AIR

Swegon Air Academy

Part A

Ventilare neccesse est...

DUNCAN:
THIS
CASTLE
HATH
A PLEASANT
SEAT;
THE
AIR
NIMBLY
AND
SWEETLY
RECOMMENDS
ITSELF
UNTO
OUR
GENTLE
SENSES

[William Shakespeare *Macbeth*]

CONTENTS

FOREWORD

Our need for fresh air, essential to our functioning as human beings, is not normally contested by anyone. This is because we have basic physiological needs - om brains and the cells in our bodies need oxygen so that they can develop and perform properly. However, the air we breathe contains more or less harmful substances and these cause more problems than most of us can probably imagine or understand. On their own, these substances might be troublesome - but collectively, they could be disastrous! Remember, that while we need about 0.75 kg of food and about 1.5 kg of liquid per day, we need at least 15 kg of air!

It is quite reasonable to compare an air handling system in a building to our own respiratory system with its airways and lungs, as both systems have enormous significance for our health and well-being. And, as the air is often used to supply or remove heat, this makes the importance of the air handling system even greater, as it significantly affects our comfort, well-being, productivity and efficiency. Buildings, too, need a continuous change of air to feel good.

LACK OF COMMON POINT OF VIEW

Bearing in mind all of the above, it is rather odd that those involved in lanning a building rarely see things from the same point of view. Short-term economic interests ~re often allowed to determine the choice of technical solutions and, when costs are not critical, buildings are all too often designed in such a way that they are neither pleasant to occupy nor energy-efficient. And, up to now, it has been rather difficult to acceptfeedback and learn from expensive mistakes, and thereby avoid repeating them.

PUBLIC HEALTH, ENERGY AND ENVIRONMENTAL ISSUES - AND ECONOMIC REALITIES

This book focuses on three main areas: Public health, energy and the environment. We are also convinced that economical aspects must be considered as well and this is a recurring topic throughout the book. No matter how efficient and health-promoting an investment might look, it would most probably never be carried out if it were not shown to be economically viable. Today, reliable research results show that there is a clear connection between poor indoor climate and ill-health. And ill-health costs a great deal of money. In other words, there is a real incentive for property owners to invest in good indoor climates now, as future tenants will almost certainly step up their demands.

CONTROL, REGULATION AND MONITORING - THE DECIDING FACTORS

In this electronic age, it is becoming increasingly obvious that control, regulation and monitoring will play a decisive role when it comes to maintaining good indoor climates and ensuring energy-efficient operation of buildings, with subsequent minimal impact on the outdoor environment. The importance of providing solutions that give the clientmaximum freedom of choice and flexibility is illustrated in Chapter 31/The intelligent building- a matter of choice, which discusses centralized building management systems, so-called BMS systems, for control, monitoring and management.

COMPLEX RELATIONSHIPS

- SIMPLE EXPLANATIONS

In this book, *Swegon Air Academy* has compiled ideas and points of view from a wide range of experts. The aim of the book is to put a spotlight on factors and circumstances that are important in the quest for pleasing - indoor environments and comfortable indoor climates, with due regard to energy issues and the outdoor environment. Our ambition has been to explain complex relationships in an intelligible way. It is our profound belief that it is possible to radically improve poorly functioning systems - if we can explain the whys and wherefores.

The passage of air through an air handling system is described, from the outdoor air intake, via an air-conditioned room and into our lungs, with a full account of what happens on the way. The physiological aspects, as well as the comfort, energy and environmental aspects, are examined. How different building designs affect the opportunities for creating good indoor climates is also discussed. Here, the effects that different factors have on each other are not always self-evident or discernable, nor are their specific effects on the indoor climate and total costs. We have, therefore, chosen to illustrate a number of them in greater detail and hope that this will contribute to future developments, for the benefit of all concerned.

TARGET GROUPS

This book is intended not only for clients, property owners and engin-eers, who can influence the design, layout and indoor climate of a build-ing, but also for everyone who would like to learn more about the air we breathe and how it affects us.

Increased insight will make it possible to avoid unnecessary costs, both in the investment stage and in the operational stage of a building project. Attractive premises are a must for survival on a competitive property market.

THE AUTHORS

This book blends theoretical knowledge from the academic world with practical market experience. Our ambition has been to portray the present-day situation and the opportunities in store in an objective and unprejudiced way, by engaging highly distinguished experts and writers from a representative cross-section of the industry.

Proceeds from the sales of this book will be reinvested in the activities run by *Swegon Air Academy*, i.e. in objective transfer of know-how and exchange of information via seminars, technical articles and publications. The contents of this book are available to schools and training programmes connected to the heating and ventilation industry at a subsidized rate.

Enjoy the book!

CONNY NILSSON
Director of the *Swegon Air Academy*

[AIR *Swegon Air Academy*]

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AIR

Swegon Air Academy

Part A

Ventilare neccesse est...

A. VENTILARE NECESSE EST

CONNY NILSSON *Swegon Air Academy*

The term ventilation is basically understood to be the removal of old, stale air from a room or a building and its replacement by fresh, clean air. Unfortunately, strong focus is often placed on sizes of air flows and air change rates, when we should really be addressing the question of air quality. The number of air changes normally required to ensure a healthy indoor climate and fresh room air, at least when airborne cooling is used, is considerably fewer than those needed to achieve a good thermal climate. Two conditions that must always be fulfilled, however, are that the air introduced into the building is as clean as possible and that the building materials are chosen so that undesirable and dangerous emissions are minimized. Materials that are quality assured, i.e. emission-tested, are now widely available on the market. If we cannot master the generation of pollutants indoors, this could mean that the ventilation system will have an impossible task. We must also master the removal of surplus indoor heat, normally achieved with the help of rather expensive and energy-demanding cooling systems. This is an area that requires the involvement of a number of the players engaged in the building process, not least of the architect.

Increased awareness about limited energy resources and the environmental consequences of high energy uses will soon necessitate radical changes in the way in which these issues are addressed. New solutions will undoubtedly arrive on the scene, hopefully, too, for cleaning indoor air.

AIR IS OFTEN ASSOCIATED WITH A SENSE OF WELL-BEING

We have all experienced that feeling of relief, while sitting in a hot plane and waiting for it to take off, when the air starts flowing from the overhead nozzle, or that feeling of well-being created by a gentle and soothing breeze on a summer evening.

Ventilation is all about removing polluted air - either literally pollut-ed or air that is just uncomfortably warm - and replacing it with clean, fresh air at the right temperature. Air cannot, however, be freely intro-duced into a room. For example, to avoid draughts, both its temperature and speed in the occupied zone must be acceptable. This means placing demands on the design engineer and the products used in the ventilation system. In buildings where there is a heat surplus, air will have to be supplied at an under temperature. To do this without causing draughts, the correct types of supply air terminal devices will have to be used. They will also have to be correctly located and properly aligned, so that the discharged air jets cannot collide with obstacles such as light fittings and columns.

"IT'S DRAUGHTY AND NOISY"

Air handling and ventilation plant are often blamed for problems that have completely different causes. Complaints about draughts and disturbing noises from poorly designed and improperly adjusted systems should, of course, be taken seriously. The real reasons for many of the inconveniences experienced must, however, often be sought elsewhere. A building is a complicated system in which everything, more or less, works interactively: if the air handling system is correctly designed and used, it is not the problem - it is, in fact, part of the solution.

HEALTH, WELL-BEING AND PRODUCTIVITY

Our bodies must be able to expel excess heat, to remain within the tight temperature limits between which we feel comfortable and can work well. If we can't do this, it will affect our well-being, our productivity and our efficiency. Then it becomes a question not only of comfort and health but also of money - for the individual and the employer, and for society as a whole. The effects that tl1e temperature of our surroundings has on our performance and mental capabilities are still the subjects of intense research.

That the human organism is a complicated creation is obvious to most, but what are our basic needs when it comes to the environment in which we live? The first part of this book examines this question from different angles, as the answers are of vital importance when making building design decisions with respect to access to natural daylight, comfortable indoor climates and clean fresh air, and to demands for good energy management.

KNOWLEDGE IS ESSENTIAL

Providing good engineering solutions, to give the client what can be reasonably expected, requires know-how and competency. We must, therefore, remember that:

- The client must first specify his requirements in such a way that they can be fulfilled.
- The building services consultant must understand the interplay between the different requirements and, based on these, suggest solutions that give the client value for money and the functions stipulated in the requirements specification - while taking into account both of-ficial regulations and environmental impact. The consultant must also be able to foresee the practical and economical consequences of the requirements and report relevant issues to the client.
- The installation engineer must have the necessary skills to complete the installation to full satisfaction, which assumes ongoing training to keep up to date with new technologies and products.
- The end user and the client must be aware of the fact that even the best solution will still require competent operating staff, as well as strict inspection and maintenance routines, if the plant is to function as planned.

MORE COOLING

The need for cooling is growing rapidly and we must ask ourselves how this can be combined with our efforts to manage energy resources more efficiently and with our concerns for the environment.

Modern architecture is often synonymous with ostentatious glass facades. Intensive solar radiation increases the need for cooling and this question must be carefully dealt with. This is discussed in Chapter 13 / People and buildings - both need light, in which our need for more daylight (larger windows) is addressed. Better windows and new types of solar shading can, of course, help reduce solar radiation and cooling needs. But, if this then affects our physical functions, via vital biological receptors and, consequently, affects our degree of alertness, whose competence should be relied on to produce an optimal solution?

A large proportion of the energy now supplied to buildings is used for lighting, which, in many instances, significantly affects the need for cooling. It is therefore extremely important to respect new findings in this field and to use the most efficient solutions from an energy point of view.

We can hardly maintain that we in the western world have the right to comfortable and cool indoor climates, while people on the other side of the world in China and India do not. This is most probably one of the greatest challenges faced by the industry and a vast and important area for research and development. We need to create realistic, commercial and practical solutions that can contribute towards efficient cooling using a minimum of energy - preferably without using artificial coolants. Promising trials are under way in different parts of the world and there are strong indications that different solutions, when applied jointly, will be of great importance in the future.

EXISTING BUILDINGS

Last, but by no means least, great attention must be paid to existing buildings. The energy-saving measures taken in these buildings are of vital importance when it comes to reducing the total use of energy, as all new buildings, at best, will only reduce the rate at which energy use is increasing - no matter how energy-efficient the measures are.

If we cannot build new buildings with a sufficiently high level of energy efficiency, we will be forced to take even greater measures in existing buildings to meet overall energy goals.

COOPERATION AND COMMON APPROACH

Of course, new and old buildings were never built witl1 the primary aim of saving energy; tl1ey were built to be used. People need somewhere to live and somewhere to work, and to be efficient and productive in their daily lives. In short, buildings have been and will be built for specific purposes. Furthermore, structural designs and building services must always be chosen so that no more energy than is absolutely required is used.

Ventilation is a necessity but, in this book, we have not taken sides with respect to using 'right' or 'wrong' techniques. However, it is emphasized that when comparing different solutions, the fundamental requirements to be fulfilled must always be the same. Easing up on wellfounded requirements, so that new paths can be explored, is not the right way to proceed. New methods and technologies must be comprehensively tested before being released onto the market.

Forthcoming developments might produce different types of solutions, but tl1e aim must always be to create a comfortable, stimulating and healthy indoor climate with the lowest possible energy demand and smallest possible environmental impact. We are ail responsible for implementing the best solutions on the market and for taking advantage of and using available know-how. And it would be very helpful, if there were an even better dialogue, with a common goal, between all the players - clients, architects, consultants, installers and tenants - involved in the building process. This would be a first step towards even better indoor climates, more efficient use of energy and less environmental impact for the benefit of all involved.

1. HEALTH AND WELL-BEING IN INDOOR ENVIRONMENTS

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OUR ENVIRONMENTAL REQUIREMENTS

Human physiology is not adapted to the climatic conditions in temperate and polar latitudes, although parts of these regions have been populated for several thousands of years. The ideal ambient temperature for a naked person at rest is about 29 °C, a climatic condition found in the mountain and savannah landscapes of Africa, the probable origin of our ancient ancestors. Without clothing and shelter, man could be regarded as a tropical animal that can only survive in a narrow zone along the equator. When our forefathers migrated north not only was proper clothing needed but a protective climatic shield also had to be developed: housing and building technology were adapted to very challenging winter climates. Originally, we were also biologically adapted to continuous supplies of fresh outdoor air for breathing and keeping our bodies cool. The term “indoor environment” is a consequence of the need for shelter against wild animals and – as Mankind moved to more weather-beaten areas – against unfavourable outdoor climates. Indoor air quality, however, depends on a number of factors, including the outdoor air quality, the amount of fresh air provided indoors and the amount of air pollution derived from numerous indoor sources. On average, an adult male with a sedentary occupation will breathe about 15 m^3, or roughly 15 kg of air, drink 1.5 litres, or 1.5 kg, of water and eat about 0.75 kg of solid food per day. Hence, the weight of breathed air constitutes about 87% of the total biological mass turnover every 24 hours.

Clothing and a building envelope provide two vital levels of shelter between the human organism and its surroundings. Indoor environments are not only vital for our survival, health and well-being but also constitute the greater part of human environmental exposure.

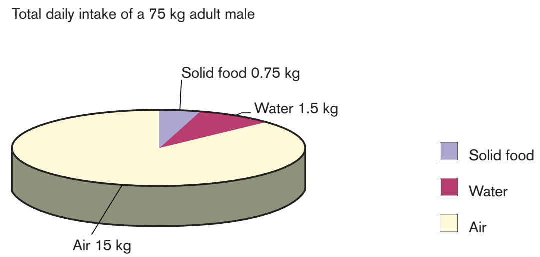

FIGURE 1. Human daily intake of food, water and air.

A BRIEF HISTORY OF BUILDING HYGIENE AND HEALTH

The ancient architect Vitruvius edited the oldest known preserved textbooks on architecture in 27 B.C. He wrote:

“Skill in physic enables him to ascertain the salubrity of different tracts of country, and to determine the variation of climates, which the Greeks call klivmata: for the air and water of different situations, being matters of the highest importance, no building will be healthy without attention to those points. Law should be an object of his study, especially those parts of it which relate to party-walls, to the free course and discharge of the eaves waters, the regulations of cesspools and sewage, and those relating to window lights. The laws of sewage require his particular attention that he may prevent his employers being involved in lawsuits when the building is finished. Contracts, also, for the execution of the works, should be drawn with care and precision: because, when without legal flaws, neither party will be able to take advantage of the other”. [Vitruvius. On Architecture. 27 B.C. as translated by Bill Thayer http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/1*.html].

All these issues are still of central importance and interest in modern architecture and building hygiene.

Throughout the Middle Ages and until the late 17th century and the start of the Age of Reason, health and living conditions in Norway were at a marginal level. The 18th century saw the introduction of remarkably positive trends with significant improvements of these conditions in terms of better living standard, lower mortality, increased longevity, and growth of population and wealth [Moseng, 2003]. These facts cannot be fully explained by the introduction of the potato and inoculation against smallpox alone. Reassessment of historical evidence suggests that developments in the 18th century must be due to “An improved epidemiological climate caused by a complex background where the changes obviously occurred in the intricate interplay between economical, social and cultural forces" [Moseng, 2003]. These forces included the public health service, educational work, increased levels of learning and good health being valued by the government.

FIGURE 2.
Hans Strøm.

The most decisive factor seems to have been increased public awareness about the effects of hygienic conditions and building hygiene on health and well-being. Prominent professionals and cultural personalities persons in the Kingdom of Denmark-Norway, such as Hans Strøm (1726–1797), Johan Clemens Tode (1736–1806) and Rasmus Frankenau, (1767–1814) were in close contact with the international scientific community. They were informed about developments and scientific controversies and were aware of important works about hygienic conditions necessary for health, such as those by Sir John Pringle (1707–82), Scotland, and Johann Peter Frank (1745–1821), Bavaria, the world's first professor of hygiene. In 1778 Hans Strøm, Figure 2, published the book "Kort Underviisning om De paa Landet, i Bergens Stift, meest grasserende Sygdomme, og derimod tienende Hjelpe-Midler" (A short treatise on the most prevalent diseases in the countryside of the Bergen bishopric and the most useful remedies for them). He wrote in depth about the impact of housing on health and illness mentioning:

- The importance of fresh air
- The dangers of lack of ventilation to save heat, particularly the dangerous lack of air that could result from using tiled stoves with external fireboxes, which obviated the need for air to be drawn through habitable rooms .
- Problems with moisture sources and dampness caused by lack of ventilation
- Pollution from stoves, tobacco smoke, cooking, cod-liver oil and other odorous sources
- The importance of cleaning, washing and clean bedding

The world's first Public Health Act was the British Act in 1848 which was a direct result of the famous works of Edwin Chadwick (1800–1890), Figure 3, "Report on the Sanitary Conditions of the Labouring Population and on its means of improvement", published in 1842. [http://www.deltaomega.org/ChadwickClassic.pdf].

Chadwick wrote in his conclusions:

"…First, as to the extent and operation of the evils which are the subject of the inquiry:

That the various forms of epidemic, endemic, and other disease caused, or aggravated, or propagated chiefly amongst the labouring classes by atmospheric impurities produced by decomposing animal and vegetable substances, by damp and filth, and close and overcrowded dwellings prevail amongst the population in every part of the kingdom, whether dwelling in separate houses, in rural villages, in small towns, in the larger towns – as they have been found to prevail in the lowest districts of the metropolis.

FIGURE 3.
Edwin Chadwick.

That such disease, wherever its attacks are frequent, is always found in connexion with the physical circumstances above specified, and that where those circumstances are removed by drainage, proper cleansing, better ventilation, and other means of diminishing atmospheric impurity, the frequency and intensity of such disease is abated; and where the removal of the noxious agencies appears to be complete, such disease almost entirely disappears…

…That the annual loss of life from filth and bad ventilation are greater than the loss from death or wounds in any wars in which the country has been engaged in modern times…

…*Secondly. As to the means by which the present sanitary condition of the labouring classes may be improved:*

The primary and most important measures, and at the same time the most practicable, and within the recognized province of public administration, are drainage, the removal of all refuse of habitations, streets, and roads, and the improvement of the supplies of water.

That the chief obstacles to the immediate removal of decomposing refuse of towns and habitations have been the expense and annoyance of the hand labour and cartage requisite for the purpose…

…That for the prevention of the disease occasioned by defective ventilation, and other causes of impurity in places of work and other places where large numbers are assembled, and for the general promotion of the means necessary to prevent disease, that it would be good economy to appoint a district medical officer independent of private practice, and with the securities of special qualifications and responsibilities to initiate sanitary measures and reclaim the execution of the law…".

The Norwegian Public Health Act of 1860 (Sundhetsloven) was highly inspired by the British Act of 1848. According to the Norwegian Act, all communities were obliged to establish a Health Commission under the leadership of the Public Medical Health Officer. Its tasks were defined as follows (Sundhetsloven 1860, §3,): "The Commission shall pay attention to the Localities' Health Conditions and what thereon may have influence, such as: Cleanliness…Dwellings that by Lack of Light or Air, by Humidity, Uncleanliness or Overcrowding of Occupants, have proved to be definitely dangerous to Health. The Health Commission must ensure that sufficient Air Change takes Place in Accommodations, wherein a larger Number of Persons constantly or regularly are gathered, such as Churches, School, Court and Auction Facilities, Theatres, Dancing Houses etc…".

Basic requirements for healthy built environments had been well established thanks to the health and hygiene movements during the 100 years before 1850 and their implementation over the next 100 years, which provided vital conditions for the remarkable improvements of general health and living standards in welfare states. Axel Holst (1860–1931), Professor of Hygiene and Bacteriology from 1893 until 1930, warned about health risks related to house dampness in cellar dwellings due to gases and microbiological pollutants from putrefactive processes in the ground. These increased the risks of several diseases, particularly respiratory infectious diseases such as tuberculosis (Journal of the Norwegian Medical Association 1894; 14: 81–6).

Until the 1920s, tuberculosis (TB) was by far the most common cause of death in Norway and most other Western countries, Figure 4. Developed societies won the battle against TB and other infectious diseases thanks to improved living, nutritional and hygienic standards, including building hygiene, and mainly before modern vaccination and antibiotics became available [Turnock, 2006]. Today, reoccurrence of TB has been most prevalent among those living under conditions of poor nutrition and inferior housing. Similar observations of historical trends in most other developed countries have been noted [Nelson, 2005]. In 1900, 194 of every 100 000 U.S. residents died from TB and most were residents in urban areas. In 1940, before the introduction of antibiotic therapy, TB was still a leading cause of death although the death rate had decreased to 46 per 100 000 persons.

Basic hygiene requirements for housing – a summary of the state-of-the-art in the 19th century.

1. Dry building ground and dry dwellings.
2. Good cleaning and adequate ventilation
3. As much access as possible to sunlight and full daylight (bactericidal effect).
4. Smallest possible risk of accumulation of waste, dust and other pollutants by suitable choice of materials and design of interiors, furniture and furnishings.
5. Fast and safe removal of all refuse and offal by skilfully executed and maintained drains and sewers, rational cleaning and other methods.
6. Abundant access to clean and good water.

During the 20th century, average life expectancy increased from approximately 45 to 75 years for citizens of Western, industrial countries and it was generally assumed to be largely the result of advances in the content and distribution of medical care [Turnock, 2006]. It was shown, however, that medical treatment accounted for 3.7 years, and clinical preventive services (such as immunization and screening tests) accounted for 1.5 years while the remaining 25 years largely resulted from preventive efforts in the form of social policies, sanitation (hygiene), community action and personal decisions. Adequately built environments, i.e. housing and work environments formed vital parts of the improved sanitary conditions.

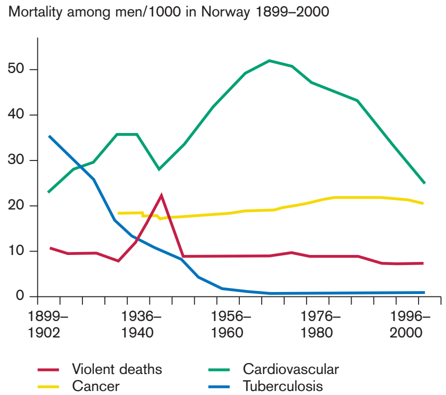

FIGURE 4. Age-adjusted mortality due to four causes [Stene-Larsen, 2006].

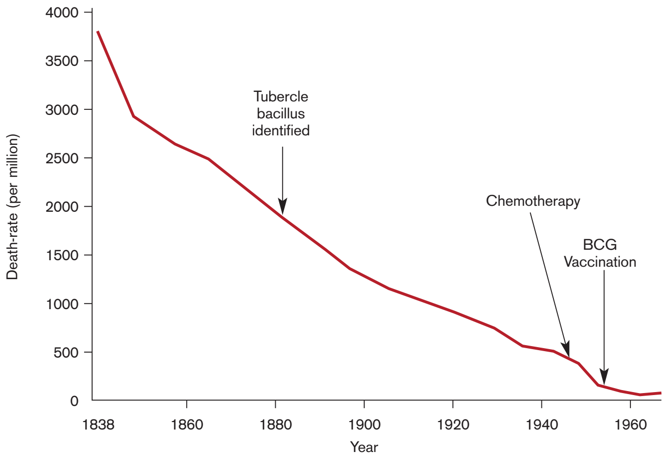

FIGURE 5. Respiratory tuberculosis (TB): mean annual death rate in England and Wales [Department of Health, UK, 1992].

Present scientific knowledge about dampness in buildings concurs with the risk assessments and requirements set out more than 150 years ago [Bornehag et al., 2001, 2004]. However, in most countries, including Norway, these matters only attract limited attention, if any, from the Health Services. Medicine now tends to focus on pathology and fails to place individuals within their socio-environmental contexts [Turnock, 2006].

Living and housing conditions, important parts of our environments, have improved immensely throughout the 20th century. For example, in Norway, the average number of persons per household has decreased while the dwelling area and area per person has increased. According to Statistics Norway, the mean dwelling area increased from 89 m^2 in 1967 to 114.2 m^2 in 1997, resulting in an increase of housing area per person from 29 m^2 in 1967 to 52 m^2 in 2002, an increase of 79%.

MODERN INDOOR ENVIRONMENTS

Current general population exposure times and their significance for risk assessment

In temperate and polar latitudes, people often spend less than 10% of their time outdoors. More than 90% is spent at home, in kindergartens, at school, at work, in public premises, in vehicles etc and most of this time is usually spent at home and in bedrooms [WHO, 1999]. About 65% of our lifetime is often spent at home, 20% in other premises and further 5% in vehicles. The working population usually spends about 20% of its time at work and an increasing proportion of employees have their workplaces in non-industrial environments. Ventilation rates are generally lower in homes and the time spent there is much longer than at work.

Vulnerable groups

People with asthma, allergies and other hypersensitivities are particularly vulnerable to inferior indoor environments [Leira et al., 2006]. Compared to those who are non-allergic, a higher percent of allergic people suffer from sick building syndrome, SBS, symptoms and complain about perceived annoyances in the indoor environment [Lundin, 1999]. This is the only group of diseases currently increasing among children in Western and developed societies. Asthma is presently the most common chronic disease during childhood, and in most Western countries the commonest cause of admission to hospital among children, comprising up to 25% of admissions to paediatric departments in many countries [EEA, 2007]. The increase of asthma and allergies in the younger population in Europe will increase the proportion of vulnerable individuals in the future work force. A 2.4 times increased risk of suffering from asthma among adults born in 1966 to 1971, compared to those born in 1946 to 1950, was reported in studies performed in 15 industrialized countries [Sunyer et al., 1999]. The increase occurred concurrently in most of the countries, in both males and females, and both in childhood and adult onset asthma.

Prevalence of chronic obstructive lung diseases (bronchitis, emphysema and asthma) is increasing all over the world [WHO, 2007] and those affected suffer more in poor indoor climates. Good environments are particularly important for their health and to prevent early retirement due to disablement.

HEALTH EFFECTS ASSOCIATED WITH INDOOR EXPOSURES

In recent years, there has been an accumulation of knowledge concerning the effects on health caused by exposure to agents present in indoor air, known as indoor air pollutants, IAPs [WHO, 1982, 1999].

Building related illness (BRI)

Infectious and irritative respiratory diseases, respiratory allergies (for example, to house dust mites, animal fur and dander), asthma and mucous membrane irritation are the most prevalent health effects that have been associated with indoor exposures.

Respiratory allergies and hypersensitivity conditions

Allergic and non-allergic asthma, rhinitis and conjunctivitis can be caused or aggravated by exposures in indoor environments. The conjunctiva of the eyes can be considered as being a part of the airways, in terms of their environmental sensitivity and hypersensitivity, since symptoms can occur simultaneously in the airways and in the eyes, and can be caused by the same agents.

Asthma is a chronic inflammatory pulmonary disorder that is characterized by reversible obstruction of the airways, Figure 6. A recent definition has been provided [GINA, 2006]: "Asthma is a chronic inflammatory disorder of the airways in which many cells and cellular elements play a role. The chronic inflammation is associated with airway hyper-responsiveness that leads to recurrent episodes of wheezing, breathlessness, chest tightness, and coughing, particularly at night or in the early morning. These episodes are usually associated with widespread, but variable, airflow obstruction within the lung that is often reversible either spontaneously or with treatment."

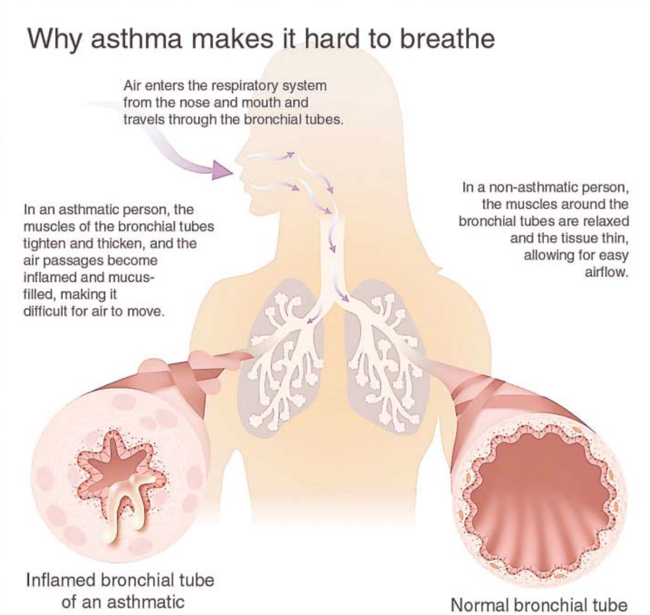

FIGURE 6. Why asthma makes it hard to breathe. Illustration: American Academy of Allergy, Asthma and Immunology.
http://www.aaaai.org/media/photos_graphics/all_photos.stm

Rhinitis is inflammation of the cells lining the nose, often resulting from the inhalation of an allergen (Figure 7). The symptoms include nasal obstruction, runny nose and sneezing. Rhinitis can be seasonal, e.g. due to an allergy to pollen (hay fever), or all year round, e.g. due to an allergy, for example, to animals or dust. Allergic rhinitis is often combined with conjunctivitis and termed "rhinoconjunctivitis".

FIGURE 7. Rhinitis.

Conjunctivitis is caused by dilatation of blood vessels in the conjunctiva, the membrane covering the eye, often as a response to an allergic reaction, Figure 8. The resulting reddening of the eyes is called allergic conjunctivitis, and is usually accompanied by itching and tears.

FIGURE 8. Conjunctivitis.

Respiratory effects of pollutants can, to a certain extent, be predicted by considering where the air pollutants are mostly likely to be deposited in the airways. Particles <5 µm (respirable particles), such as allergens from house dust mites and pets, can be carried down to the peripheral part of the lung, inducing or eliciting asthma. Coarser particles >10 µm, such as pollen, tend more to affect the eyes and upper airways eliciting allergic rhinoconjunctivitis. Hydrophilic (water soluble) gases, such as sulphur dioxide (SO_2), ammonia (NH_3) and formaldehyde tend to deposit and affect primarily upper airways, not reaching the lungs but providing strong sensory irritation. Hydrophobic gases, such as nitrogen dioxide (NO_2), can strongly affect the lungs, conveying only minor warnings with sensory effects to the eyes and upper airways.

Respiratory infections

Modern epidemiological data on the association between building dampness, indoor moulds and airway infections is limited, although the association was already well-known in the 19th century. Increased general respiratory infection proneness is associated with poor indoor climate, particularly in association with building dampness and exposure to combustion gases.

Increased infection risk is also associated to low ventilation rates in combination with crowding, such as in kindergartens, schools and barracks.

Legionellosis is an infection caused by the Gram negative bacteria Legionella, mostly by *Legionella pneumophila* [WHO, 2007a]. This is a ubiquitous aquatic organism that thrives in warm environments (25 to 45 °C with an optimum around 37 °C) and causes over 90% of Legionnaires' disease cases. *Legionnaires' disease* acquired its name in 1976 when an outbreak of pneumonia occurred among people attending a convention of the American Legion in Philadelphia. *Pontiac fever* is a milder respiratory illness without pneumonia caused by the same bacterium. Legionellosis usually occurs as single, isolated cases not associated with any recognized outbreak. When outbreaks do occur, they are usually recognized in the summer and early autumn, but cases may occur at any time of the year.

Legionellosis occurs after inhaling water droplets originating from a water source contaminated with organic matter harbouring active Legionella bacteria, often contained in amoebas or protozoa. Potential sources of contaminated water include cooling towers used in industrial cooling water systems as well as in large central air conditioning systems, evaporative coolers, hot water systems, showers, whirlpool spas, architectural fountains, room-air humidifiers, ice-making machines, misting equipment and similar disseminators that use public water supplies.

One huge outbreak in Norway in 2005 unexpectedly came from an air scrubber (an industrial air purification facility). Such an installation has never before been reported as a source of *Legionellosis* anywhere in the world. The source was identified by DNA matching, as well as by analysing increases in disease occurrence among people living near suspected sources.

Legionella will grow in water at temperatures from 20 to 50 °C (68 to 122 °F). However, the bacteria reproduce at their greatest rate in stagnant water at temperatures around normal body temperature. The most well-known causes of outbreaks are poorly managed or maintained cooling towers with the potential of spreading water droplets containing fragments of organic film with vital Legionella bacteria over long distances. Most exposures to and infections in these outbreaks thus occur outdoors. *Legionellosis* cannot be transmitted from an infected person to another person, only by inhaling water aerosols containing organic matter infected with Legionella.

Other respiratory illnesses

Extrinsic allergic alveolitis (hypersensitivity pneumonitis or farmer's lung) is very rare, but has been described in relation to indoor environment. The inflammation of the small airways or alveoli is caused by an immunological reaction to an inhaled bioaerosol (a mist or dust of biological particles), or certain reactive organic chemicals in high concentrations. Multiple causative agents have been identified and the most common are thermophilic actinomycetes, responsible for farmer's lung, and avian proteins, which induce bird fancier's lung. Sensitization occurs after a period of exposure to the antigen, varying from weeks to years. The disease can vary from acute to chronic and from mild to serious and life-threatening. It may mimic and be misdiagnosed as infectious pneumonia.

Organic dust toxic syndrome is a more prevalent flu-like illness usually due to the inhalation of grain dust, with symptoms including fever, chest tightness, cough and muscle aching. These reactions occur mostly in agricultural settings or from covering a floor with straw, etc but have also been observed in other non-industrial indoor environmental settings in association with exposure to organic dust.

Humidifier fever usually develops on a Monday or the first workday of the week and has mostly been associated with humidifiers in printing offices but has also been observed in office buildings. The hallmark of the disease is the sudden onset of fever. Other features may include muscle aches and pains and mild shortness of breath. Humidifier fever can be caused by a number of different agents including amoebas, bacteria and fungi living in the moist environment of a humidifier. Humidifier fever typically disappears once the patient is no longer exposed to the causative agent coming from the humidifier.

Cancer

Asbestos and benzene are known carcinogens but exposure is now practically non-existent. An increased risk of developing lung cancer has been linked to exposure to environmental tobacco smoke, ETS, and to radon decay products [WHO, 1999]. In areas with high radon exposure, up to

10 to 15% of all lung cancers occurring in the population may be attributable to indoor radon exposure [WHO, 1999, 2000]. With regard to ETS, it has been estimated that non-smokers living with smokers have about 30% increased risk of contracting lung cancer when compared to the non-exposed population. ETS has recently been almost eliminated in working environments in most Western countries.

Environmental cancer risk is considered a consequence of dosage, which is a product of time and exposure level. Higher ventilation rates at work create generally lower exposure levels to radon than in homes. Work exposure time is not more than a fraction of home exposure time. This implies that exposure to the two most potent indoor carcinogens, ETS and radon, is currently mainly a residential problem in countries that have effectively restricted public indoor smoking. Carcinogenic effects of radon are strongly enforced by concomitant exposure to ETS. Avoidance of ETS exposure is thus the most effective preventive action, although it is still important to limit radon exposure.

Other illnesses

The effects of IAPs on reproduction, cardiovascular disease and on other systems and organs have not been well documented to date, although exposure to ultrafine particles, UFPs, has recently been associated with cardiac disease [Weichenthal et al., 2007, Chuang et al., 2007]. To a certain extent, this may mean that no serious effects occur, but there has been little by way of research to clearly document the absence of these types of effects. A current issue is the use of plastic additives in the indoor environment, including flame retardants and plasticizers to which exposure has increased dramatically since World War II [Bornehag et al., 2004a]. Animal toxicity studies suggest that some phthalates affect male reproductive development.

Sensory irritation, sick building syndrome (SBS)

SBS consists of a group of general, mucosal and skin symptoms that are related to the time spent in particular buildings [WHO, 1982, Burge, 2004]. Building occupants complain of symptoms such as headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; concentration difficulties; fatigue and sensitivity to odours.

Various factors in the indoor air environment, including dampness, temperature, thermal conditions and particle pollutants, have been suggested as causes of these symptoms. Other factors that significantly affect the indoor environment include ventilation rates, ETS, combustion products, formaldehyde and volatile organic compounds.

What are the most important health effects associated with indoor environments?

The most important effects on public health are probably allergic respiratory sensitization, aggravation of allergic diseases, increased respiratory infection proneness and worsening of chronic obstructive lung diseases. Respiratory diseases, asthma and allergies have mainly been associated with the indoor environment in residential buildings, while a limited number of reports are related to exposure in non-industrial occupational environments. Reported respiratory illnesses seem mainly to be associated with exposure in damp buildings [Savilahti, 2000, Rudblad et al., 2004, Patovirta et al., 2004]. Heating and cooking with gas and charcoal, ETS and cleaning and washing products have also been associated with asthma [Viegi et al., 2004]. Most effects of indoor environments are results of complicated interactions between several exposures, and combinations of these are difficult to study. Indications of dampness, as well as recently repainted interior surfaces, appeared to be associated with recurrent infant wheezing, with a strengthened effect due to combined indoor exposures [Emenius et al., 2004]. Even remediation, in order to be effective, must usually comprise several solutions. Family lifestyles, according to preventive guidelines regarding breastfeeding, maternal tobacco smokers and home dampness, were associated with reductions of recurrent wheezing and asthma at two years of age [Wickman et al., 2003].

The most prevalent adverse effects of inferior indoor work environments are thus respiratory infectious diseases; mucosal, respiratory and skin irritation, including aggravation of allergies and other hypersensitivity symptoms, general symptoms including headache and fatigue, as well as reduced comfort, performance and productivity [Wargocki et al., 2000, Wyon, 2004]. Interactions and synergies among several exposures are probably important.

IMPORTANT INDOOR ENVIRONMENTAL EXPOSURES

The main indoor environment challenges, in terms of risk assessment as a basis for risk management, are still the avoidance of building dampness, the choice and maintenance of adequate ventilation rates, and the elimination of pollutants from combustion sources, cooking and heating. The effects of the thermal environment on air quality are important. Gender, organizational and psychosocial conditions also have strong impact.

Building dampness

Dampness in buildings is a risk factor for health effects among atopic (hypersensitive) and non-atopic individuals, both in domestic and in public environments [Bornehag et al., 2001, 2004]. It may increase the risk of health effects in the airways, such as coughing, wheezing and asthma by 40 to 120% or even more. Dampness is also associated with other symptoms such as tiredness, headache and airway infections. Remedial building measures have positive effects on health [Savilahti et al., 2000, Patovirta et al., 2004, Rudblad et al., 2004]. The evidence for a causal association between dampness and health effects is strong, but the mechanisms are unknown [Bornehag et al., 2001, 2004]. Several definitions of dampness have been used in studies of these associations and, no matter how they have been formulated, they all seem to be associated with health problems. The literature is not conclusive with respect to causative agents, e.g. mites, microbiological agents and organic chemicals from degraded building materials. Even if the mechanisms are unknown, there is sufficient evidence to take preventive measures against dampness, moisture and water damage in buildings.

If building structures are subject to more moisture and dampness than they were dimensioned for, this might cause damage due to chemical or microbiological decomposition of the building materials. Organic dust and filth may provide nutrition for microorganisms such as bacteria, moulds and amoebae, and insects such as mites, cockroaches and flies. Processes in built environments that are subject to more moisture than intended can therefore cause exposure to:

1. Allergens from house dust mites and other living or dead insects, germs and spores as well as from moulds and bacteria.
2. Irritants and MVOCs, microbial volatile organic compounds, with irritating and evil-smelling fumes and vapours from decay products produced by microbiologic metabolism.
3. Mycotoxins from moulds, of which many have strong biological effects. Some of these are used in medicine as antibiotics and as agents to modulate and suppress the immune system. Others are potent carcinogens such as aflatoxins, though the effects of these have not yet been associated with indoor air exposures. Microorganisms use toxins to suppress other organisms in their fight for survival and growth.
4. Endotoxins and glucanes, which are active agents originating from bacteria.

5. Chemicals, such as formaldehyde, emitted from building materials. The generation of such substances often increases due to hydrolysis and the decay of materials caused by water damage.

Although many of these potential mechanisms can, theoretically, cause health effects, most exposure levels are much too low for health effects to actually occur. One intervention study indicated age-response relationships between exposure to mould and health effects [Savilahti et al., 2000]. However, as in other indoor climate cases, the measured levels were still far too low to cause health effects, even when based on current knowledge [Eduard, 2006]. The association between dampness and health effects, on the other hand, is strong although there is no reason to believe that moisture or dampness themselves are the actual causes. Obviously, possible causes must be looked for among the agents that occur due to the effects of increased humidity in buildings and other factors, such as temperature.

Dampness is sometimes associated with mite growth that could induce mite sensitization and allergic disease [Wickman et al., 1991]. Sensitization to mites is far more common than sensitization to moulds and most subjects sensitized to moulds are also sensitized to mites or other allergens. Some authors attribute the association between dampness and health to allergy to mites. On the other hand, the association between dampness at home and bronchial obstruction in children was still strong and significant even after excluding subjects with positive mite findings in their homes [Nafstad et al., 1998].

Associations between dampness and health are also found in areas with little mite exposure, e.g. in northern Scandinavia with its dry wintertime indoor climate. Several studies have shown that the prevalence of positive skin prick tests to mites in these regions is very low (1 to 5%). The prevalence of sensitization to mites is higher in countries with more humid indoor climates (12 to 30%).

Agents other than mite allergens, which in some studies have been shown to increase the risk for symptoms and signs, are airborne moulds and bacteria. The literature, however, is not consistent. Although moulds have been associated with allergies and asthma, there is meagre evidence of any significant contribution by specific mould sensitization. A general adjuvant (enhancing) effect on specific sensitization, by exposure to moulds or any other exposure caused by moisture, might be a more probable cause than a specific sensitization to moulds themselves. It is possible that other and unknown mechanisms or exposures associated with building dampness can be more important causes of the associated effects. Specific sensitization to moulds does not seem to play an important role in the development of allergies, asthma and atopy in relation to dampness in buildings. Testing for specific allergies to mould have therefore little predictive value in the examination of individuals with suspected health effects due to exposure to damp or mouldy indoor environments.

In conclusion, it is not known which humidity-related agents in indoor air that are the main causes of the health effects. Dampness and moisture phenomena in buildings, microbial and chemical exposures and individual human responses are complex phenomena. While the causative links between exposure agents and health responses are still not well understood, the essential issue is to prevent the problems through good design, construction and maintenance of buildings.

Ventilation

The effects of ventilation on health, comfort and productivity in non-industrial indoor environment (offices, schools, homes, etc.) have been reviewed by a multidisciplinary group of scientists [Wargocki et al., 2002]. They found that ventilation is strongly associated with comfort (perceived air quality) and health in terms of SBS symptoms, nasal irritative inflammation, infections, asthma, allergy and short-term sick leave. An association between ventilation and productivity (performance of office work) is indicated. The group also concluded that increasing outdoor air supply rates in non-industrial environments improves perceived air quality; that outdoor air supply rates below 25 l/s per person increase the risk of SBS symptoms, increase short-term sick leave and decrease productivity among occupants of office buildings; and that, in Nordic countries, ventilation rates above 0.5 air changes per hour in homes reduce occurrences of house dust mites.

The practical implications are that ventilation requirements in many existing guidelines and standards may be too low to protect occupants of offices, schools, and homes from health and comfort problems and the requirements may not be optimal for human productivity. Higher ventilation rates can increase energy costs for building operation. However, these can be reduced by lowering pollution loads on the indoor air, for example, by prudent and systematic maintenance of the heating/ventilation/air-conditioning (HVAC) systems and by reducing superfluous pollution sources indoors. Energy costs can also be reduced by using efficient heat recovery systems. By applying current knowledge, indoor air quality can be improved considerably while still maintaining or even reducing ventilation rates and energy use. [Fanger, 2006].

Allergic symptoms among Swedish children in homes situated in areas with excellent outdoor air quality are related to ventilation rates lower than 0.5 air changes per hour, the limit recommended in the Swedish building regulations (Bornehag et al., 2005). Increasing mechanical ventilation in 7 Swedish classrooms reduced mean CO_2 levels of 1050 ppm to 780 ppm resulted in fewer reports of asthma symptoms among the pupils [Smedje & Norbäck, 2000].

Although no clear threshold has been found for the advantages of increasing ventilation, it is questionable whether any benefits can be achieved by ventilation rates higher than 25 l/s per person or CO_2 concentrations lower than about 600 ppm in non-industrial indoor environments in the heating season [Wargocki et al., 2002, Seppänen & Fisk, 2004]. Higher ventilation rates might reduce the relative humidity to levels that cause other problems, i.e. when the levels are reduced by 20 to 30 % [Norbäck et al., 2006, Wolkoff et al., 2006]. The airflow rate should not be decreased below 10 l/s per person since this would most probably decrease the air quality to an unacceptable level. [Strøm-Tejsen et al., 2007]. Considering these findings, it is possible that winter ventilation rates should not exceed 25 to 30 l/s and not be lower than 10 l/s per person, if there are no other significant pollution sources that need ventilation.

Heating and cooking

The increased risk of respiratory diseases associated with improperly vented, poorly ventilated or malfunctioning combustion appliances is well known in developing countries [WHO 1999, 2002, Viegi et al., 2004, Naeher et al., 2007]. These appliances even pose a real risk of acute poisoning by carbon monoxide. Combustion products and pollution from heating systems and cooking using coal, wood, kerosene and gas have also been associated with respiratory health effects in developed countries [Viegi et al., 2004, Naeher et al., 2007]. The only randomized, controlled study performed on heating systems is an Australian intervention in 18 primary schools with unflued gas heating [Pilotto, 2004]. The system was replaced by either flued gas or electric heating. Among pupils with asthma, difficulties in breathing during day and night, chest tightness and asthma attacks during the day were more than halved.

The use of gas stoves and wood-burning stoves/fireplaces was associated with shortness of breath, coughing, nocturnal asthma and restrictions in activity among adult asthmatics [Ostro, 1994]. The use of unvented gas space heaters, wood stoves and kerosene heaters was associated with respiratory symptoms among infants and women living in non-smoking households in Virginia, USA [Naeher et al., 2007]. Asthma among adults was associated with the presence of a wood stove in a questionnaire-based case-control study in Sweden [Thorn, 2001]. Wood stoves were related to coughing among children with increased hereditary risk of developing asthma [Belanger, 2003]. Exposure to freestanding wood-burning stoves was associated with otitis (inflammation in the ear) among children in the State of New York, USA [Daigler et al., 1991]. In Eastern Germany, the lowest risk of eczema was found in households with central heating systems and the highest risk where gas heaters were used [Schäfer et al., 1999].

Electric heating has traditionally been considered as "clean energy". Less attention had been paid to electric stoves as potential sources of indoor air pollution, although electric heating has been associated with increased SBS symptoms [Engvall et al., 2003] and asthma in children [Infante-Rivard, 1993]. In the State of New York, 26.7% of the asthma cases among children 0 to 10 years of age and 16.7% of the control group occurred in housing with electric baseboard (skirting) heaters [Daigler et al., 1991]. In Connecticut and Western Massachusetts, infants at high risk of developing asthma living in homes that were heated with electric baseboard heaters had higher rates of wheeze than those in homes with other heating systems [Gent, 2002]. However, this tendency was reduced when adjusted for other factors. Experimental laboratory studies have confirmed the ability of electric heating stoves to emit a large number of sub-micrometre particles and VOCs, volatile organic compounds, that inhibit cell cultures [Mathiesen, 2004]. Such problems can be avoided by keeping temperatures of surfaces that might be in contact with indoor air below 70 to 80 °C. These include heater surfaces, halogen lamps, vacuum cleaners and other electric equipment with high surface temperatures cooled by air or brought in contact with indoor air. Indoor heating in Norway is mostly provided by electric heaters. The most common type are convection heaters that bring the indoor air into direct contact with surfaces heated up to several hundred degrees Celsius.

Asthma related to ducted air heating and other heating methods was studied in a case-control study of atopic and non-atopic children in Plymouth and Dartmouth UK [Jones, 1999]. Of nine 4 to 16-year-old children, eight developed asthma, with onset while living in houses heated by ducted air. This is the only study on this issue indexed in the international scientific database PubMed.

Electric and other home cooking and heating systems contribute to the formation of indoor ultrafine particles (UFPs) [Weichenthal et al., 2007]. UFPs are generally defined as those particles with diameters < 100 nm (< 0.1 μm). Other common sources of indoor UFPs include tobacco smoke, burning candles, vacuuming, natural gas clothes dryers, and other household activities [Weichenthal et al., 2007]. Exposure to airborne particulate matter has a negative effect on respiratory health of both children and adults. The ultrafine fraction of particulate air pollution is of particular interest because of its increased ability to cause oxidative stress and inflammation in the lungs. UFPs, particularly from heating and combustion indoors and outdoors, have recently been associated with increased risk for coronary heart disease [Chuang et al., 2007]. The mechanisms behind might involve direct effects on the lung and cardiovascular system and indirect effects mediated through pulmonary inflammation and oxidative stress. The potential role played by electric and other heating and cooking appliances is of interest from both an environmental health point of view as well as for future energy politics and energy conservation solutions. More research is strongly needed.

Thermal indoor environment

There are relatively few field studies of health effects of thermal conditions [Reinikainen & Jaakkola, 2003, Mendell et al., 2002], even though thermal factors are relatively easy to assess and comprehensive international standards are available [Olesen, 2004]. High air temperature reduces the perceived air quality, increases perceived dryness and irritation of the airways [Wolkoff et al., 1997, 2006, Reinikainen & Jaakkola, 2003, Wyon, 2004, Fanger, 2006]. Each 1 °C decrease in temperature within the comfort range in public offices was related to a 19% decrease in severity of eye symptoms and to a decrease of complaints about stuffy air and feeling too warm (19% and 25%) [Mendell et al., 2002]. This greatly exceeded the related increases in perceiving draughts or feeling too cold. The reduction of air temperature to below 22 °C might thus be an effective and important measure to improve air quality and at the same time save energy in the heating season.

The need to keep thermal comfort acceptable in the heating season and to conserve energy at the same time is a challenging one. Thermal comfort is dependent on the operative temperature, which, in practice, is the average of the air temperature and mean radiation temperature from surrounding surfaces. Reducing the night temperature is a common way of conserving energy in office buildings in Norway. The air temperature is usually raised to an acceptable level when the working day starts in the morning. The mean radiation temperature might still be low when work starts, even though the air temperature has reached an acceptable level, and this might mean that the operative temperature will be too low and that employees will feel cold. Compensatory measures may then be required to avoid discomfort. An increase in air temperature is normally the result, usually to a level far above the recommended maximum level of 22 °C in the heating season. The operative temperature might have become unacceptably low because of the reduced radiant temperature from cooled indoor surfaces, particularly in buildings with heavy structures and high heating capacities. Efforts to compensate this by increasing the air temperature add to the enthalpy (energy content) of the air and might then cause decreased air quality. A high enthalpy of the air means a low cooling power of the inhaled air with subsequent insufficient convective and evaporative cooling of the respiratory tract, in particular the nose [Fanger, 2006]. This lack of proper cooling is closely related to poor perceived air quality. The recommendation that the indoor air quality (IAQ) should be dry and cool is based on the immediately perceived IAQ when entering a room [Fanger, 2006]. However, careful consideration should be given to this recommendation where continuous exposure throughout the working day is concerned [Wolkoff et al., 2006].

To avoid draughts, the velocity of the indoor air, according to current recommendations must not exceed 15 cm/s [Olesen, 2004]. However, it is questionable whether this limit is sufficiently low to avoid perceiving draughts and feeling too cold, which could lead to demands for higher operative and air temperatures. One way of achieving good air quality combined with an acceptable operative temperature in the heating season, is to keep the mean radiant temperature high, the air velocities low and the air temperature as low as possible and preferably below 22 °C.

Redecoration and other chemical exposure

Redecoration of an apartment can have a significant adverse influence on

respiratory health among children [Dietz et al., 2003, Emenius et al., 2004]. Frequent use of chemical based products during the prenatal period was associated with persistent wheezing in young children [Sheriff et al., 2005]. Hair spray used in a baby's bedroom at least once a month was associated with asthma [Ponsonby et al., 2000]. Such risks can be avoided by not exposing newborns, children and other vulnerable persons to such agents. Redecoration should be performed in good time before newborns and children move into their rooms, preferably weeks before.

An association between the concentration of phthalate esters and the risk of asthma has been found, among others by [Nafstad et al., 1998 and Bornehag et al., 2004a]. Phthalate esters are widely used as plasticizers in modern products and materials, but mostly in PVC, polyvinylchloride, products. However, current evidence is not yet sufficient to draw conclusions in terms of causality and risk assessment. Phthalates might be associated with other possible causative factors. More research is needed in order to assess this matter.

Organizational, mental and psychosocial work environments

SBS has been related to mental stress at work [Runeson et al., 2004, Marmot et al., 2006]. Mental stress has even been shown to be more important than the physical environment in explaining prevalence of SBS [Marmot et al., 2006]. Psychosocial and personal reasons also dominated in mucus membrane irritation symptoms and general symptoms among teachers in state schools when comparing "moisture-damaged" and "non-damaged" schools [Ebbehøj et al., 2005]. Negative psychosocial work factors have been associated with the risk of contracting various illnesses, especially psychosomatic disorders. High demands at work together with low social job control and low job support are combinations of mental factors that may cause various negative effects on health [Theorell & Karasek, 1996]. The results may be serious health problems such as heart disease and increased mortality [Kivimäki et al., 2002] as well as anxiety, depression, mental distress, dissatisfaction and high rates of sickness absence and turnover [Michie & Williams, 2003].

Indoor environmental problems seem to be multifactorial. As symptoms related to the indoor air factors may also be related to mental stress at work [Runeson et al., 2004, Marmot et al., 2006], the relationship to both physical and mental factors is of interest. Few studies have simultaneously examined typical indoor air symptoms, indoor environmental factors and the psychosocial work environment [Marmot et al., 2006].

Gender
Women tend to report more symptoms than men [Burge, 2004]. The reason for gender difference in reporting symptoms from indoor environments is debated. Gender differences have been observed in studies of subjective symptoms as well as in organ-specific diseases [Ihlebaek and Eriksen, 2003, Tollefsen et al., 2006]. Among possible causes are different responses to stress, coping style, work situations and physical strength, as well as different traditions and thresholds for when and how to complain. However, the real causes of these differences are not well understood, and several studies underline the importance of specifically considering the gender issue in health studies [Messing and Stellman, 2006].

ENERGY CONSERVATION AND GLOBAL SUSTAINABILITY

The EU Energy Performance of Buildings Directive (Directive 2002/91/EC) requires buildings to meet minimum energy performance ratings in order to comply with the Kyoto Protocol. The building sector accounts for about 40% of total energy usage in Europe. Both atmospheric and thermal conditions affect indoor climate and energy performance. Hopefully, energy-saving measures that are taken will improve indoor environments and not impair them [WHO, 1999].

Energy conservation measures after the energy crisis in the 1970s and 1980s included sealing houses and reducing ventilation rates. The consequences were increased indoor humidity, condensation and dampness, in turn causing an increase in the occurrence of dust mites, moisture damage and increased concentrations of pollutants from other sources. This led to more sensitization, allergies, asthma and respiratory infections, as well as increased complaints from building occupants [Wickman et al., 1991].

As a result, efforts were made to meet obvious needs for holistic approaches and to take on the challenge by establishing cooperation between all the involved sectors: Health, Building, Environment and Energy. Existing housing stocks, lifestyles, immediate environments of dwellings and social conditions should all be considered when developing healthy and sustainable housing policies, according to the declaration of the Fourth Ministerial Conference on Environment and Health held in Budapest, Hungary in June 2004. (Declaration EUR/04/5046267/6, http://www.euro.who.int/document/e83335.pdf). So far, the intentions have not been met in Norway and have only partly been met in other countries that endorsed this declaration.

It is possible to achieve considerable indoor air quality improvements while maintaining or even decreasing ventilation and energy usage, provided that current knowledge is put to use [Fanger 2006, Roulet, 2006]. This can be achieved by improving pollution source control, air cleaning, individual ventilation control (so-called personalized ventilation), delivery of cool and dry air with low air enthalpy, and the use of all these methods simultaneously. By applying good design, construction, operation and maintenance techniques, the average building stock energy use could be reduced by up to 25% according to Roulet 2006 and HOPE (Health Optimisation Protocol for Energy-Efficient Buildings, http://HOPE.EPFL.ch/).

CONCLUSIONS

Indoor environments are the main human environments and, consequently, the environments to which we are mainly exposed. This makes them an issue of public health and one that deserves considerably increased attention. Good indoor environments are needed to avoid aggravation of disease, and to improve the living conditions for asthma sufferers and other vulnerable groups. The increase of asthma and allergies in the younger population in Europe will increase the proportion of vulnerable individuals in the future population. Providing good indoor environments for these groups will benefit us all.

Although many scientific questions still need to be solved, the most urgent needs and requirements are to organize and implement our current knowledge so that health, function, comfort and productivity can be improved for everyone. This also emphasizes the need for multi and interdisciplinary cooperation in research, as well as a broad approach at a societal level to achieve holistic solutions for the challenges.

Building structures and indoor environments must be kept clean, dry and free from moisture damage and they must be properly ventilated. The key requirements are:

- The avoidance of excessive moisture exposure during the construction and operation of buildings
- The adoption of proper planning, construction and maintenance procedures for buildings as these are critical for the prevention of moisture damage
- The immediate remedy of dampness, moisture or water damage

All indoor combustion sources must be properly vented to avoid indoor pollution from combustion gases. Temperatures of heating surfaces and other indoor surfaces, such as lighting and other electric equipment, should be kept lower than 100 °C to avoid dust burning. Electric convector heaters should be avoided.

Low-temperature radiated heat, such as from wall radiators with large surfaces, is recommended. Heating by hot air, or by ducted or convective heat increases air enthalpy and impairs air quality. Important conditions for good air quality combined with acceptable operative temperatures in the heating season, are high mean radiant temperatures, low air velocities and low air temperatures, preferably below 22 °C.

It is possible to reduce energy use in buildings and at the same time improve indoor environments. One measure would be to implement and further develop indoor climate requirements based on seasonal or outdoor climates. Requirements like these are already stipulated in EN/ISO standards regarding thermal climate [Olesen, 2004].

Care must be taken with regard to exposure to irritant chemicals, sprays and redecoration. Newborns, children and people with respiratory hypersensitivity are at special risk.

Exposure to phthalate esters, used in several materials and everyday products, is strongly associated to allergies and asthma. More research is needed to assess whether this association is causal or not, and to provide foundations for preventive action.

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2. INDOOR ENVIRONMENT AND PRODUCTIVITY IN OFFICES

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This chapter summarizes how the indoor environment, in terms of ventilation, air quality, temperature and noise, affects health and productivity, and how these parameters are quantified.

The costs involved are significant. A cost analysis of any office-based business will show that the personnel costs comprise the major part of its total costs and that the economic gain thanks to small improvements in productivity or health easily pays back the increased costs for better ventilation, heating and comfort cooling.

Such an analysis will reveal that:

- even a 1% increase in work performance can be equivalent to the annual cost of ventilating an office building.
- productivity gains of just under 10% can be equivalent to the total installation and running costs in an office building.
- payback time for investments to improve the quality of the indoor environment is often less than 2 years.

In a cost-benefit analysis, it is not sufficient to have data that shows a qualitative and statistically significant effect of the IEQ, indoor environmental quality, on health or work performance: the size of the effect must also be quantified. This chapter summarizes the quantitative relationships between IEQ, health and performance that can be derived from existing data.

The conclusions derived from the relationships for offices include the following:

- Higher ventilation rates reduce prevalence of infectious diseases. For example, doubling the ventilation rate in the range of 0.5 to 2 ACH, air changes per hour, can reduce illness and sick leave prevalence by up to about 10%.
- Increasing ventilation rates up to 17 l/s per person can improve office task performance. For example, doubling the outdoor air supply rate within the range of 6.5 to 17 l/s can increase work performance by up to about 1.5%.
- Every 10% reduction in the percentage dissatisfied with the perceived air quality can increase the work performance work by about 1%.
- Optimal productivity is achieved when the indoor temperature is maintained between 20 and 24°C. If the temperature is higher than 24°C, a 1°C decrease can increase work performance by about 1.5%. If the room temperature is lower than 20°C, an increase of 1°C can increase work performance by 2%.
- Increases in ventilation rates above 10 l/s per person, up to approximately 20 l/s per person, are associated with a significant decrease in the prevalence of SBS, sick building symptoms, or with improvements in perceived air quality. A 10% decrease in the prevalence of typical symptoms such as headaches can increase productivity by 1.5%.

The chapter also illustrates how to use these relationships in a cost-benefit analysis for an HVAC installation.

INTRODUCTION

Deterioration of the indoor climate often lies behind SBS symptoms, respiratory illnesses, sick leave, reduced comfort and losses in productivity. Studies have shown that when all these problems are expressed in economical terms, the costs to society are high. Some calculations show that the costs are higher than the heating energy costs for the building in question [Seppänen, 1999, Fisk, 2000]. Potential benefits of indoor improvements include reduced medical care costs, gains in working days thanks to reduced sick leave, better work performance, lower turnover of employees, and lower costs for building maintenance thanks to fewer complaints about the indoor air quality and climate.

Typical calculations have also shown that many measures to improve the indoor air environment are cost-effective when the health and productivity benefits are included in the calculations. It is also clear, based on a total cost analysis of any office-based business, that wages are by far the largest cost item, see Figure 1, and that the value of a small improvement in productivity easily matches the increase for the first cost for an HVAC improvement.

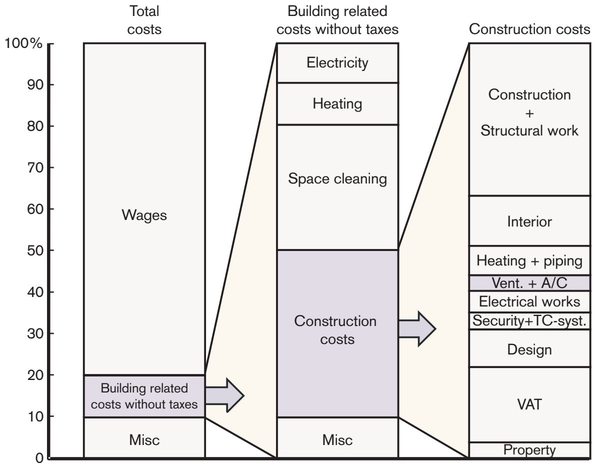

Figure 1. An example showing the relative significance of wage costs in relation to annual costs for an office building.

There is an obvious need for calculation models that include the economic value of health and work performance, based on first and operating costs, in cost-benefit calculations. The use of such models would lead to improved indoor environments, health and productivity. It is important to show to employers and building owners that investments in good indoor environment are beneficial, see Figure 2. Most critical in the economic calculations is the link between the indoor environmental factors and productivity. This chapter presents estimates of some quantitative links for cost-benefit calculations, namely, between ventilation rates and sick leave, ventilation rates and work performance, perceived air quality and work performance, temperature and work performance, and SBS symptoms and productivity.

BENEFITS DUE TO GOOD INDOOR ENVIRONMENT

The potential benefits due to improved IEQ include reduced medical care costs, working days gained thanks to reduced sick leave, better work performance, lower turnover of employees, and lower costs for building maintenance thanks to fewer IEQ complaints. The financial benefits of reduced sick leave are obvious. Performance at work is more complicated to quantify. There are three distinct aspects of performance: quantity

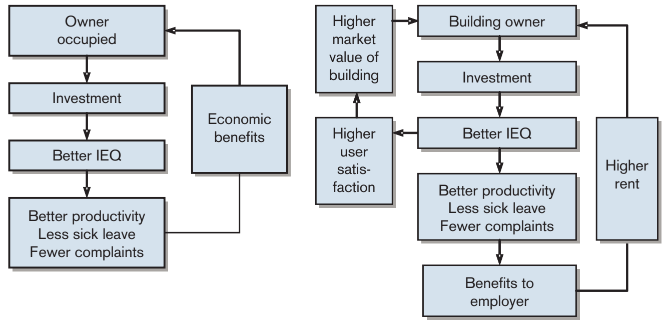

Figure 2. Benefits of improved indoor environmental quality (IEQ) are transferred directly to the building owner in owner-occupied buildings (left) and in leased buildings to the building owner via rent and long-term value of the building (right).

(speed), quality (mistake rates), and group effects (positive interaction). The quantity and quality of work have been used as metrics in laboratory and field studies, in which repetitive work, e.g. processing forms, has been studied for practical reasons.

Poor IEQ conditions could also lead to complaints and to negative talk among employees, leading to changes in attitude towards the employer and poorer work performance. If IEQ problems are not dealt with properly, employee-management conflicts could develop and complicate the problem solving process and lead to even greater reductions in productivity. A reduction in employee turnover could significantly reduce costs to employers. And a reduced number of complaints could also result in a reduced workload for the facility management personnel. The magnitude of many financial benefits depends on the increase in number of days worked, the speed at which work is carried out and the quality of the work. As a first approximation, financial benefits can be based on salaries and related benefits and overheads [Seppänen and Fisk, 2006a, 2006b, Fisk and Seppänen, 2007].

LINK BETWEEN BUILDING FEATURES, IEQ AND HUMAN RESPONSES

If the economical benefits derived from a good indoor environment are to be included a cost analysis for a building, it must be known how the design of the building and the building services affect the physical indoor environment. It is also necessary to know how the physical indoor environment then affects health, absence, performance and other cost-related factors. To date, it has not been possible to quantify all the relationships between IEQ variables and human responses. However, this is not always essential, as it is often regarded as sufficient, when data is lacking, to use observations of the direct links between building design (for example, type of HVAC plant) and operational parameters (for example, ventilation rate) and outcomes in terms of health and performance, see Figure 3. The diagram illustrates the information available at present about the links between parameters such as temperature, ventilation, SBS symptoms, health and performance.

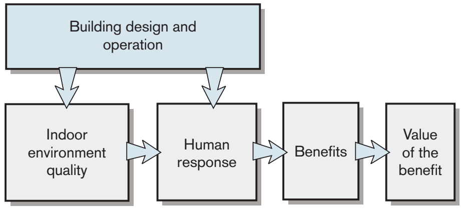

Figure 3. Simplified linkage between the building, human responses and benefits [Wargocki and Seppänen, eds. 2006].

The relationship between ventilation rate and short-term sick leave

Quantitative relationships between ventilation rate and short-term sick leave were estimated by calibrating a theoretical model of airborne transmission of respiratory infections with published field data, in which the ventilation rate was the independent variable and short-term sick leave or illness incidence were the outcomes [Fisk et al., 2005]. The model takes into account the effects that ventilation, filtration and indoor particle deposition have on airborne concentrations of infectious particles and the feedback process, by which more disease transmission in a building leads to more sick occupants who become new sources of infectious particles. The model has been calibrated, i.e., adapted to several sets of empirical data, resulting in different curves for ventilation rates and illness prevalence.

The resulting relationships are presented in Figure 4. While the model has many sources of uncertainty [Fisk et al., 2005], the effect is quite large and may be very significant in economical terms.

The relationship between ventilation rate and performance of office work

An estimate of the relationship between ventilation rate and work performance has been developed, based on five studies in offices and two studies that compiled data in a controlled laboratory experiment (Seppänen et al., 2006a). These studies quantified office work performance by measuring performance of simulated office work (typing, addition, proofreading) and by tracking the speed of actual work in call centres. Each data point was weighted by the number of subjects in the study. The different studies were also assigned weighting factors according to the relevance of the productivity metric for overall office work performance, i.e. the reaction time metric was given a low weight because it is not clear that it is a good predictor of actual office work performance. A summary of the results is presented in Figure 5, where the relative performance of typical office tasks is shown as a function of the ventilation air flow. The curves suggest that doubling the outdoor air supply rate will improve the work performance on average by 1.5 %. The analysis showed that this relationship is statistically significant up to 17 l/s per person.

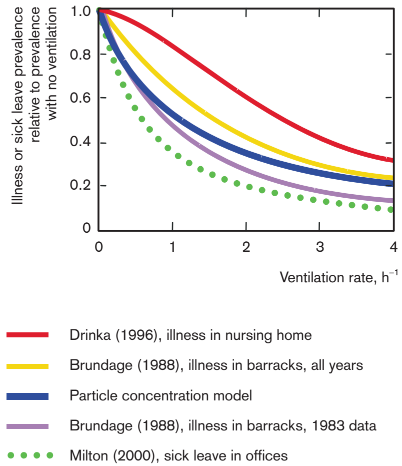

Figure 4. Predicted trends in illness or sick leave versus air change rate [Fisk et al. 2005]. The different lines represent different calibrations of the disease transmission model with empirical data, except the line labelled Particle concentration model, which is based on an assumption that the airborne disease transmission risk is inversely proportional to the total removal rate of airborne infectious particles.

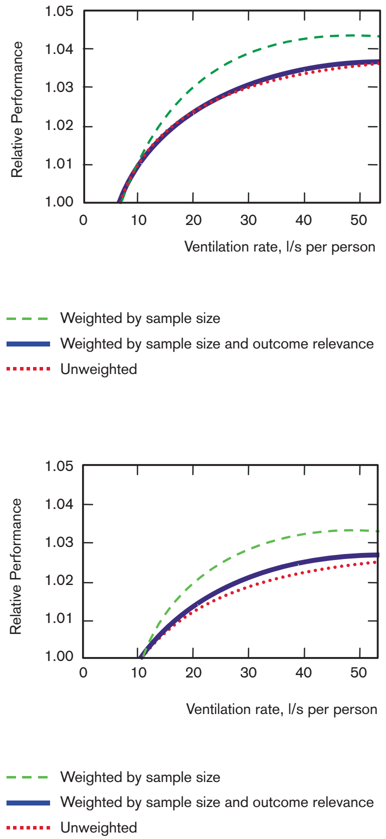

Figure 5. Effect of increasing ventilation rate on performance with respect to performance at the reference ventilation rate of 6.5 l/s per person (top figure) and 10 l/s per person (bottom figure) [Seppänen et al., 2006a].

The relationship between perceived air quality and performance of office work

An estimated relationship between perceived air quality and performance of office work is presented in Figure 6 and is based on three experiments with subjects performing simulated office work [Wargocki et al., 1999; 2000a,b; 2002]. Air quality was modified by changing the outdoor air supply rate in an office polluted by a sample of a 20-year-old carpet from a problem building, and then by removing this carpet from the office. The quantitative relationship indicates a 1.1 % increase in performance for every 10 % reduction in the proportion of dissatisfied with the air quality, in the range 25 to 70 % dissatisfied.

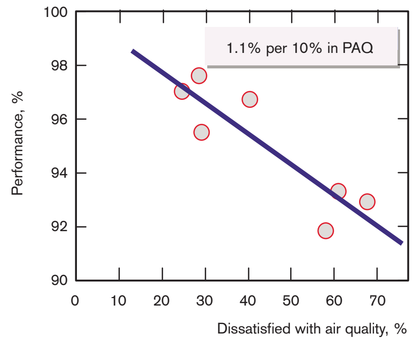

Figure 6. Performance of simulated office work as a function of proportion of dissatisfied with perceived air quality (PAQ), [Wargocki et al., 2000b].

The relationship in Figure 6 was later verified [Bako-Biro, 2004] when the data in Figure 6 was combined with the data obtained in his own studies, in which the sources of pollution were PCs with cathode-ray tube monitors, linoleum, sealant, and shelves with books and paper. Analysis of the combined data leads to the relationship between performance and air quality presented in Figure 7. The resulting relationship, about 0.8% change in performance for every 10% change in proportion of subjects dissatisfied with perceived air quality, is similar to that observed by [Wargocki et al., (2000b)]. However, in Figure 7 the performance indicator was only text typing, while in Figure 6 the performance results included performance of text typing, addition and proof-reading.

Based on the relationships shown in Figures 6 and 7, the effect of improving the PAQ in office buildings on the performance of office work can be estimated. Typical values of PAQ, given in percentage dissatisfied, vary between 10 and 40%. Air quality is considered satisfactory if the percentage of dissatisfied persons is below 20%: in problem-buildings it

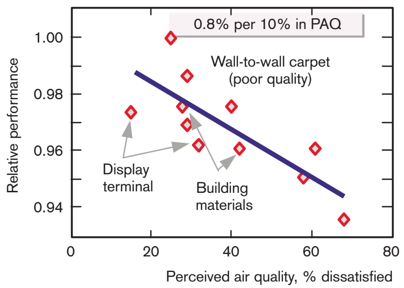

FIGURE 7. Typing performance as a function of the proportion of subjects dissatisfied with the perceived air quality, PAQ, [Bako–Biro, 2004].

can be over 50 %. Air quality can be improved by removing the pollution sources from the building and increasing the ventilation rates.

The relationship between temperature and performance of office work

A relationship between indoor air temperature and work performance is shown in Figure 8 and is based on 148 assessments of performance from 24 studies [Seppänen et al., 2006b]. These studies tracked objectively measured indicators of work performance (e.g. talk time in call centres), speed and accuracy of complex tasks or simple visual tasks, performance of vigilance tasks or manual tasks related to office work, and learning rates and precision. The results of each study were weighted by the number of study subjects and the different studies were assigned weighting factors according to the relevance of the productivity metric for overall office work performance. Study results were then normalized by calculating the percentage change in performance for a temperature change of 1 °C. Figure 8 shows the normalized data and the curve matches the data with 90 % CI, confidence intervals, meaning that with 90 % probability the correct value lies between these limits. Positive values indicate that performance improves when the temperature is increased and negative values indicate that performance is reduced when the temperature is increased. The curve crosses zero at a temperature of about 22 °C. Consequently, the data indicate that performance improves with increased temperature when the temperature is below 22 °C and decreases with increased temperature when the temperature is above 22 °C.

The relationship presented in Figure 8 is replotted in Figure 9 with 22 °C as the reference temperature. However, the statistical analysis

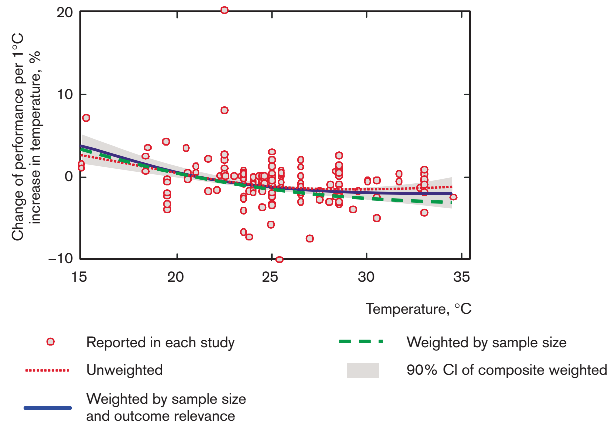

FIGURE 8. Change of performance (expressed as % change per °C increase in temperature) as a function of temperature. Positive values indicate that performance is improved when the temperature is increased and the negative values show that performance is reduced when the temperature is increased [Seppänen et al. 2006b].

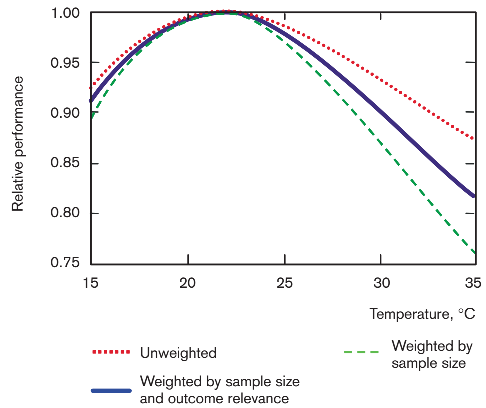

FIGURE 9. Relative performance as a function of temperature with reference to performance at 22 °C. [Seppänen et al., 2006b].

shows that the results are statistically significant only outside the range 20 to 24 °C. This means that that the optimum temperature range is 20 to 24 °C, and that work performance is improved if temperatures that are too low are raised to 20 °C, and temperatures that are too high are decreased to 24 °C. The results also show that performance is reduced by about 1.5 % for every 1 °C increase in temperature above 24 °C, and reduced by about 2 % for every 1 °C decrease below 20 °C.

SBS-SYMPTOMS AND PERFORMANCE

In many prior studies, characteristics of buildings and indoor environments have been linked to the prevalence of SBS symptoms experienced by the occupants [Seppänen and Fisk, 2006b], but these have not been quantified. Only two studies suggest the quantitative link. [Niemelä et al., 2006] suggest that, based on data from a call centre, an average reduction of 7.4 % points in the prevalence of weekly central nervous system symptoms such as headaches, fatigue and concentration difficulties in concentrating, correspond to a 1.1 % increase in productivity. [Tham and Willem, 2004] report a linear relationship between the intensity of neurobehavioral symptoms such as headaches and difficulties in thinking clearly, and average talking time in a call centre. The talking time improved, i.e. was shortened, by 5 % per 10 points change in intensity of symptoms. The intensity of symptoms was measured using an analogue-visual scale from 0 to 100.

THE EFFECTS OF NOISE ON PERFORMANCE

Auditory information can be a stimulus or a distraction. It is often the case in office buildings that noise from conversations of others is a major irritant, especially in open-plan offices. Open-plan office noise at 55 dB(A) reduced the rate at which subjects performed simulated office work when compared to quiet conditions at 35 dB(A). Noise also increased fatigue and made it more difficult to think clearly [Witterseh et al., 2004].

In a recent analysis, [Hongisto, 2005] developed a mathematical model predicting how much performance would be reduced due to disturbances arising from speech of varying intelligibility, physically determined by measuring the Speech Transmission Index, STI. A model was created based on the data reported in references, which suggests a performance decrement of between 4 and 45 % depending on the task being carried out. The model implies that performance starts to decrease at STI = 0.2, and the highest performance decrement is already reached at STI = 0.6 (at STI = 1 speech is heard perfectly, while at STI = 0 it is inaudible).

THE EFFECTS OF INDIVIDUAL CONTROL ON PERFORMANCE

Individual control of the indoor environment has been shown to reduce sick leave due to SBS and to improve performance, when estimated by the test-persons themselves. Studies of large numbers of people working in office buildings in the Netherlands show that the total amount of sick leave due to SBS is likely to be 34 % lower when office employees can control their thermal environment [Preller et al., 1990].

Studies in the U.K. indicate that self-estimated performances are significantly higher when office employees can control their own thermal environment, ventilation or the lighting levels where they work [Raw et al., 1990]. These two studies agree well with the experiment in an insurance company that showed that provision of individual control of temperature reduced the claim processing time, i.e. increased performance, by about 4 % [Kroner and Stark-Martin, 1994]. It has been estimated that the provision of individual temperature controls equivalent to a ±3 °C range around the optimum group temperature would lead to an approximately 7 % increase in work performance with regard to office work [Wyon, 1996].

In an experiment with a group of test-subjects performing simulated office work, e.g. text typing and addition, self-estimated performances improved when the outdoor air was provided by a so-called personal ventilation system and improved even more when the supply air temperature was lower than the room temperature. Under these conditions, and when compared to traditional mixing ventilation without individual controls, subjects made 15% fewer errors when typing text [Kaczmarczyk et al., 2004]. They also reported that the intensities of headaches were lower and that their ability to think clearly increased.

Studies in US offices showed that the use of a so-called TAC, task/ambient conditioning, system that provides ventilation and temperature control, together with task lighting and a white noise generator integrated into the TAC, increased overall occupant satisfaction with the thermal quality, acoustical quality and air quality. As the preferences of light levels differ between individuals, the individual control of light levels, i.e. the provision of task lighting, seems a viable approach to improve performance.

The data presented above suggests that provisions of individual controls for different indoor climate parameters may have a large impact on performance. To date, however, there is too little data to develop quantitative relationships.

CASE STUDY Summertime temperatures are often high in office buildings without air-conditioning. The following example illustrates how the effect of room temperature on work performance is integrated into the evaluation of the cost-effectiveness of various cooling alternatives [Wargocki and Seppänen, eds, 2006]. The alternatives for the improvements are: to install central mechanical cooling, to increase the operating hours of the ventilation system, and to increase the supply air flow rate.

A typical small office building in Finland was used in the analysis. The building was a concrete structure with narrow bays and individual offices located in the exterior zone of the building, i.e. not an open-plan layout. A single office room was selected for the detailed analysis. The main features of the room are described in Table 1. This basic case, used as a reference, has windows with moderate solar protection (light blinds between the panes) and solid walls to provide high thermal capacity, to counter high temperatures during the day.

The options to reduce high temperatures in the room are:

- To install mechanical cooling
- To increase the operating time of the ventilation system (the ventilation system is normally only in operation during office hours plus a couple of additional hours)
- To increase the supply air flow rate

TABLE 1. Main features of the office room used in the analysis.

Floor area	9.7 m^3
Room volume	28.2 m^3
Air leakage	0.1 h^{-1}
External wall area (excl. windows)	5.3 m^2
Lighting load	15 W/m^2
Heat load from office equipment	100 W
Desired room temperature	21°C
Room usage on average	6.6 h/day
Structure	Heavy (concrete)
Windows	3 panes, clear glass
Shading	Light Venetian blinds between middle and outer panes
Glazed area of windows	2.5 m^2
Lights switched on	08.00 to 16.00
Office equipment switched on	08.00 to 16.00
Minimum supply air temperature	14°C
Working hours per year	1550 h

TABLE 2. Description of the basic case, Case (1), and the investigated alternatives.

Case	Description
1(basic)	Solar protection with light Venetian blinds between the outer and middle panes. Supply air flow rate 2 l/s per m^2, ventilation operating 10 h/d.
2	Mechanical cooling with a cooling capacity of 20 W/m^2 for 10 h/d.
3	Operating time of the ventilation increased from 10 to 24 h/d in summer.
4	Supply air flow rate increased from 2 to 4 l/s per m^2, and operating time of the ventilation increased from 10 to 24 h/d in summer.
5	Supply air flow rate increased from 2 to 4 l/s per m^2, operating time of the ventilation and 20 W/m^2 mechanical cooling increased from 10 to 24 h/d in summer.

The basic Case (1) and Cases (2) to (5), with the different improvement options, are described in Table 2. The energy costs used in the calculations reflect the average energy costs in Helsinki, i.e. for heating, 0.04 €/kWh and for electricity, 0.1 €/kWh. The value of the annual work produced by each employee was assumed to be €50 000. If the average number of working hours was 1550 per year (taking into account holidays and vacations), the value of the work performed was 32.26 €/h.

Method

The analysis included the annual cost of the investment, the increase in operating costs (energy only), and improved work performance due to better room temperature control. The investment costs were based on a large database for refurbishment costs. The first costs have been calculated assuming 50 similar rooms to be refurbished under the same contract. In order to determine the cost per room, the total cost has been divided by 50. First costs have been converted into annual costs using an annuity factor of 0.1098, corresponding to an operational life of 15 years and an interest rate of 7%. The effects of the remedial measures on room temperature, productivity and energy consumption were calculated using a modular computer program, IDA Indoor Climate and Energy [Vuolle and Salin, 2000].

The energy consumption was calculated using reference year weather data as follows:

- Annual average temperature 4.2 °C
- Maximum outdoor temperature +28.5 °C
- Minimum outdoor temperature −30.0 °C

- Heating, base 20 °C, 5693 degree days
- Total annual solar radiation on horizontal surface 936 kWh/m^2

The total investment in remedial measures per room is shown in Table 3.

Table 3. First costs of some of the remedial measures to control high room temperatures.

Remedial measure	Description	Total cost €	Cost per room €
Increase of ventilation by 2 l/s per m^2	Air handling unit and ducts, 1 m^3/s	25 000	500
Mechanical cooling added in central air handling unit	Compressor, condenser, cooling coil and controls, 1 m^3/s air flow 12 kW cooling capacity. COP = 3	23 719	474

The calculated electrical energy in Table 4 includes all electricity used per room: lighting, office equipment, fans, and mechanical cooling. Heating energy only comprises the energy used for heating the supply air. Heat recovery from the ventilation air, at a temperature efficiency of 50%, was assumed in the calculations. The estimated loss of productivity was derived from Figure 9. The operative temperature at the assumed working location in the room was calculated for each working hour and the loss of productivity due to inadequate temperature control was estimated for the whole year. In the total cost calculations, Case (1) is the reference case, to which the other cases are compared.

Results and discussion

The results of the calculations are shown in Table 4. It should be noted that all improvements of temperature control are cost-effective and result in annual savings in total costs when the increased productivity is included in the calculations, see last row in Table 4. The total use of electricity and heat is presented for all 50 rooms and per m^2 floor area. The cost of heat and electricity increases considerably with the increase of the outdoor air flow rate but not as much with increased operation time, as this is only extended in summertime. It is interesting to note that more electricity is required when the operating time is increased, Case (3), than when the mechanical cooling solution is used, Case (2). The best

Table 4. The economical effects of different remedial measures used to reduce high indoor air temperatures in a group of 50 offices. Case (1) is used as a reference. Energy costs are based on average energy costs in Helsinki. All figures are for annual usages and annual costs, except the first costs.

Factor	Case				
	Basic	Mechanical cooling	Increased operating time	Increased outdoor air flow and operating time	All (2)+ (3)+ (4)=
	(1)	(2)	(3)	(4)	(5)
Supply air flow, l/(s.m^2) (no recirculation)	2	2	2	4	4
Operating time, h/day	10	10	24	24	24
Mechanical cooling, W/m^2	0	20	0	0	20
Electrical energy, HVAC and services, kWh	5 029	5 829	7 403	14 790	15 295
Heating energy, HVAC, kWh	47 156	47 219	49 103	72 765	71 434
Electrical energy, kWh/m^2	10.4	12.0	15.3	30.5	31.5
Heating energy, kWh/m^2	97.2	97.4	101.2	150.0	147.3
Cost of electricity per person, €	10.1	11.7	14.8	29.6	30.6
Heating cost per person, €	37.7	37.7	39.3	58.2	57.1
Energy cost per person, €	47.8	49.4	54.1	87.8	87.7
Additional energy cost per person, € **(a)**	0	1,6	6.3	40.0	39.9
First cost of remedial measure, €	0	474	0	500	974
Cost of investment per person (15 years, 7 %), € **(b)**	0	52.0	0	54.9	106.9
Lost working hours due to poor temperature control, h	1 063	777	632	327	218
Value of lost working hours per person, € **(c)**	686	501	408	211	141
Gained working hours due to improved temperature control per person, h	0	6	9	15	17
Relative value of improved productivity per person, € **(d)**	0	184	278	475	545
Total cost per person, € **(a + b + c)**	686	555	414	306	288
Total savings per person, € **(d – a – b)**	0	131	272	380	398

results for temperature control and productivity (lowest number of working hours lost due to high room temperatures) is when all measures are implemented (mechanical cooling, higher supply air low, and longer operating hours in summer, Case (5). It is also worth noting that extending operating hours in the summer will alone result in considerable savings (two thirds of the highest savings), without any investments being needed.

Energy and first costs are small compared to the productivity benefits in all cases. The first costs for mechanical cooling and increased supply air flow are approximately equal. However, longer operating hours lead to a greater gain in working hours than mechanical cooling with a supply air flow of 2 l/s per person and operating for 10 h/d. Mechanical cooling with a higher supply air flow and longer operating hours is the most effective measure for controlling temperature, Case (5). The total cost and the breakdown for each case is illustrated in Figure 10. The cost items include the value of lost working hours, the increase in energy costs and the annual costs of the remedial measure.

The results show that it is beneficial to control the room temperature in summertime in office buildings. The investment cost depends on the specific case, and may vary considerably depending on the difficulties encountered when changing the existing system and installation. This is especially true if the increased ventilation also requires new ductwork. Mechanical or desiccant cooling is then normally easier to install in an existing system [Zimmermann, 1998]. In this case, too, the existing air handling unit may limit the total cooling capacity. However, even doubling the first costs will not result in negative annual savings. An interest rate of 7% may be considered high, but has only a minor effect on the annual cost of the investment. The expected operational life of the air handling system and air-conditioning system is 15 years.

Note that Case (3) achieves 70% of the net economic benefits of Cases (4) and (5) with only a 16% rise in energy use.

The calculations above only comprise the effect of improved temperature control on productivity. However, additional improvements in performance can also be expected thanks to improvements of indoor air quality as a result of higher ventilation rates in Cases (4) and (5). The ventilation rate is increased from about 20 l/s per person to 40 l/s per person, which, according to Figure 5, may result in about 1% increase in performance. However, it should also be noted that poorly maintained air-conditioning plant might increase the risk of creating SBS symptoms

[Seppänen and Fisk, 2002]. Problems could occur due to pollution sources at or close to the outdoor air intake, excess moisture and mould in the system, fibres released from the duct liners and sound dampers, accumulated dust on surfaces of the air handling system, oil on new sheet metal surfaces, and dirty and wet filters.

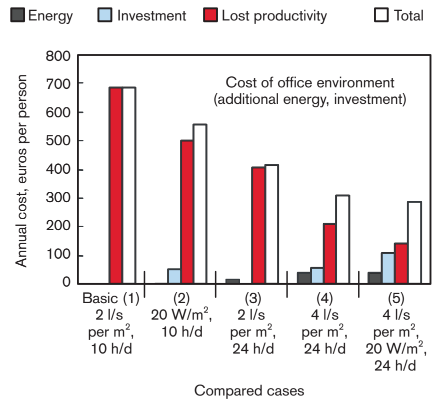

FIGURE 10. The effects of mechanical cooling, Case (2), increased operation time, Case (3), increased outdoor air flow, Case (4), and all combined, Case (5), on the cost items related to room temperature control in a typical Finnish office building (€ per person per year).

WHO RECEIVES THE BENEFITS?

Depending on one's perspective, the cost-effectiveness of investments to improve working environments and their operating costs will vary. Consider the perspectives of the building owner/employer, i.e. in an owner-occupied building, the building owner (lessor), the employer (lessee), and society in general. In owner-occupied buildings, the owners/employers benefit directly from the improvements in the health and performance of their employees. In leased buildings, the lessee will experience the direct health and productivity benefits of IEQ improvements, although the lessor should benefit from being able to increase the rent for premises with more healthy and productive occupants, and from a subsequent increase in the building's market value. [Hanssen, 1997] refers to an American study that concluded that when a tenant does not renew the lease agreement, for example, because of frequent IEQ complaints, the costs of lost rental income, remodelling, etc to the owner could be equivalent to as much as 18 months rent. In a building with superior IEQ, the lessor might also benefit from reduced operating and management costs as a result of fewer IEQ complaints. In general, neither the owner (lessor) nor the employer (lessee) benefit from reduced medical care costs, which are usually covered nationally or by insurance. However, society in general benefits from reduced medical care costs as well as from improved health and productivity.

EXAMPLE [from Wargocki and Seppänen, eds., 2006]
Case: A company leases an office space from a building owner. The floor area for each employee is 20 m², the average value of the work in the company is 60 000 € per year per employee (including gross salary, overheads and profit). The annual rent for the office space is 1800 €/m².
The owner of the building improves the air-conditioning of the building, resulting in better temperature control and better ventilation. The investment cost is 350 €/m².
Effects of improvements: Thanks to this investment the indoor environment is improved and the performance of the company employees is improved by 4%. Thanks to the indoor environment improvements tenants stay longer in the building and the lease agreements are longer. Thanks to new equipment the maintenance costs will be decreased and these are equivalent to the small increase in energy use due to higher ventilation rates and mechanical cooling. The total operation and maintenance costs will be the same as before the improvements.
Share of the benefits: The owner of the building and lessee agree that the benefits of calculated productivity improvements will be shared so that the owner receives 25% of the productivity improvements as an increase of rent.
Benefits for the employer (lessee): The annual value of the performance improvements is: $0.04 \times 60\,000$ €/person → 2400 €/person → 120 €/m².
After sharing this benefit with the owner, as an increase in rent (25% of the benefit), the net benefit to the employer is 1800 €/person per year, equivalent to a net annual increase in the output of the company of 1800 €/person. As costs, other than rent, are not incrased, this also means that the net profit will increase by the same amount.
Benefits for the building owner (lessor): It was agreed between the lessor and lessee that the estimated gross benefit be distributed so that the employer receives 75% and the owner of the building 25%. Thus the owner of the building can justify a 0.25×120 €/m² = 30 €/m² higher rent.
The investment is also very profitable for the building owner. Thanks to longer lease agreements, the annual rent increase can be assumed to be in the region of 1 week, which is equivalent to $(180 + 30)/52 = 4$ €/m².
The total net income increase is thus $30 + 4 = 34$ €/m². The return on the investment is $(34/350) \times 100$, i.e. approximately 10%.

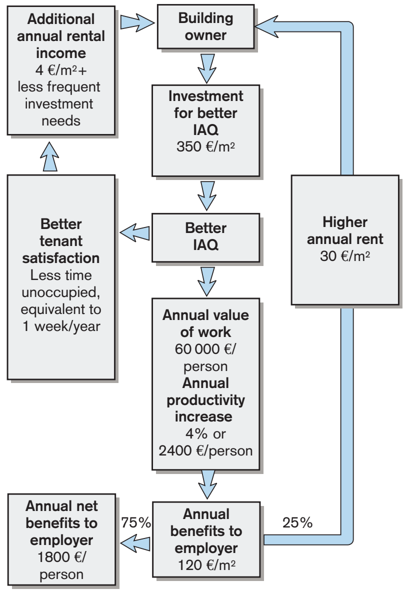

FIGURE 11. An example of profit sharing of improved productivity between the building owner and employer.

CONCLUSIONS

Personnel costs are by far the greatest cost items for any office-based business. The value of a small improvement in productivity or health easily pays back the increased costs for HVAC improvements. For cost-benefit analyses in cases like these, it is not sufficient to have data showing a qualitative and statistically significant connection between a particular indoor environment factor and health or performance: it must also be possible to estimate the size of the effect quantitatively. This chapter illustrated that it is possible, with existing data, to estimate quantitative relationships between ventilation rates and absences caused by illnesses, and to estimate quantitatively how work performance and SBS symptoms are related to ventilation rates and air temperatures. These resulting quantitative relationships have a high level of uncertainty. However, use of these relationships may be preferable to current practice, which ignores health and performance-related productivity in decisions about building design and operation. When the relationship between indoor environ-

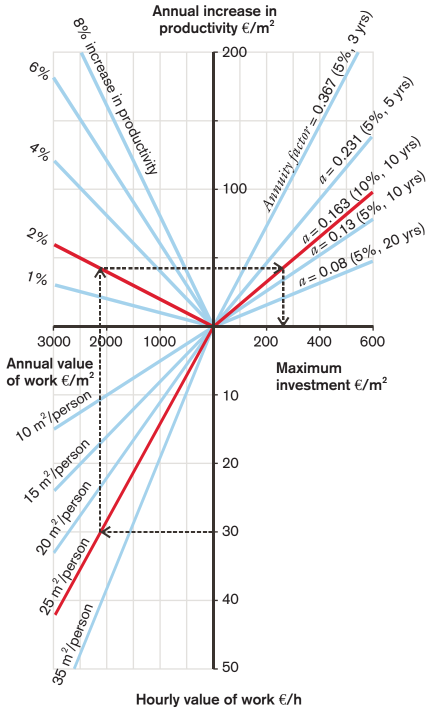

FIGURE 12. Maximum investment costs (€/m² office floor) to improve the indoor environment based on different values of work, available office space, increase in productivity, interest rates and operational lifetimes. The diagram shows parameters in owner-occupied buildings where the building owner, as an employer, receives all the benefits from improved productivity.

mental parameters and productivity is known, the economic analysis can be easily carried out, see Figure 12. The payback time for investments to improve the indoor environmental quality is generally very short, normally less than 2 years.

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COMMENT

Ventilare necesse est – to ventilate is necessary – and ventilation will always be a cost. On the other hand, gains made by ventilating sensibly are always worth far more than the consequences of doing nothing at all. Good ventilation improves our performance and is of vital importance for our health – not least for our children's. Can we afford not to pay attention to these facts?

EPILOGUE

The *Swegon Air Academy* hopes that this book will, to some extent, contribute towards an increased understanding of how a good indoor climate can help to make a building comfortable, efficient and profitable. We also hope that this book will increase understanding between the different players in the building industry and pave the way for an even better dialogue between property owners, architects, builders, consultants and installation contractors.

The chapters that discuss the present energy situation and how we ourselves affect the outdoor climate will, hopefully, cause us to reflect on these issues and stimulate active engagement. We can hardly prevent climate changes but we can join together to try and reduce them.

We would like to take this opportunity to thank all those who have made this book possible. In addition to all the contributing authors, we would like to thank Dr. Per-Erik Nilsson and his colleagues at CIT Energy Management for their valuable advice and especially Dr. Lars E. Ekberg, both for contributing three chapters and for his careful scrutiny of the other author's contributions.

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numerous ideas and suggestions, as well as a good dose of encouragement when I was almost ready to give up.

With your help and that of the authors, the result has not been a dry textbook but a timeless publication with a soul of its own. You don't have to read it from cover to cover in one go: read it as you please - just pick out a suitable chapter and satisfy your curiosity!

CONNY NILSSON

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The *Swegon Air Academy* is a forum for objective and company-neutral sharing of knowledge and experiences related to air handling and indoor climate issues.

One of our primary goals is to explain complex relationships in an intelligible way, so that those who are interested in a subject can understand it at a deeper level.

Via seminars, newspaper articles and literature, the *Swegon Air Academy* contributes to a greater awareness of the importance of indoor air quality for health and well-being, to an increased understanding of the energy issue and to a higher level of involvement in matters concerning the outdoor environment.

The *Swegon Air Academy* provides information and educational activities all over Europe and co-operates with well-known experts in relevant fields.

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