying IA(^1) impurity sources and IAQ(^2).</td>
</tr>
</tbody>
</table>

\(^1\)IA=indoor air  
\(^2\)PAH=polycyclic aromatic hydrocarbons  
\(^3\)TVOC= total volatile organic compounds  
\(^4\)VOC= Volatile Organic Compounds  
\(^5\)2E1H=2-Ethyl-1-hexanol  
\(^6\)TBIX=2,2,4-Trimethyl-1,3-pentanediol di-isobutyrate  
\(^7\)RH=relative humidity  
\(^8\)MMVF=man-made vitreous fibres  
\(^9\)FIOH=Finnish Institute of Occupational Health

The interpretation of the measurement results followed the national instructions for building investigations, the Finnish national instructions for the monitoring of the health-related conditions of housing and other residential buildings (Finnish Ministry of Social Affairs and Health, 2009), and FIOH’s reference values for workplaces’ IAQ (Salonen et al., 2007; Salonen et al., 2009a; Salonen et al., 2009b).

3.2.2 Assessment of probability of abnormal IA exposure (Sub-studies II-III)

In Sub-studies II–III, the results regarding the building, ventilation and investigation and measurements were categorised (n=95) into Category 1 to 4 of probability of abnormal IA exposure (Table 11).

The purpose of the method for assessing the probability of abnormal IA exposure is to obtain a clear picture of all the impurity sources and factors affecting the IE of a building and premises. The early model of the method was presented in the working group of the Ministry of Social Affairs and Health in 2009 (Finnish Ministry of the Social Affairs and Health, 2009). The method left too much room for interpretation and was not exact enough from the perspective of structural and building technology. During Sub-studies II–III, the method was developed and officially established in Finland in 2016 and was updated in 2017 (Lappalainen et al., 2017). The Finnish Ministry of the Environment published national guidelines for investigating buildings, moisture and IE in 2016 (Pitkäranta, 2016).

The method for assessing the probability of abnormal IA exposure (in Sub-studies II–III) is partly formed from parts of Finnish authorities’ instructions, made before 2014 (Finnish Ministry of Social Affairs and Health, 2009), the National Building Code of Finland (Finnish Ministry of the Environment, 1998,
2012) and earlier studies on the severity of mould and moisture damage (WHO, 2009; Mendell et al., 2011). All the information from the instructions is gathered and made into a practical, systematic and comprehensive method for assessing and scaling the probability of abnormal IA exposure.

To assess the probability of abnormal IA exposure, the building should be investigated using the process described in Tables 3–7 and Figure 3, and according to the latest guidelines for building structures, technology and IE investigations and the National building codes.

The results of the investigations (based on the results presented in Tables 3–7 and Figure 3 including all the described phases of investigations) form the baseline of the method, and cover the assessment of four different categories:

I. **Extent and range of moisture and mould damage in buildings**

Microbial damage is the harmful occurrence of bacteria and/or fungal spores in/on a structure (WHO, 2009; Mendell et al., 2011). In buildings, microbial damage can be on top of structures and materials as well as inside structures and on different structure layers. Evaluations must follow the national guidelines for building investigations (Finnish Ministry of the Environment, 1997), knowledge of hygrothermal behaviour impact on the structure type, and the national regulations on the health-related conditions of housing and other residential buildings (Finnish Ministry of the Environment, 1997).

The verified extent of microbial damage in the structures is assessed by:

- opening structures
- structural humidity measurements and
- microbiological analyses of material samples.

Assessment of the extent of damage is based on information on the:

- type of the structure
- hygrothermal behaviour impact on the structure type
- material properties
- IE circumstances (humidity, temperature)
- evaluation of mould contamination (Table 8).

The harmful occurrence of microbial damage is evaluated together with other investigation results (for example, air connection between damaged material and indoor air and pressure differences between indoor air and outdoor air/other spaces), which are presented in the following steps (II–IV).
Materials and methods

<table>
<thead>
<tr>
<th>Extent and Range of Moisture and Mould Damage in Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No mould damage in structures</td>
</tr>
<tr>
<td>2. Slight, limited mould damage in structures</td>
</tr>
<tr>
<td>3. Extensive mould damage in structures</td>
</tr>
<tr>
<td>S4. Extensive mould damage in several structures.</td>
</tr>
</tbody>
</table>

II. Air leaks and air pressure between indoor and outdoor air in building or between premises

The impact of an impurity source in the structure on IA is assessed on the basis of the structure's tightness and possible air leakage pathways (Table 8). High negative IA pressure in the building or in part of it increases the risk of air leakage through structural joints and penetrations of structures, whereby air flows may transfer impurities from structures into the IA (Airaksinen et al., 2004; Viitanen et al., 2010). The national building code (Finnish Ministry of Environment, 2012) previously required indoor and outdoor air pressure in the building design to be slightly negative (and, negative air pressure must not exceed 30 Pa). However, these regulations have now changed, and no precise numerical values have been given for the indoor and outdoor air pressure differences in the building design (Finnish Ministry of Environment, 2017) or the health-related conditions of housing and other residential buildings (Finnish Ministry of Social Affairs and Health 2015). National Supervisory Authority for Welfare and Health (Valvira, 2016) state that high negative IA pressure is 15 Pa and, the latest regulations (Finnish Ministry of Social Affairs and Health 2015; Finnish Ministry of Environment, 2017) state that pressure differences between indoor and outdoor air must not to cause impurities in the IA, detriment to the users of the premises, or damage to the structures of the building.

<table>
<thead>
<tr>
<th>Air Leaks and Air Pressure in Buildings or Premises</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No air leaks from or through damaged structures, no significant air pressure differences</td>
</tr>
<tr>
<td>2. A few or single air leaks from or through damaged</td>
</tr>
</tbody>
</table>
structures or from surrounding premises, no significant air pressure differences

3. Air leaks from or through damaged structures are regular and recurrent, air pressure differences change or negative pressure

Air leaks from or through damaged structures or from surrounding premises’ structures that have moisture or mould damaged materials are regular and recurrent. Air pressure differences change, and occasionally there is negative pressure (commonly 2…15 Pa) in the premises or building and/or the airtightness of the building or premises is risky \((n_{50}=3–4)\) (Finnish Association of Civil Engineers, 2013).

4. Air leaks from or through damaged structures are regular and recurrent, negative pressure is significant in the premises and or airtightness is risky

Air leaks from or through damaged structures or from surrounding premises’ structures that have moisture or mould damaged materials are regular and recurrent. Air pressure differences change, and occasionally there is negative pressure (commonly 2…15 Pa) in the premises or building and/or the airtightness of the building or premises is risky \((n_{50}=3–4)\) (Finnish Association of Civil Engineers, 2013).

1 \(IA=\text{indoor air}\)
2 \(Pa=\text{pascal}\)
3 \(n_{50}(1/h)=\text{air leakage rate at } 50 \text{ Pa}\)

### III. Impact of ventilation systems on IE

The effect of the ventilation system on the IE is assessed by the purity of the system, its functioning and the adequacy of the ventilation (Table 10).

#### Table 10. Main criteria for assessing impact of ventilation systems on indoor environment (IE). The 'Well-balanced and effective ventilation contributes to good indoor air quality (IAQ)' category is achieved only if all options fulfil the criteria (Tähtinen et al., 2018).

<table>
<thead>
<tr>
<th>Well-Balanced and Effective Ventilation Contributes to Good IE</th>
<th>Poor, Inoperative or Incorrectly Rated Ventilation System Can Reduce IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flows in premises correspond to Finnish guideline values and regulations ((6 \text{ dm}^3/\text{s}) per person, (1.5 \text{ (dm}^3/\text{s})/\text{m}^2)) (Finnish Ministry of the Environment, 2012).</td>
<td>Air flows in premises do not correspond to Finnish regulations or guideline values. Ventilation system has MMVF(^3) impurity sources in machinery and/or on duct materials.</td>
</tr>
<tr>
<td>Ventilation system has no sources of IA impurity.</td>
<td>Ventilation system materials contain asbestos and asbestos has been found on duct surfaces or on surfaces in the premises (the occurrence of asbestos fibres in dust accumulated on surfaces indicates that the action limit has been exceeded, or fibres have been found in the IA(^2) (the indoor concentration of asbestos fibres may not exceed 0.01 fibres/cm(^3)) (Finnish Ministry of Social Affairs and Health, 2009; Finnish Ministry of the Environment, 2012)).</td>
</tr>
<tr>
<td>Filtering level ((F7/G4)) of ventilation system’s supply air corresponds to Finnish guidelines and regulations (Finnish Ministry of the Environment, 2012).</td>
<td>Ventilation system has moisture- or mould damaged materials or impurity sources.</td>
</tr>
<tr>
<td>Condition of ventilation system is good, and the system is regularly serviced.</td>
<td>Ventilation system’s condition is poor (increased need for maintenance), or its functioning is uncertain.</td>
</tr>
<tr>
<td>Ventilation system maintenance is not regular, and the system’s parts are dirty and dusty.</td>
<td></td>
</tr>
</tbody>
</table>

1 \(F7=\text{separation of } 1.0 \mu \text{m particles minimum } 80\% \text{ (Finnish Ministry of the Environment, 2012)}\)
2 \(G4=\text{off-site of town or industry, coarse filter (Finnish Ministry of the Environment, 2012)}\)
3 \(\text{MMVF=man-made vitreous fibres}\)
IV. **Assessment of other IA impurities from the building or its use**

Impurity sources should be identified through building technology investigations. Measurements in general should only be conducted if impurity sources or concentrations are strongly suspected in the IA (Carrer & Wolkoff, 2018), if the impurity source is unclear or unknown, other investigation or observation results show risks of IA impurity sources, or if inadequate ventilation. If impurity concentrations are measured in the IA, the results should be interpreted with reference and limit values as appropriate for the purpose (the use of the premises e.g. offices, schools, public premises). IA measurement results form part of the assessment of the probability of abnormal IA exposure when appropriate. IA measurement results cannot generally reduce the level of probability of abnormal IA exposure assessment on the basis of building and technical investigation results because concentrations of impurities in the IA are determined by several factors, including ventilation rate and type, emission rates from sources, and materials’ ability to emit or absorb compounds (SCHER, 2007; Holos et al., 2018). These concentrations can vary in time and space (Zabiegala, 2006; Nevalainen et al., 2015). Measured high IA concentrations; abnormal spaces, emissions, particles (results over the limit or reference values for the environment), or other impurities’ concentrations in the IA increase the severity of the probability of abnormal IA exposure.

The probability of abnormal IA exposure should be assessed using the criteria in Tables 8 and 10, in accordance with those in Table 11. In cases of moisture and mould damage, air leaks from or through damaged structures into the IA must be assessed simultaneously with IA negative pressure. Not all criteria need to be met, but the most significant IA impurity source in Tables 8 and 9 must be predominant. The final assessment of the probability of abnormal IA exposure in Table 11 follows the selected predominant factors. The impact of the ventilation system on IA (Table 10) and other possible measured IAQ results must be considered simultaneously with the final result of the assessment of the probability of abnormal IA exposure (Table 11).

The main criteria for the probability of abnormal IA exposure are as follows: (1) unlikely probability of abnormal IA exposure, (2) possible probability of abnormal IA exposure, (3) likely probability of abnormal IA exposure, and (4) very likely probability of abnormal IA exposure (Table 11).
Table 11. Main criteria and categories for assessing probability of abnormal indoor air (IA) exposure in buildings/floors and building sectors. In cases of moisture and mould damage, air leaks through or from damage to IA must be looked at simultaneously with indoor negative pressure. The predominant IA impurity source is the determining source (Tähtinen et al., 2018; Tähtinen et al., 2019).

<table>
<thead>
<tr>
<th>Categories</th>
<th>Main Criteria for Assessing Probability of Abnormal IA Exposure in Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlikely</td>
<td>✓ No moisture or mould damage in structures.</td>
</tr>
<tr>
<td></td>
<td>✓ No air leaks from or through damaged structures.</td>
</tr>
<tr>
<td></td>
<td>✓ Ventilation system can be controlled by indoor pressure difference from the building envelope.</td>
</tr>
<tr>
<td></td>
<td>✓ Room’s acoustic materials and ventilation system have no MMVF sources.</td>
</tr>
<tr>
<td></td>
<td>Possible mould-damaged structure type is not widespread in building and it is easily definable (less than 1 m²).</td>
</tr>
<tr>
<td></td>
<td>✓ A few or single air leaks from or through damaged structures or from surrounding premises.</td>
</tr>
<tr>
<td></td>
<td>✓ Room’s acoustic materials or ventilation system have MMVF sources and fibres may end up in the IA or on surfaces.</td>
</tr>
<tr>
<td></td>
<td>✓ Concrete floor has extensive moisture, which can cause water vapour damage to permeable floor coating (emissions).</td>
</tr>
<tr>
<td></td>
<td>✓ IAQ does not correspond to national reference values or the guidelines set for the premises, and IA impurity source has been identified.</td>
</tr>
<tr>
<td>Likely</td>
<td>✓ Building or premises have widespread mould-damaged structure.</td>
</tr>
<tr>
<td></td>
<td>✓ The damage is significant and affects a large part of the (one) structure, in the building or premises, e.g., whole base floor structure.</td>
</tr>
<tr>
<td></td>
<td>✓ The damage in the type of the structure is recurrent.</td>
</tr>
<tr>
<td></td>
<td>✓ Air leaks from or through the damaged structure or from surrounding premises and moisture or mould damaged materials are regular and recurrent in the structure.</td>
</tr>
<tr>
<td></td>
<td>✓ Occasionally there is negative pressure in the premises and/or airtightness is risky.</td>
</tr>
<tr>
<td></td>
<td>✓ IAQ does not correspond to national reference values nor the guidelines set for the premises, and an IA impurity source has been identified.</td>
</tr>
<tr>
<td></td>
<td>✓ Creosote has been used in the structure and air leaks into the IA from the structure.</td>
</tr>
<tr>
<td></td>
<td>✓ There is a notable smell of creosote (e.g., naphthalene) in the IA.</td>
</tr>
<tr>
<td>Very likely</td>
<td>✓ The building or premises has a great deal of extensive mould damage in several structures.</td>
</tr>
<tr>
<td></td>
<td>✓ The damage is significant and affects several structures in the building or premises e.g., whole façade and whole base floor.</td>
</tr>
<tr>
<td></td>
<td>✓ The damage in the type of structure is recurrent.</td>
</tr>
<tr>
<td></td>
<td>✓ Air leaks from or through damaged structures are regular and recurrent, negative pressure is significant in the premises and/or airtightness is very risky.</td>
</tr>
<tr>
<td></td>
<td>✓ IAQ does not correspond to national reference values nor the guidelines set for the premises, and an IA impurity source has been identified.</td>
</tr>
<tr>
<td></td>
<td>✓ Creosote has been used in the structures and air leaks into the IA from the structures.</td>
</tr>
<tr>
<td></td>
<td>✓ Concentrations of PAH or separate components exceed the set national values and guidelines (Finnish Ministry of the Environment, 2012).</td>
</tr>
<tr>
<td></td>
<td>✓ Dust sample tests have found asbestos fibres in the premises, and the pollution source has been defined.</td>
</tr>
</tbody>
</table>

1 MMVF=man-made vitreous fibres
2 IAQ=indoor air quality
3 The extent and impact of the problem and impurity source must be taken into account in the assessment
4 PAH=polycyclic aromatic hydrocarbons

The criteria are only for guidance. The researcher’s competence (building technology, building health, IAQ) in assessing all the factors and investigation results (Figure 3) is always of great importance. Therefore, a multiprofessional team should make the final assessment of the probability of abnormal IA exposure. Studies II–III used a multiprofessional team to interpret the results regarding the condition of the building, the IAQ and the IA.
Materials and methods

Figure 3. Process for investigating building technology and probability of abnormal IA exposure in Sub-Studies II–III (Tähtinen et al., 2019).

Explanations:
= progression of the process
= cooperation
= products during the process
= use of instructions
= goals

Urgency of measures:
Assessment of probability of abnormal IA exposure
Health and experience information from users of premises and Indoor air questionnaire results
When the guidelines in Tables 3–10 and Figure 3 and the national guidelines for building investigations and IAQ are followed, the scope and depth of the building technology and IE investigation is sufficient. Following the guidelines can also lead to the building and its systems not requiring wider investigations. This decision can be made when the background information, maintenance and possible indoor air group interviews and walkthroughs have been conducted and their results evaluated. In these cases, the necessity of the investigations are thoroughly evaluated. In this phase, the building, IA and ventilation experts’ role and proficiency are highlighted. Every building is different, and their investigation needs are of different scales and depths. After the investigation process is completed, the probability of abnormal IA exposure can be assessed.

3.2.3 Content and realisation of indoor environment questionnaires (Sub-studies I–III)

The questionnaire used in Sub-studies I–III were FIOH’s IE questionnaire (Hellgren et al., 2008), based on the IE questionnaire of the Örebro MM-40 (Andersson, 1998) and modified slightly by FIOH in 2006–2008 (Hellgren, 2012). The link to the questionnaire was emailed to the employees with a survey information letter. The employees responded to the questionnaire online. The survey was voluntary. As the data of the IE questionnaire were processed in Sub-studies I–III without personal identification of the respondents and without the names of the buildings, no individual respondents or buildings could be identified. According to Finnish legislation, questionnaire-based surveys in which participation is voluntary and which conduct no intervention on individuals do not require ethics committee processing.

The respondents had to have mainly worked in the premises (three days a week) that the questionnaire concerned, for at least three months. The questionnaire asked whether they associated their symptoms with their work environment, and whether they perceived symptoms weekly. The complaints about the work environment concerned the last three months.

FIOH’s questionnaire is divided into four parts and contains questions on:

1) IE: draught, stuffy and dry air, insufficient ventilation, mould or other unpleasant odours, room temperatures, tobacco smoke, noise, dim light or reflections, and dust or dirt.

2) Work arrangements: Do you regard your work as interesting and stimulating? Do you have too much work? Are you able to influence your working conditions? Do your fellow workers help you with work-related problems? The response options are: (1) yes, often, (2) yes, sometimes (3) no, seldom or rarely (4) no, never.

3) Individual allergy history: individual allergy history such as past or present asthma, allergic rhinitis, or atopic eczema.
4) IE-related symptoms: fatigue, headaches, heavy-headedness, concentration difficulties, fever or chills, irritation of the eyes, hoarse or dry throat, coughing at night, irritation of the nose, coughing, wheezing, shortness of breath, irritation of the skin on the face, joint pain, irritation of the skin on the hands, and muscular pain. To study perceived stress, a validated measure of questions on stress symptoms is used (Elo et al., 2003): ‘Stress means a situation in which a person feels tense, restless, nervous or anxious or is unable to sleep at night because his/her mind is troubled all the time. Do you feel this kind of stress these days?’ The response options are: (1) not at all, (2) just a little, (3) some, (4) quite a lot, and (5) very much. In the analyses (Sub-studies II and III), we combined (1) not at all and (2) just a little into one level, and (4) quite a lot and (5) very much into one level.

In Parts 1, 2 and 4 the questions have three response options: ‘yes, often’, ‘yes sometimes’ and ‘no, never’. In Sub-studies I–III we focused on the IE-related symptoms and complaints that occurred weekly and the response alternative ‘yes, often’. We did not use the information on employees’ individual allergy history in Sub-studies I–III.

3.2.4 Statistical analyses (Sub-studies I–III)

**Sub-study I** used the SPSS 25.0 (SPSS Finland Oy, Espoo, Finland) program to study the IE questionnaire’s response percentages, confidence intervals and distributions for office, school and health care environments. In the analyses, the confidence intervals for percentages were calculated on the basis of normal distribution.

**Sub-studies II–III** used the SPSS 24.0 and 25.0 (SPSS Finland Oy, Espoo, Finland) program with a statistically significant level of \( p < 0.05 \). The statistical analysis used weighted means of group IE questionnaire response rates. The Mann–Whitney-U test studied the differences between the probability of abnormal IA exposure categories (unlikely, possible, likely, and very likely) and the IE questionnaire responses (addressed at group level) concerning employees’ work-related symptoms, environmental complaints and psychosocial work environment. The Mann–Whitney-U test also compared the difference between the two groups’ (yes/no) ventilation adequacy, ventilation MMVF sources, ventilation moisture problems, and expired ventilation lifespan, as well as the employees’ IE-related complaints and symptoms. Fisher’s exact test studied the association between the probability of abnormal IA exposure categories and the categorised group-level information on employees’ health. The group-level health information was categorised as ‘yes’ and ‘no’ as follows: case of new onset asthma or aggravation of existing asthma, having to change workroom or workplace because of work environment-related symptoms, increased number of employees’ OHS appointments, and increased sickness absences due to respiratory symptoms.
4. Results

4.1 Perceived indoor environment, symptoms and psychosocial work environment in office, school and health care workplaces in Finland (Sub-study I)

4.1.1 Indoor environment-related complaints (Sub-study I)

IE-related complaints differ in office, school and health care environments in Finland (Figure 4).

The health care employees reported stuffy air over 15% more often, dry air and insufficient ventilation over 22% more often, and mould odour and unpleasant odours over 18% more often than the office employees (Figure 4). The calculated confidence level was 95% (Appendix I).

In Sub-study I, the background information on the workplaces was divided into two categories: (a) the workplace had suspected IE-related problems and a survey conducted to study the perceived IE and extent of the problem, and (b) questionnaire survey conducted to only monitor the state of perceived IE (e.g. after IA-related repairs or refurbishment).
Figure 5. Indoor environment (IE)-related complaints at workplaces that were only monitoring the state of perceived IE.

Figure 5 demonstrates the IE-related complaints among the health care employees in the subgroup of workplaces that only monitored the state of perceived IE. IE-related complaints were also general in these health care workplaces and complaints were more often reported than among the school and office employees. The IE-related complaints most often made by health care employees concerned stuffy and dry air, insufficient ventilation, unpleasant odours and draught. Stuffy air was reported more often in the workplaces only monitoring the state of perceived IE than in the workplaces with suspected IE-related problems (Figures 4 and 5).

Figure 6. Indoor environment (IE)-related weekly complaints (%) P25–95 distribution of responses (N=7040) in health care workplaces.
Figure 6 shows the distribution of perceived IE-related weekly complaints in the health care workplaces. The mean values of the IE-related complaints (Figure 4) are between the P50–P75 values of the data (Figure 6).

4.1.2 Indoor environment-related symptoms (Sub-study I)

Perceived IE-related symptoms differed in the office, school and health care environments. The health care employees perceived irritation of the nose over 17% more often and irritation of the eyes over 16% more often than the office employees. The most often perceived symptoms among the health care employees were irritation symptoms; hoarse, dry throat; shortness of breath; fatigue; and feeling heavy-headed (Figure 7). The calculated confidence level was 95% (Appendix II).

Figure 7. Indoor environment (IE)-related weekly symptoms (%) in offices, schools and health care workplaces.

In Sub-study I, the background information of the workplaces was divided into two categories: (a) the workplace had suspected IE-related problems and a survey was conducted to study the perceived IE and the extent of the problem, and (b) questionnaire survey conducted to only monitor the state of perceived IE (e.g. after IA-related repairs or refurbishment).
Figure 8. Indoor environment (IE)-related weekly symptoms (%) in workplaces that were only monitoring the state of perceived indoor air (IA).

Figure 8 illustrates the IE-related symptoms at the workplaces that were only monitoring the stage of perceived IA (e.g. after IA-related repairs or refurbishment). IE-related symptoms were also common in these workplaces. The most often perceived symptoms among the health care employees were irritation symptoms; feeling heavy-headed; fatigue; and hoarse, dry throat. Irritation of the eyes and nose and fatigue were more often reported in the workplaces only monitoring the state of perceived IE than in the workplaces with a suspected IE-related problem (Figures 7 and 8).

Figure 9. Indoor environment (IE)-related weekly symptoms (%) P25–95 distribution of responses (N=7040) in health care workplaces.
Figure 9 shows the distribution of perceived IE-related weekly symptoms in the health care workplaces. The mean values of the IE-related symptoms (Figure 7) are between the P50–P75 values of the data (Figure 9).

4.1.3 Psychosocial work environment and stress (Sub-study I)

Figure 10 summarizes the perceived psychosocial work environment in office, school and health care workplaces. The reported experience of stress ‘quite a lot and very much’ among the employee groups was between 15% and 17%. The health care employees more often received help from their colleagues than the other groups. The calculated confidence level was 95% (Appendix III).

Figure 10. Experience of psychosocial work environment in office, school and health care workplaces in Finland.

The health care employees perceived their work as more interesting and stimulating than the office employees. The health care employees more often felt that they had too much work to do than the school employees and they were more rarely able to influence their working conditions than the school and office employees. The health care employees felt that they received help from their fellow-workers in their work more often than the office and school employees (Figure 10).

4.2 Probability of abnormal IA exposure (Sub-studies II–III)

The probability of abnormal IA exposure was assessed in the investigated hospital building floors or building sections (n=95). All the assessed building floors or sections were hospital wards, which were confined to their own airspace by fire doors and other doors. Public entrances, corridors or other public spaces were not included in the assessed floors and sections, but their possible influence on the hospital wards’ IA were taken into account. The probability of abnormal IA exposure was classed into unlikely (7% of building floors or sections),
Results

possible (41%), likely (39%) and very likely (13%) categories. Over half of the floors or building sections were assessed as work premises with many impurity sources that were likely to negatively affect the IA (likely category 39% and very likely category 13%). They mainly had moisture and mould damage, but the IA also had other impurity sources. The moisture and mould damage in the building was most typically in the structures that faced the ground, typically in the basement, and these floors and sections were more often placed in the very likely category than the other building floors. Technology channels (a horizontal or vertical case or structure with heating or sewer pipes) in the premises were common and often had moisture- and mould-damaged materials with air leaks into the IA of the workplace. In addition, intermediate floors with double concrete structures and insulation inside the structure were frequently damaged.

Damage and sources of impurities related to structures, structure layers and materials were the most common on structures facing the ground. These structures were generally old, the life cycle of their materials had exceeded, they functioned defectively and had moisture and mould damage on their surfaces, as well as other damage in their coatings. The materials of the old (1940s–1960s) concrete floor structures had been damaged during and after the construction phase or through, for example, current use of bathrooms or kitchens. In general, the tightness of the structures and structure joints was deficient, and often there were air pathways through the structures or between their layers.

Air leakage paths were regular in the structures and between their joints. Insufficient ventilation for the premises was common in the possible, likely and very likely probability of abnormal IA exposure categories.

The building floors or sections contained several different ventilation systems and machines that served different parts of the building. The repairs, refurbishment, maintenance, reliability, and age of the ventilation systems varied across the floors and building sections. In all the categories (unlikely, possible, likely and very likely), more than a half of the ventilation systems’ lifespans were exceeded. The MMVF source was commonly in the ventilation system when the system’s lifespan had been exceeded.

In most of the buildings investigated, the factors influencing IA were identified as originating from structures, materials, ventilation, and activities. Generally, several IA impurity sources were present at the same time. The more likely the assessed category of probability of abnormal IA exposure, the more deficiencies the ventilation system had.

4.3 Perceived indoor environment, psychosocial work environment and stress in categories of probability of abnormal indoor air exposure (Sub-studies II–III)

4.3.1 Indoor environment-related complaints in categories of probability of abnormal indoor air exposure (Sub-study II)

Figure 11 presents the employees’ IE-related complaints in the investigated hospitals and in the assessed of probability of abnormal IE exposure categories. The more probable the abnormal IA exposure was assessed as being, the more the
employees’ reported IE-related discomfort from the smell of mould and unpleasant odours.

![Graph showing employees' indoor environment (IE)-related complaints in probability of abnormal indoor air (IA) exposure categories compared with reference values (Hellgren et al., 2008).](image)

**Figure 11.** Employees’ indoor environment (IE)-related complaints (%) in probability of abnormal indoor air (IA) exposure categories compared with reference values (Hellgren et al., 2008).

The smell of mould was more often perceived in the very likely probability of abnormal IA exposure category and the researchers also detected the smell of mould in these premises during the building investigation. Stuffy air was more often perceived in the likely probability of abnormal IA exposure category. Stuffy air and insufficient ventilation exceeding FIOH’s reference values (Hellgren et al. 2008) were perceived in all the categories of abnormal IA exposure.

### 4.3.2 Indoor environment-related symptoms in categories of probability of abnormal indoor air exposure (Sub-study III)

Figure 12 demonstrates the employees’ weekly IE-related symptoms in health care buildings and in the assessed probability of abnormal IA exposure categories.
The most often perceived symptoms were in the likely probability of abnormal IA exposure category. In all the categories of probability of abnormal IA exposure, the most often perceived symptoms were different irritation symptoms. Irritation of the nose and fatigue were perceived most often in the likely abnormal IA exposure category. Irritation of the eyes and skin on the face were perceived more often than FIOH’s earlier reference data showed (Hellgren et al., 2008).

4.3.3 Psychosocial work environment and stress in categories of probability of abnormal indoor air exposure (Sub-study III)

Most of the employees (88%) felt that their work was often stimulating and interesting, 74% believed they would receive help from their colleagues if needed, 53% had no feelings of stress and 21% often had the opportunity to influence their own work and working conditions. Fourteen per cent of employees reported a heavy workload. Stress (16% of respondents) and lack of help (4% of respondents) from colleagues were perceived more often than in FIOH’s comparable reference data (Hellgren et al., 2008) (Figure 13).
Results

Employees more often reported heavy workload in the possible (26%) and very likely (27%) abnormal IA exposure categories. Stress was more often perceived in the unlikely (26%) abnormal IA exposure category than in the other categories. Work was more often perceived as interesting and stimulating in the likely (90%) abnormal IA exposure category than in the other categories (Figure 13).

4.4 Information from occupational health services and indoor air groups for categories of probability of abnormal indoor air exposure (Sub-studies II–III)

According to OHS group-level information on employees’ health (43 groups), the amount of sickness absence due to respiratory symptoms and the number of employees’ OHS appointments due to IAQ-related issues had increased in all the categories of abnormal IA exposure. In addition, some employees had changed their work premises or workplace due to IAQ-related symptoms and some employees had new asthma onset or aggravation of previous asthma in all the categories of probability of abnormal IA exposure (Table 12).

Table 12. Occupational health services’ group-level information on employees’ health in investigated buildings and in assessed categories of probability of abnormal indoor air (IA) exposure.

<table>
<thead>
<tr>
<th>OHS group-level information on employees’ health and IAQ-related problems</th>
<th>Unlikely n=2 (%)</th>
<th>Possible n=16 (%)</th>
<th>Likely n=20 (%)</th>
<th>Very likely n=5 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some employees had new asthma onset or aggravation of previous asthma</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (100)</td>
<td>5 (31)</td>
<td>5 (25)</td>
<td>3 (60)</td>
</tr>
<tr>
<td>No</td>
<td>0 (0)</td>
<td>10 (63)</td>
<td>14 (70)</td>
<td>2 (40)</td>
</tr>
<tr>
<td>No information</td>
<td>0 (0)</td>
<td>1 (6)</td>
<td>1 (5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Some employees had changed work premises or workplaces due to IAQ-related symptoms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>1 (50)</td>
<td>4 (25)</td>
<td>4 (20)</td>
<td>2 (40)</td>
</tr>
<tr>
<td>No</td>
<td>1 (50)</td>
<td>13 (80)</td>
<td>16 (80)</td>
<td>3 (60)</td>
</tr>
<tr>
<td>No information</td>
<td>0 (0)</td>
<td>1 (6)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>The amount of employee’s OHS appointments due to IAQ-related issues had increased</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2 (100)</td>
<td>5 (31)</td>
<td>10 (50)</td>
<td>3 (60)</td>
</tr>
<tr>
<td>No</td>
<td>0 (0)</td>
<td>10 (63)</td>
<td>10 (50)</td>
<td>2 (40)</td>
</tr>
<tr>
<td>No information</td>
<td>0 (0)</td>
<td>1 (6)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

Figure 13. Perceived psychosocial work environment and stress (%) according to categories of probability of abnormal IE exposure.
The amount of sickness absence due to respiratory symptoms had increased.

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>No information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 (50)</td>
<td>0 (0)</td>
<td>1 (50)</td>
</tr>
<tr>
<td>4</td>
<td>4 (25)</td>
<td>7 (44)</td>
<td>5 (31)</td>
</tr>
<tr>
<td>8</td>
<td>8 (40)</td>
<td>11 (55)</td>
<td>1 (5)</td>
</tr>
<tr>
<td>1</td>
<td>1 (20)</td>
<td>3 (60)</td>
<td>1 (20)</td>
</tr>
</tbody>
</table>

The group-level health information does not contain information on how many employees have IAQ-related health symptoms on specific building floors or sections, nor on the assessed categories. IAQ=indoor air quality; OHS=occupational health services.

The hospitals’ multiprofessional IA group provided information on the duration of IE-related problems in the assessed building floors or sections (n=40). The duration of the efforts to solve IE-related problems (problems lasting one year or more) was longer in the very likely (100% of the cases), likely and possible (44% of the cases) abnormal IA exposure categories. No IE-related problems were estimated in the unlikely (50% of cases), possible (44% of cases), likely (33% of cases) and very likely (0% of cases) abnormal IA exposure categories.

4.5 Association between abnormal indoor air exposure categories and perceived indoor environment, psychosocial work environment, stress and health information (Sub-studies II–III)

The statistical analysis of the differences between the probability of abnormal IA exposure categories (unlikely, possible, likely and very likely) and the employees’ IE-related complaints revealed a significant difference (p=0.042) between the unlikely and likely groups in terms of the smell of mould. No other statistically significant differences were revealed between the probability of abnormal IA exposure categories (unlikely, possible, likely, very likely) and employees’ weekly IE-related complaints and symptoms.

Statistically significant differences did not emerge between the probability of abnormal IA exposure categories (unlikely, possible, likely, very likely) and the employees’ experience of psychosocial work environment and stress.

An analysis of the differences between the probability of abnormal IA exposure categories (unlikely, possible, likely, very likely) and the group-level information on employees’ health revealed no statistically significant differences.

4.5.1 Association between ventilation deficiencies and perceived indoor environment (Sub-studies II–III)

The statistical analysis of the differences (p<0.05) between the ‘yes’ and ‘no’ groups (categorisation based on building investigation results) in terms of (i) insufficient ventilation for the premises and their purposes, (ii) expired ventilation system lifespan, (iii) MMVF sources in ventilation system and (iv) moisture problems in the ventilation system and employees’ weekly IE-related complaints revealed statistically significant differences in the following: insufficient ventilation and dirt and dust; MMVF source in ventilation system and stuffy air.

The statistical analysis of the differences (p<0.05) between the ‘yes’ and ‘no’ groups (categorisation based on building investigation results) in terms of (i) insufficient ventilation for the premises and their purposes, (ii) expired ventilation system lifespan, (iii) MMVF sources in ventilation system and (iv) moisture problems in ventilation system and employees’ weekly IE-related symptoms revealed statistically significant differences in the following: insufficient
ventilation for the premises and their purposes and hoarse, dry throat and wheezing; expired ventilation system lifespan and irritation of the eyes, headaches, concentration difficulties, hoarse, dry throat, coughing, coughing at night, joint pain, wheezing, shortness of breath, muscular pain and irritation of skin on hands; and MMVF sources in ventilation system and irritation of the eyes, headaches, concentration difficulties, hoarse, dry throat, fatigue, irritation of the nose, coughing, muscular pain and irritation of skin on hands.
5. Discussion

5.1 Perceived indoor environment and psychosocial work environment in health care workplaces

The purpose of Sub-study I was to investigate perceived IE-related complaints, symptoms and psychosocial work environment and to collect new reference material for interpreting the IE questionnaire results from health care workplaces.

Previous corresponding research results and reference data on Finnish work environments are mainly from the 2000s (Lahtinen et al., 2004b; Reijula & Sundman-Digert, 2004; Hellgren et al., 2008).

The background information on the workplaces was divided into two categories: (a) the workplace had a suspected IE-related problem and a survey was conducted to study perceived IE and the extent of the IE-related problem, and (b) the questionnaire survey was conducted to only monitor the state of perceived IE (e.g. after IE-related repairs or refurbishment). The responses from the workplaces only monitoring the state of perceived IE were examined in subgroups.

There was no current information on the organisations’ situation and condition of the buildings. More advanced statistical analyses of the symptoms and the psychosocial work environment, and the symptoms and individual factors were excluded from the Sub-study I. Thus, Sub-study I was unable to draw far-reaching conclusions concerning the reasons affecting IE-related complaints, symptoms and psychosocial work environment.

5.1.1 Symptoms and complaints

IE-related symptoms. According to the results of Sub-study I, there were significant differences between the prevalence of perceived IE-related symptoms in office, school and health care workplaces.

The most often perceived symptoms among the health care employees were irritation symptoms of the nose and skin, fatigue, feeling heavy-headed, and a hoarse, dry throat. Various symptoms of irritation, headache, hoarse throat, coughing, and concentration difficulties were common and had increased from previous corresponding Finnish studies in health care conducted in 2006 and 2008 (Hellgren & Reijula, 2006; Hellgren et al., 2008). Perceived IE-related symptoms were as common in the health care workplaces with suspected IE-
related problems as in the subgroup of health care workplaces only monitoring the state of perceived IE.

Sub-study I’s results support those of earlier studies (Hellgren et al., 2008; Chang et al., 2015; Keyvani et al., 2017; Loupa et al., 2017; Rautiainen et al., 2018; Kalender Smajlović et al., 2019) that show a higher prevalence of IE-related symptoms among hospital employees than among office employees (Andersson, 1998; Hellgren et al., 2008; Magnavita, 2015). The most often perceived symptoms were irritation symptoms, and another recent study (Rautiainen et al., 2018) has shown similar results in terms of irritation symptoms among health care employees. One factor in the irritation symptoms may be partly due to hospital work that required several chemical products and employees frequently washing their hands (Aarnio et al., 2005). The results of Sub-study I are also similar to those of the study by Rautiainen and colleagues (2018), which reported increasing perceived symptoms among health care workplaces.

IE-related complaints. According to the results of Sub-study I, there were significant differences between the prevalence of reported IE-related complaints in office, school and health care workplaces. Reported IE-related complaints were as common in the health care workplaces with suspected IE-related problems as in the health care workplaces that were only monitoring the state of perceived IE. The health care employees more rarely perceived noise and too high room temperatures than in previous studies (Hellgren & Reijula, 2006; Hellgren et al., 2008). The most commonly reported IE-related complaints were stuffy and dry air, and mould and other unpleasant odours, and these were reported more often than in the corresponding study by Hellgren and colleagues (2008). The results of Sub-study I also support an earlier Finnish follow-up study’s (Aarnio et al., 2005) results, which stated that IE-related complaints of stuffy air, odour, dry air, and high room temperature were experienced increasingly more often each year.

Although no information on the condition of the buildings was available in Sub-study I, it is known that health care buildings are commonly old (Reijula et al., 2012; Hellgren, 2012; Reijula et al., 2012; Leskelä et al., 2016) and that in 15% of floor areas of Finnish hospital buildings are in need of repair (Reijula, 2005). Moreover, the prevalence of significant moisture and mould damage is estimated to be 20% to 26% of floor areas of health care institutions in Finland (Reijula et al., 2012). In comparison, based on the same research by Reijula and colleagues (2012), in schools, the estimated prevalence of significant mould and moisture damage is 12% to 18% and in offices 2.5% to 5% of floor areas. Nordström (1999) has found that mould damage can strengthen users’ experience of stuffy air, and several other studies (Reponen et al., 2010; Cho et al., 2016; Täubel et al., 2016; Mendell & Kumagai, 2017) have found that mould odour indicates mould damage in a building. It is also known that mould damage in premises are associated with respiratory symptoms (Park, 2004; Patovirta, 2004; Mendell & Kumagai, 2017). In the light of this knowledge, the building and its condition may also be considered a potential factor contributing to the results of Sub-study I.
An interesting result of Sub-study I is that perceived IE-related symptoms and reported complaints were as common in the workplaces with suspected IE-related problems as in the workplaces only monitoring the state of perceived IE. Although there was no information on why the workplaces were monitoring perceived IE, it is known that this monitoring is a general measure after IE-related repairs. IE-related repairs may possibly have been unsuccessful and IE-related complaints and symptoms could also have been slightly higher than in a random sample. On the other hand, Brauer and Mikkelsen (2010) reported that in their study, some employees had perceived IE-related problems even though no IE-related problems had been detected. Bakke and colleagues (2007) and Rautiainen and colleagues (2018) also reported study results of IE-related symptoms and complaints of employees in buildings and premises with no detected building-related factors or IA impurities. Sub-study I had no current information on the condition of the buildings or any other information on the organisations’ situations. Hence, far-reaching conclusions cannot be drawn regarding the organisations’ situations, the condition of the buildings or their impacts on the results of Sub-study I.

5.1.2 Psychosocial work environment, stress and individual factors

**Psychosocial work environment and stress.** In Sub-study I, health care employees were more likely to find their work inspiring and interesting, they less often had too much work and they more often felt they received help from their fellow-workers. The health care employees experienced less stress than the school or office employees. In addition, they were more likely to be able to influence their work or working conditions than before (Hellgren et al., 2008). The results of Sub-study I support those of several others; they found that hospital employees considered their work interesting and stimulating and that they often received help from their fellow-workers (Hellgren et al., 2008; Stankovic et al., 2008; Loupa et al., 2017). However, in Sub-study I the health care employees also more often and more extensively reported IE-related complaints and symptoms than the school and office employees.

Hellgren and colleagues (2008) reported no significant association among hospital employees between psychosocial work environment, symptoms and buildings needing repairs, but they did experience heavy workload. Heavy workload, general symptoms and buildings needing repairs were interconnected, and in this case heavy workload explained fatigue and concentration difficulties better than buildings needing repairs (Hellgren et al., 2008). However, although several studies do report a relation between employees’ IE-related complaints, symptoms and psychosocial work environment (Lahtinen et al., 2004b; Runeson & Norbäck, 2005; Runeson, 2006; Runeson et al., 2006; Bakke et al., 2007; Hellgren et al., 2008; Brauer & Mikkelsen, 2010; Azuma et al., 2017), their detailed building investigation results rather rarely explained the associations between psychosocial work environment and symptoms.

**Individual factors.** Brauer and colleagues (2010) highlighted the role of the psychosocial work environment, on the individual level, in the differences between employees’ perceived IE. A Finnish study (Finell & Seppälä, 2018) of the
working population suggested that the risk of experiencing the workplace as harmful was higher among employees who reported mould problems than among those who reported ventilation deficiencies at the workplace. The results of Sub-study I were similar; the employees perceived symptoms and poor IE more often in the workplaces only monitoring the state of the IE than in the workplaces with a suspected IE-related problem.

Runeson’s study (2006) found that female employees more often reported symptoms than male employees and suggested that this may be due to differences in experience of the psychosocial work environment. In Sub-study I, 70% of the respondents were women, and this may have affected the results, which showed more often reported symptoms and complaints. A literature review by Norbäck (2009) also showed that individual factors such as gender, atopy and smoking habits were associated with building-related symptoms. According to Jaakkola and Jaakkola (2010), IE factors or combinations of factors may cause different types of symptoms and health issues in different individuals, depending on the various mechanisms involved and personal susceptibility. In addition, in Magnavita’s study (2015) of employees, 2%–25% of the explanatory variables of perceived IE were related to individual factors, and 75% of the explanatory factors remained unclear.

Although the health care workers in Sub-study I experienced a more positive psychosocial work environment than the other groups, they also reported more symptoms and IE-related complaints. As the associations between perceived symptoms and psychosocial work environment were not studied, and we had no information on the condition of the buildings, we could not completely explain the impact and significance of the condition of the building in this phenomenon. Hence, we cannot draw far-reaching conclusions about the reasons for the prevalence of IE-related complaints and symptoms and the perceived psychosocial work environment in the health care workplaces in Sub-study I.

5.1.3 Use of presented results for interpreting MM-40 questionnaire results in the future

Sub-Study I found the mean and distribution values of the IE questionnaire results. As 59% of the questionnaire responses were from workplaces with suspected IE-related problems, presenting the results of the distribution was considered justified. The mean values of the IE-related complaints and symptoms were between P50 and P75, and in most cases close to P50. The distribution diagram format shows the changes in the P75 and P95 points (mould odour, too high room temperature, unpleasant odours, irritation symptoms, headache, coughing) that may indicate a need for further surveys at the workplace.

The calculated confidence level of the mean values was 95%. From a statistical point of view, mean values may be used as reference material. In practice, however, the mean value may not be the optimal value for interpreting IE questionnaire results, because the scale is too extreme and may lead to the interpretation of any score higher than the mean value as a ‘problem’ at the workplace and any score below the mean value as a ‘good situation’ at the workplace. The interpretation should be more flexible and should not be based on only mean values.
Thus, in the interpretation of the IE questionnaire results, in addition to mean values, the distribution values should be considered in proportion to the other workplaces results.

Earlier studies have shown that buildings and spaces, factors affecting IE, people’s subjective and individual differences, and psychosocial work environments vary (Figure 1) (Jaakkola, 1998; Brauer & Mikkelsen, 2010; Ghaffarianhoseini et al., 2018) make it difficult to define unambiguous reference values for interpreting IE questionnaires. Instead of exact reference values, comparing the IE questionnaire results with the distribution and mean values may direct the problem-solving towards a wider context that contains information from the employer, OHS, occupational safety representatives, and the building technology.

According to the results, IE-related complaints and symptoms were also common in workplaces that only monitored the state of perceived IE, which is a similar result to those of earlier studies, in which employees in buildings with no detected IE-related problems have also shown IE-related symptoms (Reijula & Sundman-Digert, 2004; Bakke et al., 2007; Brauer & Mikkelsen, 2010).

The reported IE-related complaints and symptoms with values between <P25 and P75 may represent workplaces that are unlikely to require further surveys (e.g. building technology and IE investigations, OHS surveys), and the reported IE-related complaints and symptoms with values between P75 and >P95 may represent workplaces that need further investigations. In this context it is advisable to emphasise a comprehensive approach to solving IE-related problems.

Even if the IE questionnaire results do not indicate an IE-related problem, it is still worth comparing the results with other information from the workplace, occupational safety representatives, OHS and the building technology. The IE questionnaire results do not provide information on the condition of the building nor on the situation of the workplace, nor do they report the employees’ individual health issues or individual psychosocial work environment. Thus, it is advisable to evaluate the situation multiprofessionally.

If the IE questionnaire results indicate a need for further investigations, these investigations may concern OHS’ information and surveys of employees’ health and psychosocial work environment, employer’s and occupational safety representative information on employees, and information on the workplace situation and problem-solving processes. Information on the building technology situation from the building owner and maintenance is also needed. In addition to the questionnaires, the further need to investigate the IE and the condition of building technology should always be evaluated (building and IE investigation instructions (Pitkäranta, 2016; Lappalainen et al., 2017) should be followed). Following building technology and IE investigation instructions and guidelines can result in the building and its systems not requiring investigations. This decision can be made when the building technology and IE background information, maintenance and possible IA group interviews and walkthroughs have been conducted and their results evaluated. In these cases, the necessity of the building technology and IE investigations are thoroughly evaluated. Every
building is different, and their investigation needs are of different scales and depths.

OHS’ assessment of the situation and their information on employees’ health is also needed in the problem-solving. IE questionnaires do not provide information on employees’ health issues or individual analyses of employees’ health or psychosocial work environment. At workplaces, individual factors (illnesses, allergy, etc.) should also be taken into account if needed and solved on the individual level in OHS and, if needed with the employer and occupational safety representatives. Thus, cooperation between the employer, OHS and occupational safety representatives is important.

The presented distribution and mean values enable the analysis of the psychosocial work environment at the workplace and the evaluation of possible effects on symptoms and complaints.

The IE-related problem-solving process should proceed in stages (Lahtinen et al., 2008). The need for further investigation and the progress of the process should be conducted in a multiprofessional manner (Lahtinen et al., 2002; Lahtinen et al., 2004; Lahtinen et al., 2008; Lappalainen et al., 2009).

The IE questionnaire offers one method for increasing employees’ participation in the problem-solving process (Lahtinen et al., 2004). According to Lahtinen et al. (2008), the participatory approach encourages employees to be part of problem-solving and creates confidence between those dealing with the problems. Building technology solutions to IE-related problems may be easier than managing the problem-solving process (Lahtinen et al., 2008).

Symptoms and IE-related complaints have become more common in health care than they were in a previous corresponding Finnish study (Hellgren et al., 2008). The reference material can be reviewed in the future, for example, in next 10 years’ time. However, the timing also depends on what kinds of health care space solutions emerge in the future, and it may be possible to update the reference values earlier. Thus, the presented distributions and mean values can be used as new reference material in health care workplaces.

### 5.2 Probability of abnormal IA exposure in health care buildings

Sub-studies II–III examined the association between the probability of abnormal IA exposure and employees’ perceived IE, symptoms and OHS information. All the 27 hospital buildings and their IE were investigated, and the results were categorised using the method of probability of abnormal IA exposure. All the assessed building floors were hospital wards, which were confined to their own airspace by fire doors and other doors. Public entrances, corridors or other public spaces were not included in the assessed sections, but their possible influence on the hospital wards’ IA were estimated.

Sub-studies II–III differed from previous studies in that their building technology investigations were very detailed. In this respect, they were extensive. In addition, the building-related data were systematically analysed and categorised according to the probability of abnormal IA exposure. The research group was multiprofessional and conducted all the field investigations and
conclusions. FIOH’s researchers did not know the results of the IE questionnaires before the building technology investigations.

The assessment considered the IA impurity sources, the ventilation affecting the building, the building’s operation and indoor activities, and the combined effect of these factors on IE. The method of probability of abnormal IA exposure is based on national instructions, regulations and acts on the design of buildings and structures, construction, building, IAQ and ventilation condition investigations, IAQ and material sampling, and IE and IAQ limit values (made before 2014). This determines the accuracy of the investigations.

The purpose of the categorisation is to provide OHS and employers with a classified overall picture of the impurities affecting the IA and information on the quality of the IE at the workplace, and to thereby help OHS and workplaces (e.g. IA group) assess the health significance of the workplace IE for the employees.

The comprehensive, simultaneous factors affecting the building technology and the IE, and their relationship with the IE questionnaire responses and employee group-level health information have not been frequently studied. Earlier research has quite often focused on the association between employees’ self-reported symptoms, experiences of the IE and the psychosocial work environment, but there is little research on whether these are also associated with the investigation results concerning the building condition and probability of abnormal IA exposure results. This leaves more room for interpreting the significance of the information on the condition of the building and IA exposure and their associations with IE-related symptoms, complaints and psychosocial work environment.

In Sub-studies II–III, the investigations related to the condition of the building and building technology and IE were carried out extensively and the sources of impurities affecting the IA were verified. This provided more detailed information on how the condition of the building and the exposure conditions are related to IE-related complaints, symptoms, group-level health information, and psychosocial work environment. The results suggest, regardless of the probability of abnormal IA exposure category, that employees’ experience of the IE and psychosocial work environment is subjective and can vary. Thus, the role of the building technology investigation process and the assessment of probability of abnormal IA exposure in the IE problem-solving process is important, because this method, based on national building technology and IE investigation instructions, can provide both quantitative and qualitative information on the condition of the building technology and the probability of abnormal IA exposure. IE questionnaires and other surveys based on employees’ experience do not provide information on the condition of the building technology. Monitoring the building technology proactively would presumably reduce the potential for IE-related problems, because the possible building condition and IE-related issues and improvements could be done before they develop into IE-related problems from the technical point of view.

Over 80% of the buildings were built before the 1990s and nearly 50% were built between the 1940s and 1950s. The buildings were old and planning and
building instructions have changed over the decades. In addition, building materials were different in earlier decades. When the lifespan of building structures and materials ends or is exceeded, the structures and materials are at risk of malfunctioning, causing damage to the building materials. When material is old, its functioning is impaired, and external moisture may penetrate it and its structure layers. The results of Sub-studies II–III support earlier studies’ findings (Reijula, 2005; Reijula et al., 2012) that hospital buildings need repairs and that moisture and mould damage is common in health care buildings in Finland.

5.2.1 Information from indoor air groups

The hospitals’ multiprofessional IA group provided information of duration of IE-related problems longer in category of abnormal IA exposure very likely, possible and likely. The hospital multiprofessional IA groups estimated there were no IE-related problems also in premises which researcher group assessed premises in categories of abnormal IA exposure possible and likely. IA group estimation of IE-related problem in building floors or sections was often contradicted to researchers’ estimation. The contradict may be because the IA group may not have the experience or expertise to assess the need of the building technology investigations and the impact of the structures and ventilation on IA. Secondly, it may be that the IA group has not received enough information from an OHS or employer about the perceived IE or symptoms of employees. The importance of cooperation play an important role to IE-related problem-solving process. The results underline that the IE-related problems should be evaluate in multiprofessional teams and from many perspectives, as argued in several earlier studies (Reijula & Sundman-Digert, 2004; Lahtinen et al., 2008; Lappalainen et al., 2009; Bluysen, 2010; Carrer & Wolkoff, 2018).

Early phase assessment of the investigations of the condition of the building technology and impurities affecting IA should always be investigated in accordance with the instructions of building, ventilation and IE investigation process and evaluate the factors affecting IA. This will ensure that IA group also has more reliable information related to the building technology and IE.

5.2.2 Association between abnormal IA exposure and perceived indoor environment and health information

The employees’ experience of IE-related complaints and symptoms were surveyed using FIOH standardised (Örebro MM-40 based), established and commonly used IE questionnaire. The response rate of the questionnaire was good. The employees did not know the building investigation results before answering the questionnaire.

The employees often reported poor IE, for example, stuffy air and inadequate ventilation, and similar results have been obtained in previous studies of hospital employees (Seppänen & Fisk, 2004; Aarnio et al., 2005; Hellgren et al., 2011; Magnavita, 2015). The more abnormal IA was found to be, the more the employees considered the air stuffy. In these premises, several factors influenced the IE, such as inadequate ventilation and impurity sources in the premises or
in structures. In these facilities, the employees were also more likely to report the odour of mould. The researchers also observed the smell of mould and moisture and mould damage in the structures. This result that mould odour and moisture damage are associated is similar to those of earlier studies (Reponen et al., 2010; Cho et al., 2016; Täubel et al., 2016; Mendell & Kumagai, 2017). A statistically significant association was found between the probability of abnormal IA exposure categories and mould odour. Previous studies have found similar results according to which mould damage may strengthen users' experience of stuffy air (Nordström, 1999). Mould odour may be a good indicator of mould damage in a building. On the other hand, the higher the probability of abnormal IA exposure, the more frequent were deficiencies in ventilation systems. Previous studies have also found deficiencies in ventilation to be associated with poor IAQ (Seppänen & Fisk, 2004; Norbäck & Nordström, 2008; Hellgren et al., 2011; Turunen et al., 2014; Haverinen-Shaughnessy et al., 2015; Loupa et al., 2017).

The employees more often perceived symptoms than is shown in FIOH’s comparable data (Hellgren et al., 2008). Most of the symptoms were perceived in premises in which the probability of abnormal IA exposure was assessed as being likely. In the premises in which extensive mould and moisture damage were detected, ventilation deficiencies and impurity sources were often found in the ventilation system (e.g. MMVF source), unsealed MMVF sources were often found in interiors and/or moisture damaged floor coverings, and air pathways were very often found in structures. Previous studies have stated the greater the extent of moisture and mould damage in the premises, the more common are respiratory symptoms (Park, 2004; Patovirta, 2004; Mendell & Kumagai, 2017).

Previous studies have found that MMVF sources in ventilation systems and on surfaces may cause upper respiratory tract symptoms and, for example, eye irritation (Schneider, 2008; Salonen et al., 2009a; Hellgren et al., 2011). Symptoms of the same type can also be caused by IA dryness and IA temperature (Wolkoff, 2018). On the other hand, these symptoms were also experienced in premises in which no sources of IA impurities were found, or in which the extent of the impurities was limited. This may indicate that symptoms are also experienced in premises without sources of significant impurity sources or ventilation problems. Magnavita et al. (2015) reported in their study that 65% of office employees complained of environmental problems in their premises even when no IAQ problems had been detected. Similar results have been found in other studies in which employees reported IE-related symptoms and complaints in buildings with no detected impurity sources or abnormal (over limit values) IA concentrations (Bakke et al., 2007; Brauer & Mikkelsen, 2010; Rautiainen et al., 2018).

Sub-studies II–III found a statistically significant association between ventilation deficiencies, impurity sources and employees’ perceived symptoms. However, no statistical relationship was found between the probability of abnormal IA exposure and symptoms. Neither was any statistical relationship found between OHS’ information on users’ health and the categories of abnormal IA

71
exposure, and contacts with OHS had increased in all the categories of abnormal IA exposure.

The building investigations and the assessment of the probability of abnormal IA exposure were far more detailed and holistic in Sub-studies II–III than in earlier studies that have roughly divided buildings into mould damaged and undamaged buildings (Hellgren et al., 2008), buildings with dampness (Bornehag et al., 2001), buildings with users reporting dampness, buildings with other IE-related factors (Bornehag et al., 2004; Magnavita, 2015; Claudio et al., 2016; Keyvani et al., 2017; Dhungana & Chalise, 2020) and buildings with observed mould damage (Cox-Ganser et al., 2009). This may be the reason for the differences in the results: earlier studies have more often found significant associations between building condition and symptoms, poor IE and psychosocial work environment. The result may also indicate that employees may perceive several symptoms even though no major sources of contamination have been found in the premises. Furthermore, as IE, psychosocial work environment and human individual factors are all interconnected, it might be impossible to determine the main reason for the IE-related complaints and symptoms, and the proportion that contributes the most to the phenomenon.

However, the sample size of Sub-studies II–III was small in the unlikely and very likely abnormal IA exposure categories, and this may have caused bias and lack of statistical power in the study. There were also only a few building floors or sections in the unlikely (no abnormal IA exposure) category and with no impurities affecting the IA.

When a premises has multiple sources of impurities in its IA, as well as deficient ventilation, symptoms are simultaneously affected by many factors in the IE. Therefore, it is important to thoroughly investigate the building technology and holistically evaluate the factors that influence IE. After this, mitigating the harmful exposure might be easier.

5.2.3 Association between abnormal IA exposure and psychosocial work environment

Sub-study III examined the psychosocial work environment and stress using FIOH’s IE questionnaire (based on Örebro MM-40). The employees perceived more IE-related stress and lack of social support from their colleagues than in FIOH’s comparative data from 2008 (Hellgren et al., 2008).

Earlier studies based on MM-40 questionnaire results have shown a significant association between poor IAQ and the psychosocial work environment (Lahtinen et al., 2004b; Runeson, 2006; Hellgren et al., 2008; Brauer & Mikkelsen, 2010). Previous studies have also shown a relation between IE-related symptoms and the psychosocial work environment (Magnavita et al., 2011; Miskulin et al., 2014; Magnavita, 2015), between buildings needing repairs and employees symptoms (Hellgren et al., 2008), and between job stressors and symptoms (Azuma et al., 2017).

Sub-study III found no association between the probability of abnormal IA exposure categories and the psychosocial work environment. Moreover, the employees regarded their work as stimulating and interesting, which is similar to
earlier findings among hospital employees (Hellgren et al., 2008; Stankovic et al., 2008).

The results of Sub-study III suggest that in the unlikely abnormal IA exposure category, employees more often perceived irritation symptoms, lack of social support from colleagues and higher stress than those in other groups. In these premises, the building investigation results showed no damage in or on structures and materials, no ventilation unfit for purposes, no abnormal IA impurity sources in the IA, nor any other factors that negatively affected IA (including operations in the premises). According to these results, it seems that symptoms, poor IE and psychosocial workload may also be experienced in buildings with no abnormal IA exposure.

The association between employees’ perceived symptoms and psychosocial work environment was not studied in this research, which complicates the interpretation of the results: i.e. of the association between building and IE in the chain of symptoms and psychosocial work environment in IE-related problem cases. Sub-study III suggests that regardless of the category of probability of abnormal IA exposure, employees’ experience of the IE and psychosocial work environment may vary.

The questions on psychosocial work environment in the IE questionnaire were quite limited and may not provide a comprehensive picture of the psychosocial work environment. In addition, we had no information on organisational situations or leadership, which may also have influenced the perceived psychosocial work environment (Jaakkola, 1998). Other factors, such as those related to work and organisation, as well as individual factors that were not investigated in this study, may have also partially influenced the experiences and contributed to the results of Sub-study III. The sample size was small in the unlikely and likely abnormal IA exposure categories and thus, the conclusions are only indicative.

5.3 Reliability and validity of the study

Questionnaire The number of respondents to the MM-40 questionnaires was extensive and the mean of the response rate was good in Sub-studies I–III. The questionnaire used was a validated and commonly used tool for eliciting employees’ experiences of IE and the psychosocial work environment. Several MM-40 questionnaire study results are available both nationally and worldwide from different workplaces. Thus, the questionnaire results of Sub-studies I–III are comparable to those of other similar questionnaire (MM-40) studies. In Sub-studies II–III the respondents did not know the building’s research results until the survey was completed. Questionnaire surveys were conducted in early spring and late autumn, in line with the recommendations given in Finland.

Sub-study I had no information on the buildings’ condition, but according to earlier studies and the results of Sub-studies II–III concerning building condition, it seems that hospital buildings are often old and have deficient building technology and IE. Thus, the questionnaire results may be quite similar to those of random samples in Finland.
Sub-study I analysed responses from workplaces with suspected IE-related problems and responses from workplaces that were only monitoring the state of perceived IE. The background information on the IE situation was based on the workplaces’ own assessments, and this may introduce bias. No information was available on why the workplaces only monitored perceived IE, although monitoring the state of perceived IE is a general measure after IE-related repairs. The perceived symptoms and reported complaints may have been slightly higher than in a random sample, because 59% of the responses were from the workplaces with suspected IE-related problems.

The psychosocial work environment questions were quite limited and may not completely accurately describe the psychosocial work environment in the workplaces. In Sub-study I there was no current information on the organisations’ situation. In addition, human individual factors were not studied. These individual variables (such as asthma, allergy, gender) may be confounding variables and could partly explain the results regarding perceived symptoms, complaints and the psychosocial work environment.

Sub-study I’s questionnaire results were analysed using mean values and distribution values. In this respect, they may be generalised to apply to most health care workplaces and used as new reference material. The questionnaire method may include some random errors related to the actions of individual respondents, but the systematic risk of error is low and may relate more to the technical processing of the material. However, the sample size is high and random errors are not likely to have affected the results.

**Building investigations and assessment of probability of abnormal IA exposure.** The building area investigated was wide, and the investigations were detailed and focused diversely on the most common factors influencing IE. The background information on the buildings was gathered and analysed systematically, with special care. The building and premises investigations were conducted following building and IE investigation processes and national instructions. The analyses of the investigation results followed the national instructions and legislation related to building, ventilation and IE design. The probability of abnormal IA exposure was assessed on the basis of the building technology and IE investigation results. All the assessed building floors or sections (hospital wards) had their own IA space confined by fire doors or other doors. General entrances or corridors were not in the assessed categories, but their possible influence on hospital wards were assessed. The same research group analysed the background information, performed the building technology and IE investigations, and assessed the probability of abnormal IA exposure. The researchers did not know the results of the IE questionnaires before the building technology investigations. At all phases, the building investigation process and the assessment of probability of abnormal IA exposure were based strongly on the competence of the researchers and involved a subjective perspective in all assignments. The focus was to detect the main impurity sources in the IA, not to measure all the IA concentrations. This may also be considered a minor weakness of Sub-studies II–III. On the other hand, it is also one of the strengths of the study because it shows that the assessment of IA concentrations
Discussion

is challenging due to several factors (ventilation rate, type and emission rates from sources, material characteristics, ability to emit or absorb compounds on or in materials (SCHER, 2007; Holøs et al., 2018) and that concentrations may vary in time and space (Zabiegala, 2006; Nevalainen et al., 2015), which impacts the IA. Furthermore, IA measurements are rarely able to define the impurity source, its severity and extent in the premises (Hyvärinen et al., 2001; Lappalainen et al., 2001).

This method for assessing the probability of abnormal IA exposure is a pragmatic and qualitative system that categorises the factors affecting the indoor climate. It is impossible to determine the exact character and amount of pollutants affecting the indoor climate inaccuracies are inevitable. Thus, this method is only indicative. The qualitative definitions in this method are also open to interpretation. The categories of probability of abnormal IA exposure cannot be precisely delineated. In addition, every building and its technology is different and numerous factors affect the quality of the indoor climate. The researcher’s competence also affects the assessment of the probability of abnormal IA exposure.

To conclude, the building technology and IE investigations, and the assessment of the probability of abnormal IE exposure should be easily repeatable using the present method (Sub-studies II–III) and the national instructions and methods described in this dissertation. Some of the national instructions and legislation has been updated after Sub-studies II–III, and thus the method of probability of abnormal IA exposure should follow the newest instructions and legislation in the future.

Buildings. The background information revealed that some of the building floors or sections had previously unsolved IE-related problems (Sub-studies II–III). Thus, the data may have included more buildings with IE-related problems than random samples. In other words, in Sub-studies II–III, over 80% of the investigated buildings were old and only a few building floors and sections had no problems with building technology and no significant IA impurity sources. Thus, the sample may represent Finnish hospitals relatively well, because 49% of Finnish hospital buildings have been built between 1960 and 1989, after which the floor areas built have been significantly smaller (Reijula et al., 2012). Moreover, earlier studies have stated that hospital buildings are old, have significant moisture and mould problems, and need repairs (Reijula, 2005; Hellgren, 2012; Reijula et al., 2012; Leskelä et al., 2016).

OHS’ information. One limitation was that OHS’ information was on a group level and did not reflect how many employees had IE-related symptoms or IE-related absences or workplace changes (Sub-studies II–III). The researchers did not have access to patient files. Furthermore, the focus of Sub-studies II–III was not on medical aspects. Thus, far-reaching conclusions and generalisations cannot be made on the associations between the probability of abnormal IA exposure and group-level health information.

Statistics. The sample size of Sub-studies II–III was small in the unlikely and very likely abnormal IA exposure categories and this may have caused bias and lack of statistical power in the study. In this manner, the results of Sub-studies
II–III concerning the probability of abnormal IA exposure may be only partly generalised to apply to all health care workplaces.

5.4 Recommendations for future research

The focus of this dissertation was on health care environments, the probability of abnormal IA exposure categories and employees' perceptions of IE.

Future studies should assess the relationship between the probability of abnormal IA exposure categories and IE-related symptoms, complaints and psychosocial work environment in office and school environments. Further studies are needed of the psychosocial environment, which address both IE-related complaints and symptoms and the investigated condition of the building.

Studies should also assess whether other factors, such as individual, organisational, leadership, communication and interaction factors have significant associations with symptoms, environmental complaints, and perceived psychosocial work environment in the different probability of abnormal IA exposure categories.
6. Conclusions

The main conclusions of the Sub-studies (I-III) are:

1. IE-related complaints and symptoms were common in health care workplaces and had increased noticeably since FIOH's earlier study results and reference values in 2008. The presented distribution and mean values can be used as new reference material for health care workplaces. (Sub-study I)

2. There was no association between the probability of abnormal IA exposure categories and employees’ IE-related complaints (except of mould odour), symptoms, psychosocial work environment and group-level health information. Regardless of the category of probability of abnormal IA exposure, employees' experience of the IE may vary. Employees may also perceive many symptoms even if no major sources of impurities are detected on the premises. Other factors, such as individual factors and the psychosocial work environment may also influence perceived IE (Sub-studies II–III).

3. An association was found between ventilation system deficiencies and perceived IE-related symptoms and complaints. Other factors, such as individual factors, may also influence perceived IE. However, when there are multiple sources of impurities in the IA and deficient ventilation in premises, many environmental factors may affect symptoms and complaints. Therefore, it is important to thoroughly follow the building technology and IE investigation process to evaluate the factors that may influence the IE (Sub-studies II–III).

4. Most of the common IA impurity sources and their impact on IA can be identified and the method of assessing the probability of abnormal IA exposure provides a comprehensive picture and rating system of the factors that impact the IE. The method provides OHS, employers and IA groups with comprehensive, pragmatic information on the probability of abnormal IA exposure in premises and buildings. In all cases, IE-related problems should be multiprofessionally evaluated from many perspectives (Study I–III).


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Appendices

Appendix 1.
Perceived IE-related complaints in office, school and health care environments (Sub-study I)

Appendix 2.
Perceived IE-related weekly symptoms in office, school and health care environments
(Sub-study I)

Appendix 3.
Perceived psychosocial work environment and stress in office, school and health care work
(Sub-study I)
Appendix 1

Perceived IE-related complaints (% of respondents who reported environmental complaints every week) in office, school and health care environments (Sub-study I).

<table>
<thead>
<tr>
<th>IE-related weekly complaints</th>
<th>Office employees (N=16 545)</th>
<th>School employees (N=5 241)</th>
<th>Health care employees (N=7 040)</th>
<th>Total (N=28 826)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean%</td>
<td>95% CI</td>
<td>n</td>
</tr>
<tr>
<td>Stuffy air</td>
<td>4831</td>
<td>30.0</td>
<td>29.3-30.7</td>
<td>2175</td>
</tr>
<tr>
<td>Dry air</td>
<td>4445</td>
<td>27.7</td>
<td>27.0-28.4</td>
<td>1500</td>
</tr>
<tr>
<td>Insufficient ventilation</td>
<td>3995</td>
<td>25.0</td>
<td>24.3-25.7</td>
<td>1933</td>
</tr>
<tr>
<td>Noise</td>
<td>2407</td>
<td>15.1</td>
<td>14.5-15.7</td>
<td>1658</td>
</tr>
<tr>
<td>Draught</td>
<td>2616</td>
<td>16.7</td>
<td>16.1-17.3</td>
<td>890</td>
</tr>
<tr>
<td>Unpleasant odour</td>
<td>1945</td>
<td>12.2</td>
<td>11.7-12.7</td>
<td>1010</td>
</tr>
<tr>
<td>Dust or dirt</td>
<td>2670</td>
<td>16.6</td>
<td>16.0-17.2</td>
<td>1029</td>
</tr>
<tr>
<td>Too low room temperature</td>
<td>2435</td>
<td>15.4</td>
<td>14.8-16.0</td>
<td>848</td>
</tr>
<tr>
<td>Varying room temperature</td>
<td>2067</td>
<td>13.1</td>
<td>12.6-13.6</td>
<td>627</td>
</tr>
<tr>
<td>Mould odour</td>
<td>1346</td>
<td>8.5</td>
<td>8.1-8.9</td>
<td>789</td>
</tr>
<tr>
<td>Dim light or reflections</td>
<td>1297</td>
<td>8.2</td>
<td>7.8-8.6</td>
<td>467</td>
</tr>
<tr>
<td>Too high room temperature</td>
<td>1146</td>
<td>7.3</td>
<td>6.9-7.7</td>
<td>337</td>
</tr>
<tr>
<td>Tobacco smoke</td>
<td>315</td>
<td>2.0</td>
<td>1.8-2.2</td>
<td>62</td>
</tr>
</tbody>
</table>

CI=Confidence interval
Appendix 2

Perceived IE-related weekly symptoms (% of respondents who reported symptoms every week) in office, school and health care environments (Sub-study I).

<table>
<thead>
<tr>
<th>IE-related weekly symptoms</th>
<th>Office employees (N=16 545)</th>
<th>School employees (N=5 241)</th>
<th>Health care employees (N=7 040)</th>
<th>Total (N=28 862)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean %</td>
<td>95 % CI</td>
<td>n</td>
</tr>
<tr>
<td>Irritation of the nose</td>
<td>3524</td>
<td>21.5</td>
<td>20.9-22.1</td>
<td>1413</td>
</tr>
<tr>
<td>Irritation of the eyes</td>
<td>3484</td>
<td>21.4</td>
<td>20.8-22.0</td>
<td>1221</td>
</tr>
<tr>
<td>Hoarse, dry throat</td>
<td>3138</td>
<td>19.2</td>
<td>18.6-19.8</td>
<td>1470</td>
</tr>
<tr>
<td>Fatigue</td>
<td>2397</td>
<td>14.6</td>
<td>14.1-15.1</td>
<td>1113</td>
</tr>
<tr>
<td>Feeling heavy-headed</td>
<td>1930</td>
<td>11.9</td>
<td>11.4-12.4</td>
<td>985</td>
</tr>
<tr>
<td>Irritation of the skin on the hands</td>
<td>1737</td>
<td>10.7</td>
<td>10.2-11.2</td>
<td>804</td>
</tr>
<tr>
<td>Irritation of the skin on the face</td>
<td>1684</td>
<td>10.4</td>
<td>9.9-10.9</td>
<td>737</td>
</tr>
<tr>
<td>Headache</td>
<td>1488</td>
<td>9.2</td>
<td>8.8-9.6</td>
<td>785</td>
</tr>
<tr>
<td>Coughing</td>
<td>1240</td>
<td>7.6</td>
<td>7.2-8.0</td>
<td>568</td>
</tr>
<tr>
<td>Concentration difficulties</td>
<td>1379</td>
<td>8.5</td>
<td>8.1-8.9</td>
<td>381</td>
</tr>
<tr>
<td>Joint pain</td>
<td>638</td>
<td>3.9</td>
<td>3.6-4.2</td>
<td>243</td>
</tr>
<tr>
<td>Muscular pain</td>
<td>687</td>
<td>4.3</td>
<td>4.0-4.6</td>
<td>180</td>
</tr>
<tr>
<td>Shortness of breath</td>
<td>488</td>
<td>3.0</td>
<td>2.7-3.3</td>
<td>266</td>
</tr>
<tr>
<td>Fever or chills</td>
<td>382</td>
<td>2.4</td>
<td>2.2-2.6</td>
<td>193</td>
</tr>
<tr>
<td>Coughing at night</td>
<td>306</td>
<td>1.9</td>
<td>1.7-2.1</td>
<td>158</td>
</tr>
<tr>
<td>Wheezing</td>
<td>248</td>
<td>1.5</td>
<td>1.3-1.7</td>
<td>120</td>
</tr>
</tbody>
</table>

CI=Confidence interval
## Appendix 3

Perceived psychosocial work environment and stress in office, school and health care work (Sub-study I).

<table>
<thead>
<tr>
<th>Response options</th>
<th>Office employees (N=16 545)</th>
<th>School employees (N=5 241)</th>
<th>Health care employees (N=7 040)</th>
<th>Total (N=28 826)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean%</td>
<td>95 % CI</td>
<td>n</td>
</tr>
<tr>
<td><strong>Do you regard your work as interesting and stimulating?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, often</td>
<td>12201</td>
<td>74.2</td>
<td>73.5-74.9</td>
<td>4433</td>
</tr>
<tr>
<td>Yes, sometimes</td>
<td>3583</td>
<td>21.8</td>
<td>21.2-22.4</td>
<td>703</td>
</tr>
<tr>
<td>No, seldom or rarely</td>
<td>608</td>
<td>3.7</td>
<td>3.4-4.0</td>
<td>76</td>
</tr>
<tr>
<td>Never</td>
<td>57</td>
<td>0.3</td>
<td>0.2-0.4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Do you have too much work?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, often</td>
<td>2822</td>
<td>17.2</td>
<td>16.6-17.8</td>
<td>725</td>
</tr>
<tr>
<td>Yes, sometimes</td>
<td>9114</td>
<td>55.6</td>
<td>54.8-56.4</td>
<td>3010</td>
</tr>
<tr>
<td>No, seldom or rarely</td>
<td>4029</td>
<td>24.6</td>
<td>23.9-25.3</td>
<td>1317</td>
</tr>
<tr>
<td>Never</td>
<td>439</td>
<td>2.7</td>
<td>2.5-2.9</td>
<td>153</td>
</tr>
<tr>
<td><strong>Are you able to influence your working conditions?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, often</td>
<td>5470</td>
<td>33.5</td>
<td>32.8-34.2</td>
<td>1797</td>
</tr>
<tr>
<td>Yes, sometimes</td>
<td>7277</td>
<td>44.5</td>
<td>43.7-45.3</td>
<td>2576</td>
</tr>
<tr>
<td>No, seldom or rarely</td>
<td>3087</td>
<td>18.9</td>
<td>18.3-19.5</td>
<td>746</td>
</tr>
<tr>
<td>Never</td>
<td>512</td>
<td>3.1</td>
<td>2.8-3.4</td>
<td>77</td>
</tr>
<tr>
<td><strong>Do your fellow workers help you with work-related problems?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, often</td>
<td>11945</td>
<td>72.7</td>
<td>72.0-73.4</td>
<td>3824</td>
</tr>
<tr>
<td>Yes, sometimes</td>
<td>3782</td>
<td>23.0</td>
<td>22.4-23.6</td>
<td>1178</td>
</tr>
<tr>
<td>No, seldom or rarely</td>
<td>628</td>
<td>3.8</td>
<td>3.5-4.1</td>
<td>186</td>
</tr>
<tr>
<td>Never</td>
<td>77</td>
<td>0.5</td>
<td>0.4-0.6</td>
<td>27</td>
</tr>
<tr>
<td><strong>Do you experience stress?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td>2247</td>
<td>13.8</td>
<td>13.3-14.3</td>
<td>704</td>
</tr>
<tr>
<td>Just a little</td>
<td>6055</td>
<td>37.2</td>
<td>36.5-37.9</td>
<td>1878</td>
</tr>
<tr>
<td>Some</td>
<td>5222</td>
<td>32.1</td>
<td>31.4-32.8</td>
<td>1712</td>
</tr>
<tr>
<td>Quite a lot</td>
<td>2163</td>
<td>13.3</td>
<td>12.8-13.8</td>
<td>687</td>
</tr>
<tr>
<td>Very much</td>
<td>588</td>
<td>3.6</td>
<td>3.3-3.9</td>
<td>156</td>
</tr>
</tbody>
</table>

CI=Confidence interval