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.

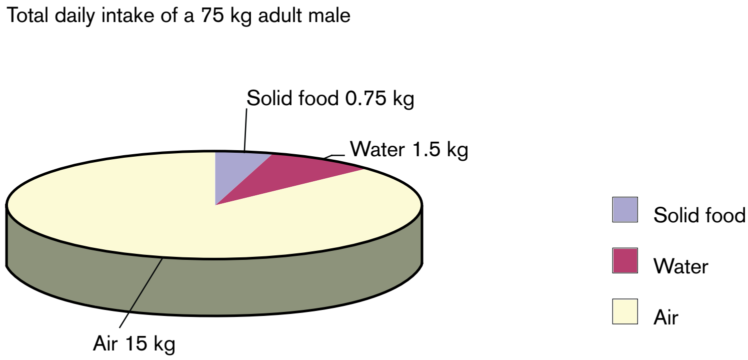

FIGURE 1. Human daily intake of food, water and air.

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.

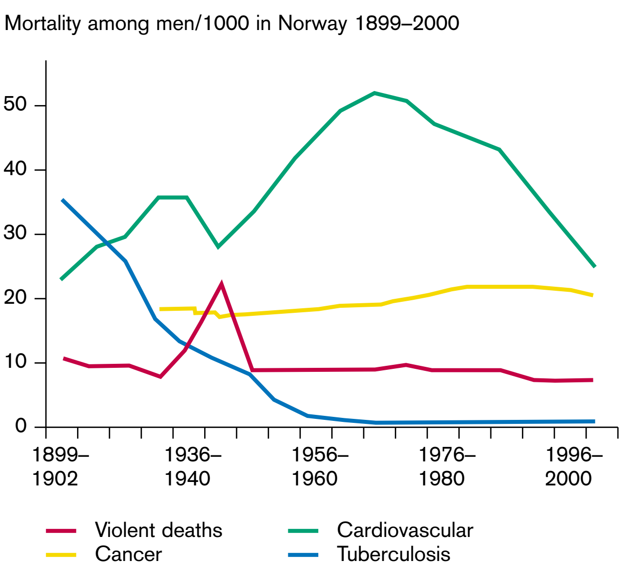

FIGURE 4. Age-adjusted mortality due to four causes [Stene-Larsen, 2006].

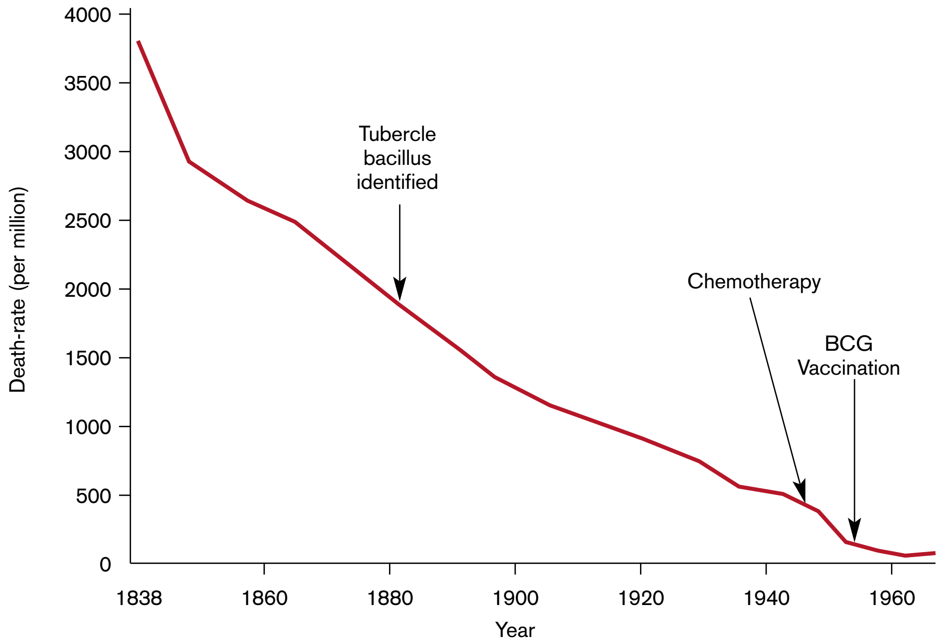

FIGURE 5. Respiratory tuberculosis (TB): mean annual death rate in England and Wales [Department of Health, UK, 1992].

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%.

Current general population exposure times and their significance for risk assessment

MODERN INDOOR ENVIRONMENTS

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 inflamma-

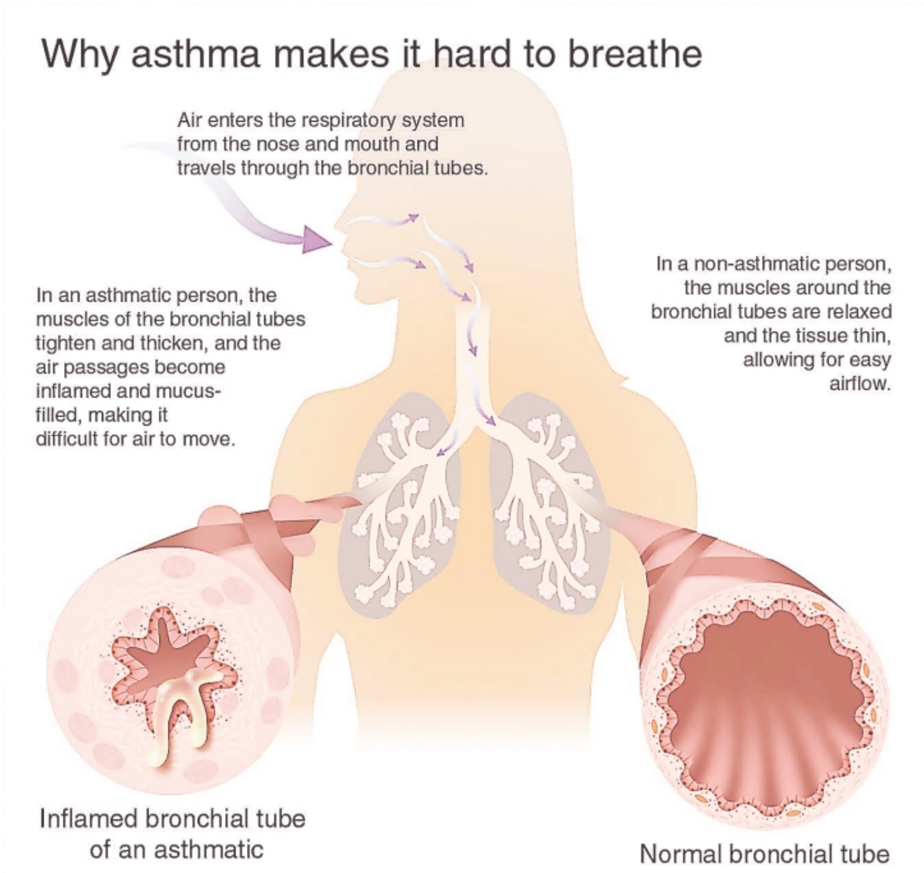

FIGURE 6. Why asthma makes it hard to breathe. Illustration: American Academy of Allergy, Asthma and Immunology.
http://www.aaaai.org/media/photos_graphics/all_photos.stm

tory 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."

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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