Indoor Environment in University Buildings

Assessment of subjective and objective parameters and outcomes

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Scientific environment

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Abstract

In 2004, symptoms, perceptions and indoor exposures were studied among 173 (86%) of the employees in four University buildings of which two were claimed to have dampness problems (problem buildings), two other buildings served as controls. In addition, physiological signs from eyes, airways and blood were examined. The main objective was to study symptoms and physiological signs in relation to the indoor environment.

The buildings were inspected and characterised, including noise and lighting assessments. Indoor climate measurements of air temperature (T-air), relative humidity (RH%), carbon dioxide (CO_2), air velocity, and particulate matter, assessed gravimetric as particles with less than 10 μm aerodynamic diameter (PM_{10}), were performed in a number of representative rooms that were categorised according to location, size and function. In total, 56 logging points were covered. The logging periods were mostly set to two days (9 am to 4 pm) and one night (4 pm to 9 am) in each room. Measurements were collected every fifth minute through the monitoring period for the thermal data, CO_2, air velocity and RH%. Outdoor meteorological data were also collected. The results were modelled according to building and office size in order to assign data for the work site of all participants. Microbiological assessments included viable microbiological sampling in air aiming to compare microbial flora composition between outdoor air, air intakes and indoor air. Air samples were collected from outdoors near the air inlets, inside the ventilation aggregates, between the filter and the fan, in technical rooms and in user areas including offices. A total of 191 air samples were collected.

A questionnaire with standardised questions about symptoms and perception of indoor climate, demographic and life-style factors, home environment and job demands, control and social support at work were answered by the participants. A symptom score (SC) was constructed from the number of weekly symptoms. Job demands and control were combined to the factor “strain”. Multiple linear and logistic regressions were applied.

A medical investigation was performed at the workplace in March 2004, after the influenza season and before the pollen season. Tear film break-up time was measured by ocular microscopy (NIBUT) and by recording the time the individual could keep their eyes open without blinking (SBUT). Nasal patency was measured by acoustic rhinometry. Nasal lavage fluid analysis (NAL) included eosinophilic cationic protein (ECP); myeloperoxidase (MPO), lysozyme and albumin. Total serum IgE and specific IgE (Phadiatop®) were analysed.

The microbial airborne flora was normal in all buildings and other environmental exposures were within prevailing requirements and recommended standards. Comparing the buildings, no differences were found in psychosocial environment. Workers in the problem buildings had higher prevalence of one dermal and five

general symptoms, but no increase of ocular, nasal or other respiratory symptoms, specific IgE (Phadiatop), total IgE or any physiological signs.

In general, both NIBUT and SBUT were shorter at lower night temperature. Adjusted day NIBUT and SBUT increased at higher night air temperatures with B; 95% CI: 0.6; 0.04-1.2 and 1.3; -0.02-2.5, respectively. Low air temperature at 6 a.m. was associated with decreased tear film stability during work hours. This association was weaker for air temperature at 8 a.m. and no associations were found for air temperature at 10 a.m. Higher relative humidity at mean day air temperature $< 22.1^{o}$C was associated with increase of adjusted NIBUT and SBUT; B; 95% CI: 0.16; 0.03-0.29 and 0.37; -0.01-0.75, respectively. Air velocity below prevailing winter recommendations and lower relative humidity in the range of 15-30% were associated with perceiving dry air and too low temperature.

15% of the participants had a damp dwelling, and 20% had a cat or dog. Home building dampness was associated with increased NAL-lysozyme (p=0.02) and an increase of airway infections (OR=3.14: p=0.04). Pet keeping was associated with more difficulties to concentrate, feeling heavy-headed and tiredness but less airway infections.

Women reported more often health symptoms than men and also more complaints on physical but not psychosocial factors at work. Men's symptoms and complaints were more specifically associated to air velocity and humidity. For both genders, symptoms were related to both strain (*P*=0.02) and perceived physical environment (*P*=0.01). Lower relative humidity in the range of 15–35% was associated with perception of too low temperature and dry air.

Perceiving "dry air", having ocular symptoms and lower BUT were strongly associated in office environment employees. To have experienced "ever asthma" and "ever hay fever" were predictors for symptoms and perceived air quality respectively. Markers of atopy in terms of Phadiatop, Total IgE, familiar allergy and "ever eczema" were not associated to symptoms or perceived environments. Gender was associated to environmental perceptions, BUT and nasal patency. Age was associated to nasal patency. Recent airway infections were predictors for nasal lavage markers.

In conclusion, workers in the problem buildings had more general and dermal symptoms, but not more objective signs than the others. However, thermal climate and ventilation in university buildings, may affect both symptoms and physiological signs. Both gender, psychosocial and physical environment factors were related to symptoms and perceived indoor climate. Reduced night time temperature might create impaired indoor environment. A combined use of questionnaires of symptoms, perceived air environmental complaints, measurements of tear film break up time, nasal patency and NAL-markers can be a useful method to study human reactions to the indoor environment. A holistic perspective is needed.

List of publications

1. Bakke JV, Norbäck D, Wieslander G, Hollund BE, Florvaag E, Haugen EN & Moen BE. Symptoms, complaints, ocular and nasal physiological signs in university staff in relation to indoor environment - temperature and gender interactions. Indoor Air 2008; 18: 131-143.

2. Bakke JV, Norbäck D, Wieslander G, Hollund BE & Moen BE. Pet keeping and dampness in the dwelling: associations with airway infections, symptoms, and physiological signs from the ocular and nasal mucosa. Indoor Air 2007; 17, 60–69.

3. Bakke JV, Moen BE, Wieslander G & Norbäck D. Gender and the physical and psychosocial working environments are related to indoor air symptoms. J Occup Environ Med 2007; 49: 641-650.

4. Bakke JV, Wieslander G, Norbäck D & Moen BE. Atopy, symptoms and indoor environmental perceptions, tear film stability, nasal patency and lavage biomarkers in university staff. Int Arch Occup Env Health 2008; 81:861-72. Epub 2007 Dec 8.

Contents

Some definitions, basic terms and abbreviations

Atopy has been defined as a tendency to become sensitized and produce IgE antibodies in response to ordinary exposure to allergens implying that the term can not be used until an IgE sensitization has been documented (Johansson et al 2004).

The term "*indoor environment*" usually refers to the combination of the seven factors; thermal-, atmospheric, acoustic, actinic (lighting and radiation), mechanical, psychological and aesthetic environments.

The term "*indoor climate*" often refers to the combination of the five components; thermal-, atmospheric, acoustic, actinic (lighting and radiation) and mechanical environments, not including psychological and aesthetic environments.

WHO guidelines for indoor air quality cover indoor settings in which the general population or especially susceptible population groups like children, elderly, asthmatics etc. are potentially exposed to indoor air pollution (WHO 2006 a). These include homes, schools, day care centres, public places as libraries or institutionalized settings like nursing homes. However, conditions that are specific to exposures in industrial settings, agriculture, mining, and in other occupational settings where the exposure is related to the occupational activity, cannot be adequately addressed in general guidelines for indoor air quality. Such settings are typically covered by specific work safety legislation or guidance.

Hence, the terms "*indoor environment*", "*indoor climate*" and "*indoor air*" usually, and in this context, covers indoor non-industrial exposure, including indoor environment and exposure inside transport vehicles.

"*Thermal environment*" cover air temperature, radiation temperature, operative temperature, asymmetric radiation temperature, air relative humidity and air velocity. Perceiving "draught" can be caused by air movements as well as exposure to asymmetric radiation temperature, i.e. like sitting near a cold wall or window surface.

"*Thermal Comfort*" is defined in the ISO 7730 standard as: "That condition of mind which expresses satisfaction with the thermal environment". The Thermal Comfort Equation derived by P.O. Fanger combines the effect of 6 parameters:

- Metabolism [MET]
- Clothing level [Clo]
- Air Temperature
- Mean Radiant Temperature
- Air Velocity
- Humidity

"*The equivalent temperature (Teq)*" is defined as the temperature of an imaginary enclosure with the mean radiant temperature equal to air temperature and still air in which a person has the same heat exchange by convection and radiation as in the actual conditions (Nilsson and Holmér 2003).

Some other precise physical definitions are available from The Commission for Thermal Physiology of the International Union of Physiological Sciences (IUPS Thermal Commission 1987):

"*Globe temperature*": The temperature of a blackened hollow sphere of thin copper (usually 0.15 m diameter) as measured by a thermometer at its centre (C^o) and approximately equals operative temperature.

"*Mean Radiant Temperature*": The temperature of an imaginary isothermal, "black" enclosure, in which a solid body or occupant would exchange the same amount of heat by radiation as in the actual non-uniform enclosure (C^o).

"*Operative temperature*": The temperature of a uniform (isothermal) "black" enclosure in which a solid body or occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment (C^o).

Of the four physical parameters, the "*Air Temperature*" and "*Mean Radiant Temperature*" can be combined into the "*Operative Temperature*". The "*Air Temperature*", the "*Mean Radiant Temperature*", and the "*Air Velocity*" can be combined into the "*Equivalent Temperature*". *Air humidity* is also often considered when estimating the "*Equivalent Temperature*" due to increasing impact of air humidity in combination with higher air velocity.

The *equivalent temperature* is derived from the *operative temperature* by the inclusion of the effect of *air velocity* on a heated body (Nilsson and Holmér 2003). The *operative temperature* considers the air temperature and the mean radiant temperature and reflects an approach to perceived thermal environment when air temperature and mean radiant temperature differs significantly from each others. The *equivalent temperature* represents an even more exact objective assessment of perceived or "subjective" thermal conditions when also air velocity and possibly also air humidity are sufficiently high to affect the results.

Local thermal comfort: Thermal dissatisfaction can be caused by unwanted cooling (or heating) of one specific part of the body (ISO EN 7730). This phenomenon is called *local thermal discomfort.* Most conditions of local thermal discomfort can be grouped under one of the following categories:

1. Local cooling of body parts can be caused by *air movement* (real draught, *convection*).
2. *Radiant temperature asymmetry* (Figure 1) may be caused by cold (or hot) windows, walls, ceilings and heated panels by cooling or heating of parts of the body by radiation. Loss of radiant heat is often perceived as draught

although there might not be any air movement (radiant cooling). Wanted heat from a wall and cooling from the roof is comfortable. Heat from the roof and a cold wall is uncomfortable.

3. Cold feet and warm head at the same time can be caused by large *vertical air temperature differences*.
4. Hot or cold feet can be caused by *uncomfortable floor temperature*.

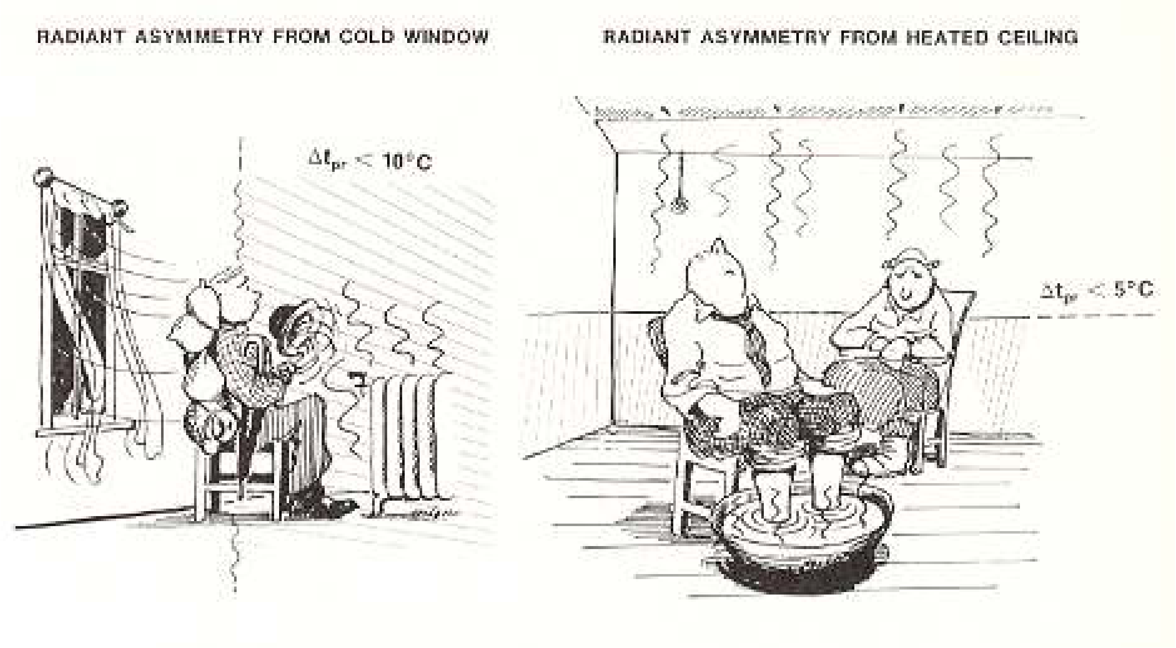


Figure 1. Radiant asymmetry.

Heating can essentially be provided from a heat source to an individual by:

1. Direct contact with a warm surface
2. Radiation heat from surrounding surfaces (e.g. radiation heaters)
3. Convection heaters conveying energy directly from heated surfaces to air and then providing heat to the occupants by conveying warm air to the individual (e.g. fan heaters, electric convection heaters and heating by “ducted air”)

Radiation heat can provide heat and thermal comfort nearly without increasing the enthalpy (energy content) of the air. Radiation heaters provide most of the heat as radiation heat.

Convection heaters are based on mainly increasing the air enthalpy. Increased air enthalpy decrease air quality (Fang et al 1998 a, b).

Air heaters provide energy to the premises with hot air from a central aggregate through ducts (“ducted air”) or local equipment such as electric fan heaters by *convection*. These methods contribute strongly to air enthalpy.

Contact heat is used e.g. in car seats in order to increase thermal comfort when entering a cool vehicle.

"*Building dampness*": Several different definitions have been used in epidemiologic studies. However, it is not possible to give a health relevant definition of a ''damp'' building according to current international scientific consensus (Bornehag et al 2001, 2004 a).

Sick Building Syndrome (SBS)
SBS consists of a group of general, mucosal and skin symptoms that are temporally related to staying in particular buildings. It is the occupants, who are symptomatic, but the indoor environment, building or its services which are the cause.

Building related illness (BRI)
Clinical conditions or medical problems encountered in the indoor environment where aetiology and symptomatology are those for specific medical conditions. Examples are extrinsic allergic alveolitis, organic dust toxic syndrome and humidifier fever, building related asthma and rhinitis, building related infections, and cancer (ETS, radon, asbestos or other carcinogenic agents).

Enthalpy of air denotes energy content of the air which is dependent on air temperature and RH.

Abbreviations

BRI	Building related illness
BUT	Tear film break up time
CI	Confidence interval
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
ECA	European collaborative action
ECP	Eosinophilic cationic protein
ETS	Environmental tobacco smoke
HVAC	Heating, ventilation and air conditioning
IAP	Indoor Air Pollutants
IAQ	Indoor Air Quality
IgE	Immunoglobulin E
MCA	Minimum cross-sectional area in the nasal cavity
MCA1	Anterior minimum cross-sectional area in the nasal cavity
MCA2	Posterior minimum cross-sectional area in the nasal cavity
MVOC	Microbial volatile organic compounds
MPO	Myeloperoxidase
NAL	Nasal airway lavage (fluid)

NIBUT	Non invasive (tear film) break up time
OR	Odds ratio
PM	Particulate matter
Ppm	Part per million
RCT	Randomized controlled study
RH	Relative humidity
SBS	Sick building syndrome
SBUT	Subjective (tear film) break up time
TB	Tuberculosis
TVOC	Total volatile organic compounds
TSP	Total suspended particles
UFP	Ultrafine particles with diameters <100 nm (<0.1 µm)
VOL	Volume in the nasal cavity
VOL1	Anterior volume of the nasal cavity
VOL2	Posterior volume of the nasal cavity
WHO	World Health Organization

1. Introduction

1.1 Human environmental requirements and exposure

Human physiology is not adapted to the climatic conditions in our latitudes although the area has been populated for several thousands of years. For a nude resting individual, the ideal ambient temperature is about 28 to 30°C which is compatible with the climatic conditions of the African mountainous Savannah landscapes that seem to have harboured our ancient ancestors (Åstrand & Rodahl 1986). Not only solid clothing was needed, a protecting climatic shield had to be developed by housing and building technology adapted to very challenging winter climatic surroundings as our forefathers migrated north. We are also originally biologically adapted to continuous supply of fluent fresh outdoor air for breathing and cooling. The term "indoor environment" is a consequence of the need for shelter against wild animals and against unfavourable outdoor climate. However, indoor air quality depends of out door air quality; amount of fresh air provided indoors and amount of pollutions added to air indoors from many sources. An adult sedentary man daily breathes on average about 15 m^3 of air, corresponding to 15 kilograms (Kg), drinks 1,5 litres of water (1,5 Kg) and eats about 0,75 Kg of solid food. Hence, the weight of breathed air constitutes almost 90% of the total mass biological turnover through 24 hours.

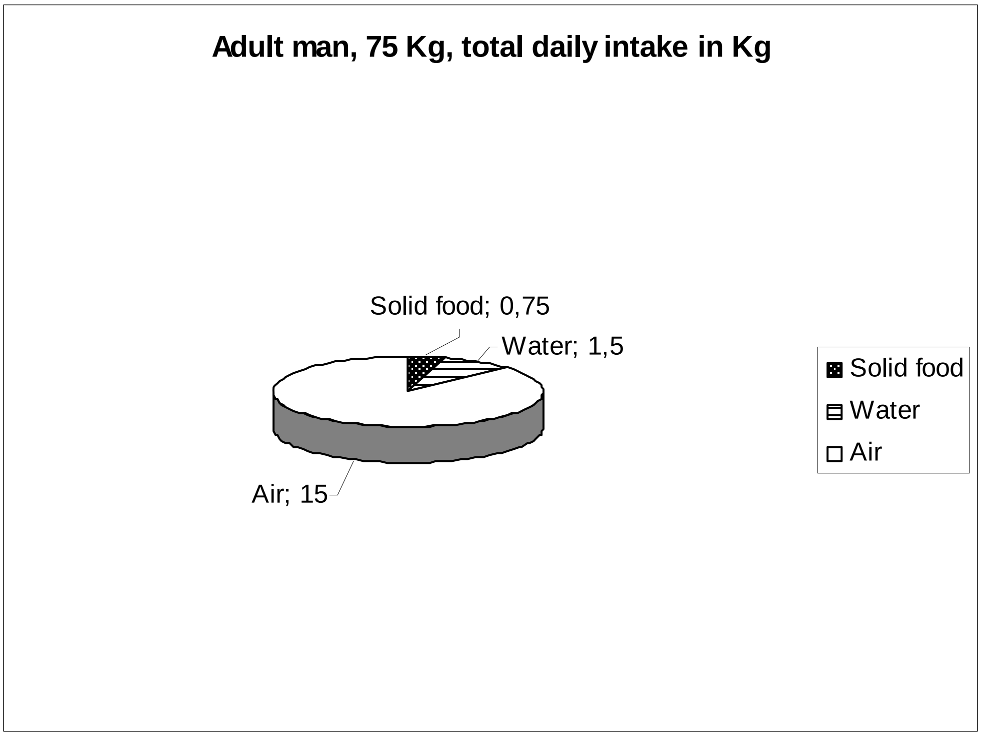


Figure 2. Approximations of daily intake for an adult man with 75 Kg body mass.

Clothing and a building envelope provide two levels of shelter between the human organism and the surroundings. The ancient architect Vitruvius edited the oldest known preserved textbooks in architecture 27 B.C. He stated:

"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 currently still of central importance and interest in modern architecture and building hygiene.

1.1.1 Current population exposure times - significance for risk assessment

At our latitude, often less than 10 % of the time is spent outside different kinds of indoor compartments. More than 90% is spent at home, in kindergartens, at school, at work, in public premises, in transport vehicles etc. However, most of the time is at home and in the sleeping room (WHO 1999). About 65% of lifetime is spent at home while around 20% might be spent in other premises, such as in schools, day care centres and at work and further 5% might be spent in e.g. transport vehicles. The working population usually spends about 20% of the time at work; and an increasing part of the employees in the Western world have their work place in non-industrial work environment (OECD 2005). The ventilation rates are generally lower at home, and the time spent at home is much longer than at work.

1.2 Historical aspects of indoor environment and health in Norway

Indoor environment is vital under our climatic conditions, and constitute basic parts of our essentials for life. Buildings with firing technology and integrated ventilation were developed at a fairly advanced stage 1200 years ago in our parts of the world (Figure 3).

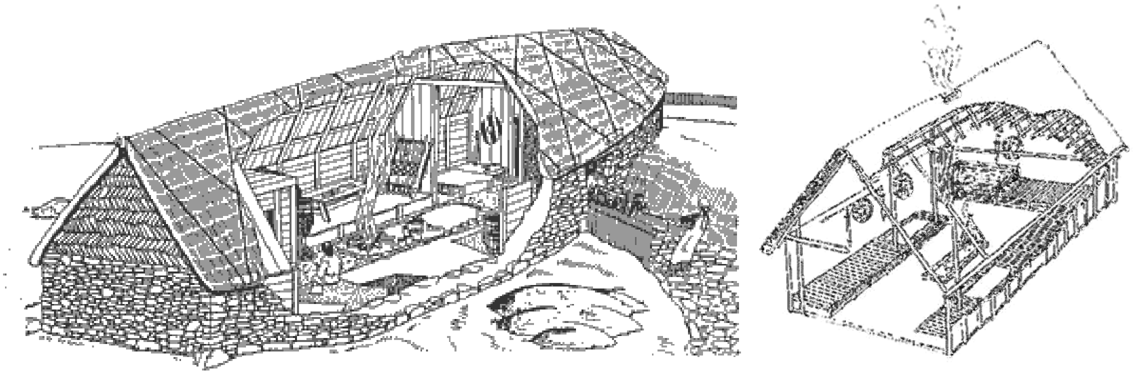


Figure 3. Viking Longhouse (http://www.cne-siar.gov.uk/museum/actsheet1a.htm) and illustration of basic principles showing the similarities to the traditional Norwegian ”Årestue” (http://www.viking.no).

Need of shelter, availability of construction materials and durability were determining factors for shaping of the houses. The Viking Longhouse, localised on dry ground, was provided with a large central fireplace in the middle. Furs and tapestries on the walls helped to insulate the house. Smoke escaped through holes in the roof. Lamp dishes were filled with fish oil. The ends of the house were used as work rooms and storage areas. These could be heated by hot stones from the fireplace placed in large sand filled metal trays on stands. The outer stonewalls provided shelter from strong gale and storm outside almost not affecting the slow air infiltration near the floor caused by the motive force of the central fire which entailed an effect close to modern “displacement ventilation” which in recent decades have improved industrial as well as non industrial ventilation and air quality (Skistad 2002).

Open combustion indoors has often been an important pollution source for indoor air. However, both air quality and thermal conditions in the Viking longhouse were probably better than present conditions for 2-3 billions of humans globally in less-developed countries. Worldwide, approximately 50% of all households and 90% of rural households utilize solid fuels for cooking or heating (WHO 2000 b, Smith 2003, WHO 2004, 2006 b, 2007, Bousquet et al 2007). Solid fuels are commonly burned in inefficient simple stoves and in poorly ventilated conditions. In such situations, solid fuel use generates substantial emissions of many health-damaging pollutants, including respirable particulates and carbon monoxide, and results in indoor air pollution exposures often far exceeding national standards and international guidelines. Hence, current human exposure conditions might be worse than in the traditional Norwegian ”Årestue” (Figure 4).

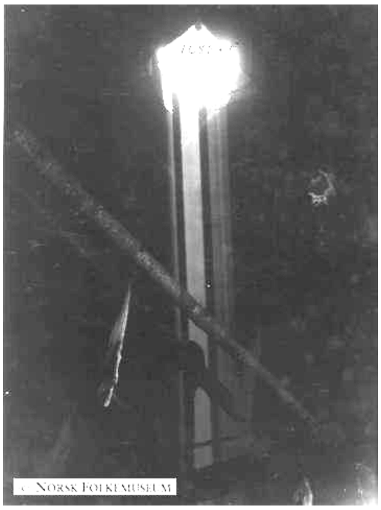


Figure 4. ”Årestue”, medieval. Smoke from the central fireplace escapes through a smoke vent, the “ljore” in the roof above.

Pictures: Norwegian Folk Museum. http://www.norskfolke.museum.no

The Norwegian Sociological pioneer researcher and priest Eilert Sundt (1817-75) studied among many other issues also living and building conditions in Norway including indoor climate issues. He finished his report “On the Building Practice in Rural Norway” in 1862 (Sundt 1862). It provided valuable evidence for the living and building history of rural Norway confirming that the same basic principles of building physics from the Viking longhouse had prevailed up to the nineteenth century in the so-called “Open-hearth rooms” (Figure 4). Eilert Sundt’s drawings illustrate the smoke stove which probably was gradually introduced through later medieval time (Figure 5).

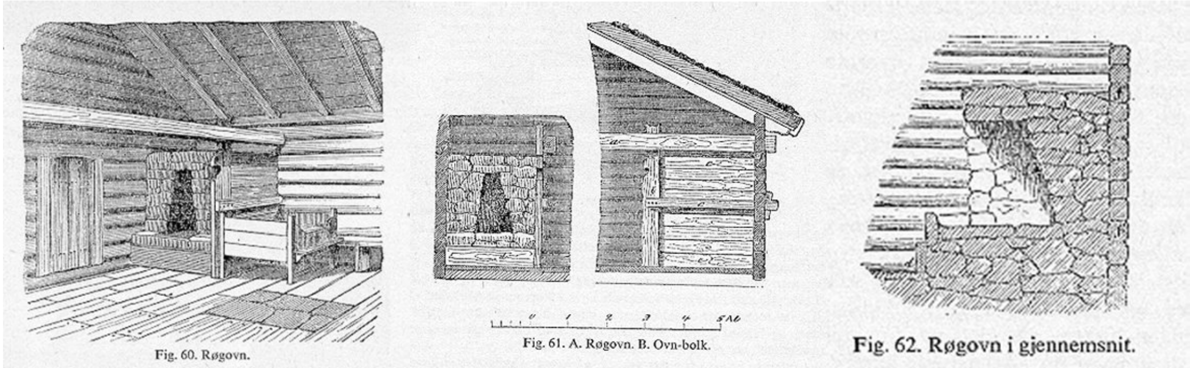


Figure 5. The smoke stove (Eilert Sundt 1862)

Introduction of the smoke-stove moved the heat source to a corner. This stove could conserve huge amounts of heat energy in the heavy stonework. Firing and exposure to combustion gases could be limited to about half an hour twice a day. Some smoke-stove buildings and even some open-heart rooms were still in use through the 19th century although Norwegian farmers in 1776 were required by Royal command not to build houses without vented combustion (Sundt 1862).

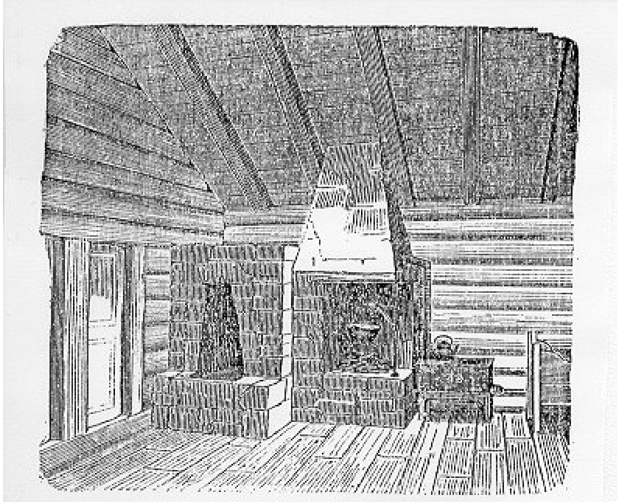
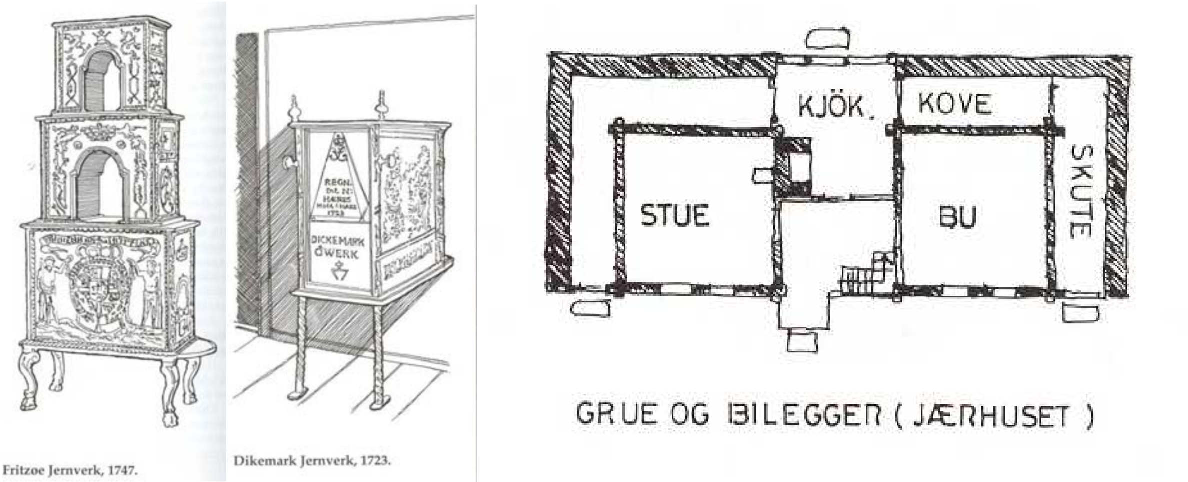


Fig. 66. Stue i Sogn.

Figure 6. Introduction of chimney and vented cooking (Eilert Sundt 1862).

Introduction of a chimney to vent the fireplace gained speed through the 17th century making the ”ljore” (smoke vent) in the roof superfluous and allowing new floors on the houses (Figure 6). The combustion gases from heating could be more effectively vented out of the house. Need of light from other sources increased and could also be provided from the open fireplace. Introduction of windows gave light during the days. Fish oil lamps provided light during the nights. The open fireplace could then be moved into a separate kitchen and be replaced by wind-stoves in the living rooms.



Fritzoe Jernverk, 1747.

Dikemark Jernverk, 1723.

Figure 7. Wind stove, external firebox stove (”Bilegger”) (www.riksantikvaren.no) and floor plan lay-out showing firebox in “stue” (living room) (Eilert Sundt 1862).

Use of external firebox outside or in the kitchen (Figure 7) could leave the firing to the servants, eliminated fire smoke as well as the need of air and draught through the sitting rooms or bedrooms.

Hygienic and living conditions in Norway seem to have been kept at a relatively high level during the Viking- and medieval ages until the Black Death killed a large part of the Norwegian population around 1350. Health and living conditions were at a marginal level until late 17th century and the start of Age of Reason. The 18th century brought remarkably positive trends with significant improvements of the conditions in terms of better living standard, lower mortality, increased duration of life, growth of population and wealth (Moseng 2003). This cannot be fully explained by introduction of the potato and inoculation against smallpox only (Moseng 2003). Reassessment of available historical evidence was performed in connection with The Norwegian Public Health Service celebration of its 400 years anniversary in 2003. The findings suggested that the development in the 18th century must be due to “An improved epidemiological climate caused by a complex background where the changes obviously occurred in interplay difficult to follow between economical, social and cultural forces” (Moseng 2003). This included public health service, educational work, increased level of learning in society and that the government valued good health.

The bishop Erik Pontoppidan (1698 - 1764) emphasized topics such as: ”Diseased and Injured Recovery, Young Peoples Upbringing and Education (Syge og Qvestedes helbredelse, Unges Opfostring og Underviisning)”. Education, information and enlightenment concerning hygienic matters played an important role thanks to priests, medical officers and others that were engaged in these matters. They performed what we currently in occupational and environmental medicine denote as risk assessment and risk communication in order to achieve environmental risk management and promote health, well-being, productivity and not least wealth. Domestic building hygiene formed important parts of this enlightenment.

Prominent professionals and culture persons in the Danish Norwegian kingdom such as Hans Strøm (1726-1797) (Figure 8), Johan Clemens Tode (1736-1806) and Rasmus Frankenau, (1767- 1814) had good contact with the international scientific community. They were informed about developments, scientific controversies and were aware of important works such as those of Sir John Pringle (1707-82), UK, and Johann Peter Frank (1745-1821), Austria, the world’s first professor in Hygiene. Hans Strøm published in 1778 the book "Kort Underviisning om De paa Landet, i Bergens Stift, meest grasserende Sygdomme, og derimod tienende Hjelpe-Midler" (Short Education About the, on the Countryside, in Bergen Bishopric,

Figure 8. Hans Strøm

most raging Diseases and against them most useful Remedies). He wrote thoroughly about the impact of housing on health and illness (page 44-47), mentioning

- Importance of fresh air
- Danger of lack of ventilation to save heat, particularly the perilous lack of air that could arise by use of tiled stoves with external firebox which made superfluous the need of air through the living rooms for draught to the stove. Use of stoves with external firebox outside or in another room eliminated the fire smoke and the need of draught through the living rooms through the 1700s (see Figure 7).
- Problems with moisture sources and dampness by lack of ventilation
- Pollutions from stoves, tobacco smoke, cooking, cod-liver oil and other evil-smelling sources
- The importance of clean-up, washing and clean bedding

Rasmus Frankenau studied hygiene abroad. He was medical officer of health in Arendal 1798-1803 and Copenhagen 1803-11 and published “Det offentlige Sundhedspolitie under en oplyst Regiering” (The Public Health Police under an Enlightened Government. Copenhagen 1801). This was the first comprehensive description of a Public Health Policy system in Denmark-Norway. Important issues were

- Clearness of the water and cleanliness of sources, wells, lakes and brooks
- Foods and beverages` freshness and goodness
- Buildings` arrangements
- Construction of plants that can be dangerous to health
- The streets cleanliness and order

The last chapter was dedicated to “public amusements” and how recreation, gymnastics, sports, outdoor life, theatre and humour can contribute to good health.

Figure 9. Edwin Chadwick

Fredrik Holst (1791-1871) (Figure 10) was created as the first professor in Hygiene in Norway in 1824. He did important works in preparing the Public Health Act of 1860, highly inspired by the British Act from 1848 which was a direct result from the famous work of

Edwin Chadwick (1800-1890) (Figure 9): ”Report on the Sanitary Conditions of the Labouring Population of Great Britain in 1842” (Chadwick 1842, Schjønsby 2001). Chadwick stated among other things: “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”.

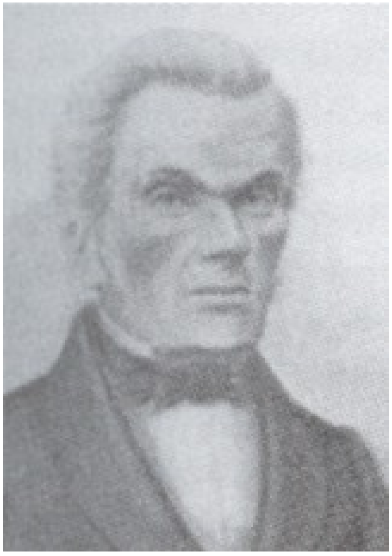


Figure 10. Fredrik Holst

According to the Norwegian Public Health Act, all communities were obliged to establish a Health Commission under the leadership of the Public Medical Health Officer. The tasks were (Sundhetsloven 1860, §3, translated to English):

“The Commission shall keep its attention on 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 still have to see 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...” (Sundhetsloven 1860).

Original citations in Norwegian from:”Sundhetsloven av 16. mai 1860”, alle kommuner skulle etablere en Sundhedscommission (senere Helseråd) under ledelse av Distriktslægen. Sundhedscommissionens (Helserådets) oppgaver (§3): "Commissionen skal have sin Opmærksomhed henvendt paa Stedets Sundhedsforhold, og hvad derpaa kan have indflydelse, saasom: Reenslighed, ...Boliger som ved Mangel paa Lys eller Luft, ved Fuktighed, Ureenslighed eller Overfyldning med Beboere have viist sig at være bestemt skadelige for Sundheden. Sundhedscommissionen har fremdeles at paase, at tilstrekkelig Luftvexling finder Sted i Huusrum, hvori et større Antal Mennesker stadigen eller jevnligen samles, som Kirker, Skole-, Rets- og Auctionslocaler, Theatre, Dandsehuse o.d....."

Figure 11. Max von Pettenkofer

Max von Pettenkofer (1818-1901) (Figure 11) had at that time estimated the amount of ventilation needed for the salubrity of indoor air based on measurements, experiments, observations and calculations (Pettenkofer 1858). He suggested that the CO_2 level should be kept lower than 1 ‰ (1000 ppm) by sufficient air change in order to provide healthy indoor environments and particularly emphasized the need of ventilation in schools in order to prevent diseases among pupils (p 105-106). He also demonstrated the need of mechanical ventilation in order to achieve sufficient amounts of fresh air. However, he strongly underlined the need of source control. "If there is a pile of manure in a space, do not try to remove the odour by ventilation. Remove the pile of manure" (as interpreted by Fanger 2006).

Pettenkofer, original citation in German: ”Ein Raum, welcher einen verwesenden Misthaufen einschliesst, wird trotz aller Ventilation eine enkelthafte Wohnstätte, ein Herd für schlechte Luft bleiben. Erst wo die Reinlichkeit durch rasche Entfernung oder sorgfältigen Verschluss luftverderbender Stoffe nichts mehr zu leisten vermag, beginnt das Feld für die Ventilation“. (Max von Pettenkofer 1858, p 73)

Figure 12. Axel Holst

Axel Holst (1860-1931) (Figure 12), professor in Hygiene 1893-1930, warned about health conditions related to housing dampness (Holst 1894):

"Cellar dwellings are more affected by sanitary disadvantages than other dwellings…It is primarily most vulnerable to dampness. It is nearest the ground and evaporation from the ground dampness will therefore primarily prevail in the cellar…

…It will, in addition to dampness, convey pollutions in gas form, - metabolites from the putrefactive and other microbes that exist in the ground…

…Humidity and darkness promote vigorous growth of contagions, and all kinds of putrefactive and similar processes as well, mould going on clothes and foodstuffs, mould on walls and floors, which all of it contributes to decay of the air of the cellar…

…Experiences from several doctors are that cold fever, where it prevails, is striking prevalent in cellar dwellings, and that rheumatic affections, renal diseases, airways-, lung diseases and scrophulosis (relate to tuberculosis) have a conspicuous tendency to thrive there…"

Basic requirements for healthy housing (textbox) were well established before 1850 and implemented during the next 100 years as a vital condition for the remarkable

Axel Holst 1894. Original citations in Norwegian:

"Kjellerboliger er mer utsatt for sanitære ulemper enn andre boliger......Den er for det første mest udsat for fugtighed. Den ligger nærmest grunden og derfor vil fordampning av grundfuktigheden først og fremst gjøre seg gjældende, i kjelderen....

...ved siden af fugtighed fører den ogsaa let med sig gasformige forurensninger, -stofskifteprodukter fra de forraadnelses- og andre mikrober, som findes i grunden....

...Fugtighed og mørke fremmer smittestoffenes trivsel; de fremmer ogsaa alle slags forraadnelses- og lignende processer, mugning af klædesplag og madvarer, mug paa vægge og gulve, hvad der altsammen bidrager til at "bederve" kjelderens luft....

...Forskjellige lægers erfaringer gaar ud paa, at koldfeber, hvor den forekommer paafaldende hyppig optræder i kjelderboliger, og at revmatiske affektioner, nyresygdomme, luftrørs-, lungesygdomme og skrofulose har iøinefaldende let for at trives der...."

Basic hygienic requirements to housing - sum up state-of-the-art in 19th Century

1. Dry building ground and dry dwellings.
2. Good cleaning and adequate ventilation
3. As much as possible access to sunlight and full daylight (bactericidal)
4. Smallest possible chance for accumulation of waste, dust and other pollution by suitable choice of materials and shaping of interior, furniture and furnishings.
5. Fast and safe removal of all refuse and offal by skilled executed and maintained outlets, sewers, rational cleaning and removal of refuse.
6. Abundant access to clean and good water.

improvements of general health and living standard in our Western welfare states.

Tuberculosis was by far the most important mortality cause in Norway until the 1920ies (Stene Larsen 2006). Our Western developed societies won the battle against tuberculosis and other infectious diseases by improved living-, nutritional and hygienic standards, including building hygiene, and mainly before modern vaccination and antibiotics was available (McKeown 1979, Turnock BJ 2004) (Figure 13 and 14). This was also emphasised in a report to the British Parliament (The Health of the Nation 1992).

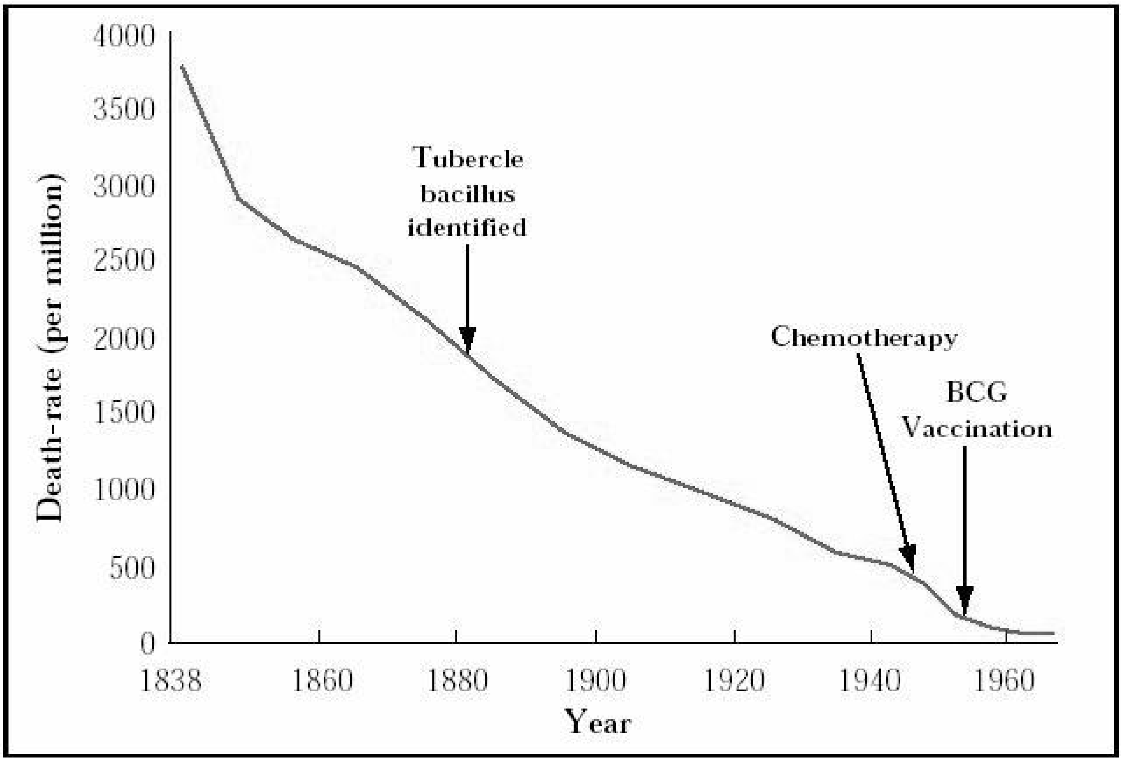


Figure 13. Respiratory tuberculosis (TB) - mean annual death rate England and Wales. From (McKeown 1979) and a report to the British Parliament (The Health of the Nation. Department of Health 1992).

Like in other Western countries, deaths from infectious diseases declined markedly in United States through the 20th century (Figure 14) (US-CDC 1999). This decline contributed to a sharp drop in infant and child mortality and to the almost 30 year increase in life expectancy (Figure 15). The 19th century shift in population from country to city that accompanied industrialisation and immigration led to overcrowding in poor housing served by inadequate or nonexistent public water supplies and waste-disposal systems (US-CDC 1999). These conditions resulted in repeated outbreaks of cholera, dysentery, TB, typhoid fever, influenza, yellow fever, and malaria. By 1900, however, the incidence of many of these diseases had begun to decline because of public health improvements, implementation of which continued into the 20th century. These were based on public environmental disease prevention activities, including sewage disposal, water treatment, food safety, and public education about hygienic practices. The incidence of TB declined as improvements in housing reduced crowding and TB-programs were initiated. In 1900, 194 of every 100 000 U.S. residents died from TB; most were residents of urban areas (US-CDC 1999). In 1940, before the introduction of antibiotic therapy, TB remained a leading cause of death, but the crude death rate had decreased to 46 per 100 000 persons.

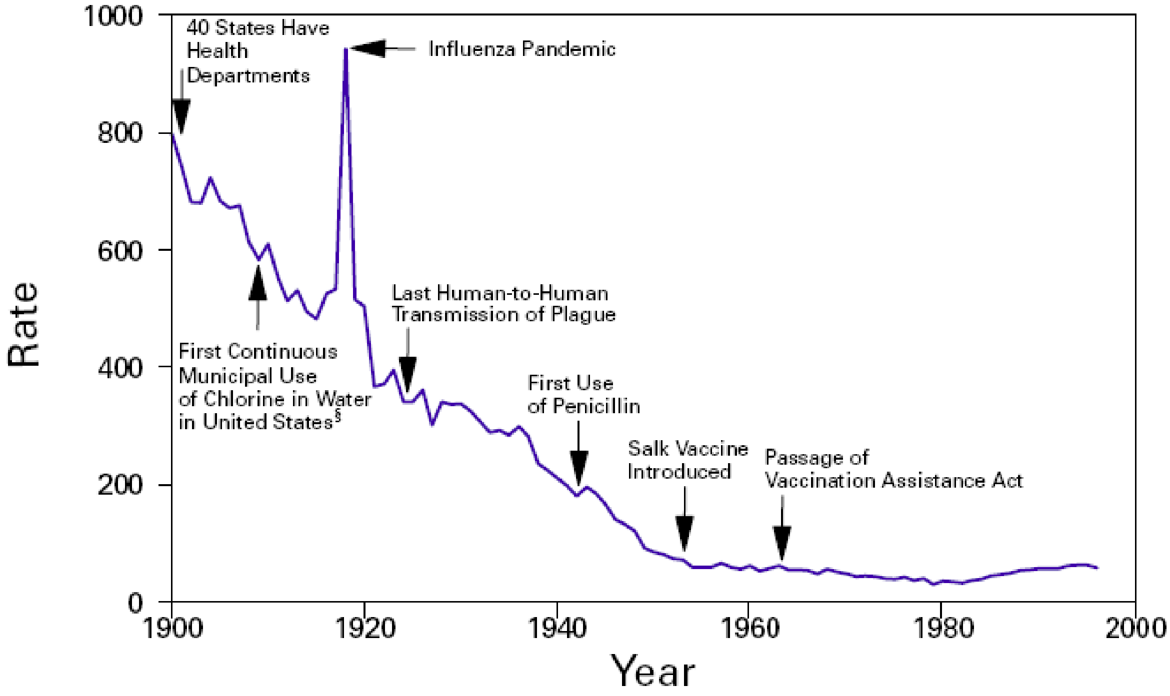


Figure 14. Crude death rate per 100 000 population per year for infectious diseases - United states 1999, adapted from US-CDC 1999, which is based on Armstrong et al 1999.

Within the 20th century, average life expectancy increased from approximately 45 to 75 years for citizens of Western, industrial countries, however assumed by many to be largely the result of advances in the content and distribution of medical care (Bunker et al 1994, Turnock BJ 2004). Only a little more than 5 years of the 30-years improvement are the result of medical care. Medical treatment accounts for 3.7 years, and clinical preventive services (such as immunizations and screening tests) account for 1.5 years. The remaining 25 years have resulted largely from prevention efforts in the form of social policies, hygiene, community actions, and personal decisions.

When the necessary collective actions are not taken, even the most important public policy problems remain unsolved, despite periodically becoming highly visible (Turnock BJ 2004). Among the most important basic issues are sanitary conditions, including fresh water supply, adequate built environment, housing and work environment, as well as public education systems, employment, discrimination, and poverty. Important life style factors are smoking, substance abuse, nutrition and physical activity. However, poverty, poor housing and bad built environment are important obstructions for the possibilities of choosing a better life style (Bashir SA 2002).

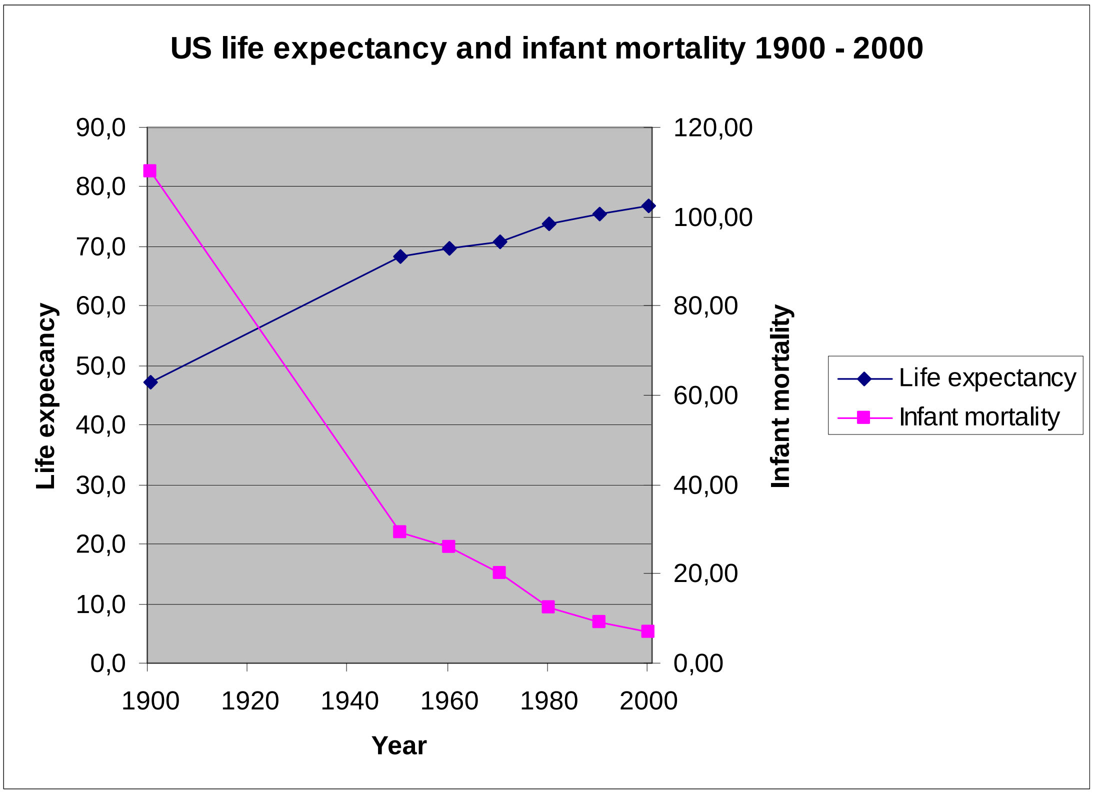


Figure 15. Constructed from statistics downloaded November 2007 from United States Department of Health & Human Services; http://www.hhs-stat.net/index.htm.

Modern re-flourishing of tuberculosis has been most prevalent among those that are exposed to the most inferior nutrition and housing conditions (Mangtani et al 1995, Bhatti et al 1995, Drucker et al 1994). This tendency corresponds to similar observations of historical trends from most other developed countries (Nelson 2005). One can argue that this reflects that curative medicine's efficacy has been overstated and that improvements in health have been largely due to improved nutrition and living conditions, hygiene, and changing patterns of reproduction (Turnock BJ 2004).

Present scientific knowledge about dampness in buildings as a risk factor for health has been defined in multidisciplinary scientific reviews by NORDDAMP and EUROEXPO (Bornehag et al 2001, 2004 a). The conclusions are in line with the risk assessments and requirements set for more than 150 years ago (Chadwick 1842, Sundhetsloven 1860). However, in most countries, such as in Norway, these matters now attain only limited attention, if any, by the Health Service. Medicine now tends to focus solely on pathology and fails to locate the person within his or her socio-environmental context (Nettleton 1995).

1.3 Changes through the 20th century in Norway

Living and housing conditions, as an important part of our micro environments, have improved immensely through the 20th century (Table 1). Average number of persons per households has decreased parallel with an increase of mean dwelling area and area per person (Figure 16 (SSB) and Figure 17 (Berge 2003)). Mean dwelling area in Norway has increased from 89 m^2 in 1967 to 114.2 m^2 in 1997 entailing an increase of housing area per person from 29 m^2 in 1967 to 52 m^2 in 2002, representing an increase of 79%, holiday houses not included. This is by far the highest national numbers in Europe.

Development of community electricity supply for domestic use in Norway started between 1910 and 1920. 75 % of the population had electricity supply in 1937/38, 84% in 1949 and 100% in 1960 (Bøeng 2005).

Table 1. Households and dwellings in Norway, historical traits and key numbers, from SSB, and Bøeng 2005

Year	1920	1930	1946	1950	1960	1970	1980	1990	2001
Average number of persons per household and rooms per dwelling									
Persons per household	4,30	3,98	3,36	3,25	3,27	2,94	2,66	2,40	2,30
Rooms per dwelling							3,6		4,1
Dwellings according to building types, percentages									
Farmhouse	53,3		42,6		20,2	15,4	11,0	58,1	57,1
Detached houses					25,6	31,8	41,9		
Un-detached houses					31,8	31,5	19,4	21,7	21,2
Apartment houses	46,7		57,4		18,0	17,6	17,9	18,8	18,4
Others					4,4	3,7	1,7	1,4	3,4
Mean energy use per household in 1000 kWh									
Total mean energy use					20,0	23,0	24,5	22,0	22,0
Electricity		2,0	4,5	5,0	7,0	11,0	15,0	17,0	18,0
Kerosene, oil or LPG					5,0	10,0	6,5	3,0	2,0
Firewood					5,5	2,5	3,0	3,0	3,5
Main heating sources, percentages									
Central heating					10	11	14	9	7
Electric heating					16	28	39	59	69
Liquid fossil fuel					6	30	23	10	6
Solid fuel					68	31	24	20	18

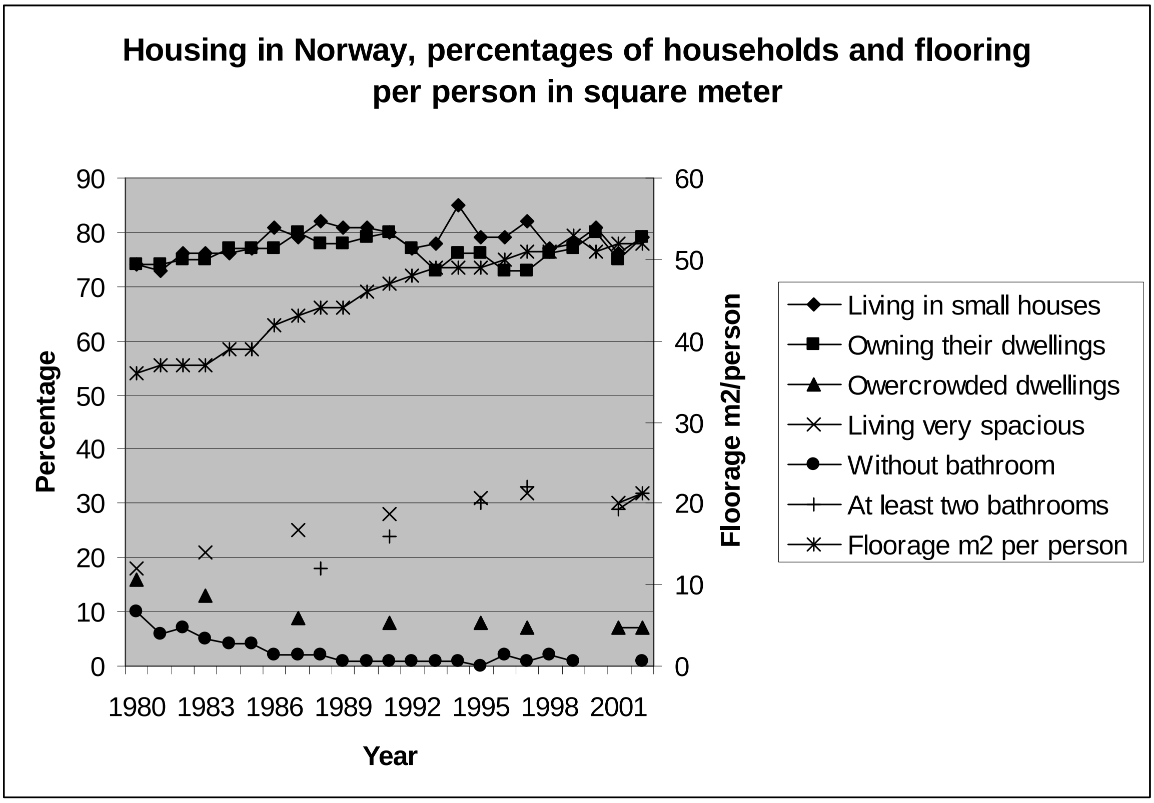


Figure 16. Housing in Norway 1980-2002, data from SSB 2007.

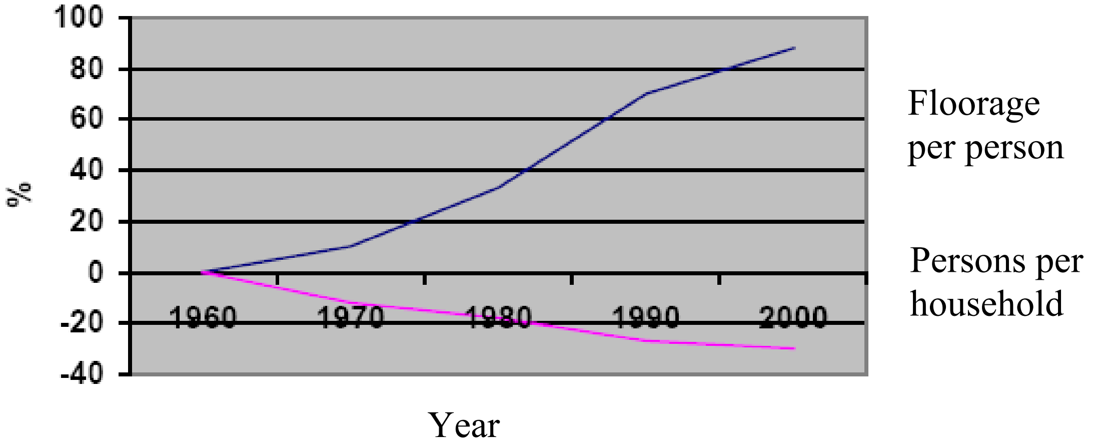


Figure 17. Housing area development in Norway (Berge 2003).

Heating by electricity as main heating source was unusual until the middle of the 1950ies, although electric heaters had been used as additional heating source since World War One (Bøeng 2005). The strong expansion of electricity production through the 1970ies provided sufficient supplies of inexpensive electric power for everybody (Table 1). 68 % of the household used solid fuels (firewood, charcoal, coal or dried turf) as main heating source in 1960 as compared to 18% in 2001. Use of oil culminated about 1970 at an estimated consume of 10 000 kWh/household.

Mean home use of electricity per household person per year 1995-2002 was about 8000 kWh in Norway and 2000 kWh in Denmark. Water borne district heat supplied 20-30 % of the total household energy use in the other Nordic countries but only 1% in Norway in the same time period (Bøeng 2005) (Table 2). The Norwegian society is less centralised as compared with the other Nordic countries however this can hardly explain this huge difference in use of water borne district heat. Norwegian energy consume is characterized by an extraordinary high consume of electricity for heating purposes.

1.4 Current conditions

1.4.1 Buildings in Norway 2005 (areas estimated 2001)

A total of 3.686.525 buildings were registered in 2005 (SSB 2005) with an estimated total utility space of about 333 mill m^2 in 2001 (Enova 2006). 2.285.665 non-residential buildings were registered (SSB 2005). 1.524.393 of these were holiday houses, residential garages etc. 761.272 buildings were industrial and non-residential buildings with total utility space of 118 mill m^2 in 2001 (Enova 2006). The stock of office- and business buildings in 2001 had an estimated total utility space of 53 mill m^2, buildings used for education 18 mill m^2, and hospital and institutional care buildings 9 mill m^2 (Enova 2006).

Of the total building stock 1 400 727 buildings with 212 mill m^2 (2001) are for residential purpose. Among residential buildings, detached houses are the dominant type of building, accounting for 1 104 641 buildings, with an estimated total utility space of about 145 mill m^2 (2001). This makes up 79 per cent of all residential buildings in Norway and 57 per cent of the dwellings. 20.9 % of the dwellings were in houses with two dwellings or in un-detached houses and 17.5% in apartment houses. 1 961 548 inhabited dwellings were registered in Norway in 2001. Almost two of three inhabitants lived in detached houses.

1.4.2 Sustainable use of energy in buildings

Energy is required in buildings in order to provide acceptable indoor environment in terms of thermal conditions (heating and cooling) and for ventilation. Energy is also used to provide hot water, lighting, to operate washing machines, tumble driers, refrigerators, dishwasher machines and to supply other energy needs in residential and non-industrial commercial and public buildings. About 40 % of the total energy resources in developed countries are spent in buildings; Norway used 80 TWh or 36% of total spent energy outside the energy sectors in buildings in 2005 (OED 2006).

The differences between the Nordic countries are interesting. The data in Table 2 are collected from several Nordic national sources which are not fully comparable and consistent. The figures must be considered as approximations. Main sources are Statistics Norway (http://www.ssb.no/english/subjects/01/03/10/energi_en/), which also provides national, Nordic, and European links. Also, The Norwegian Water Resources and Energy Directorate (NVE) provide energy statistics and links (http://www.nve.no/modules/module_111/news_group_view.asp?iCategoryid=623&lang=e). NVE 2006: Energy in Norway 2006 Edition can be downloaded from http://www.nve.no/modules/module_109/publisher_view_product.asp?iEntityId=1015Total net energy consumption in Norwegian energy-intensive industry was 54 TWh, of which electricity consumption was 35 TWh leaving 78 TWh for other purposes of which buildings consumed about 80%. About 35% of Norwegian consume of electricity outside energy-intensive industry was used directly for heating purposes.

Table 2. Net energy consumption in the Nordic countries 2005 (TWh)

	Norway	Sweden	Denmark	Finland
Total consumption	225	402	181	301
Transport/ % of total	71/32	99/25	59/33	51/17
Stationary	154	303	122	250
Total electricity consumption	113	131	37	85
El-use % of total/stationary (%)	51/73	33/43	21/31	28/34
Total energy consumption in buildings	80	136	83	64
- Part of total/stationary (%)	36/52	34/45	46/68	21/26
For heating purposes	48*			
Use of electricity in buildings	60	69	21	38
- Part of total and of el-consume (%)	27/53	17/53	12/56	13/44
El-consume for heating purposes	27*	21	2,0	8*
- Part of total and of el-consume (%)	12/24	5,1/15	1,1/5,4	2,7/9,4
Bio energy	12	69	25	58
District heat	2,5	47	29	30
Total energy consumption, industry	80	154	31	145
Total El-consumption industry	51	56	10	44

*Figures from other years than 2005 or normative values.

More than 50% of total electric energy consume in Norway was used in the building stock (60 TWh of totally 113 TWh). Denmark has approximately the same population as Norway. Total electricity consume in Denmark in 2005 was 37 TWh, which is 27 TWh less than used in the Norwegian building stock alone although total energy use in buildings in Denmark was 83 TWh the same year. This is more than the total of 80 TWh in Norway but in Denmark mostly provided by water borne district heating. In Norway, the newest office buildings used more energy than older office buildings, but mostly in those with electric heating (ENOVA 2006).

Energy conservation measures after the energy crisis in the seventies and eighties included tightening of houses and reduced ventilation. The consequences were reduced ventilation, increased indoor humidity, condensation and dampness, entailing infestation of the dwellings by dust mites, moisture damages and increased concentration of pollution from other sources. This has been related to more sensitisation, allergy, asthma and respiratory infections as well as increased complaints among habitants. Studies have shown significant association between allergy, hypersensitivity, asthma, mite sensitisation and energy conservation measures (Wickman et al 1991).

This understanding was followed up by several efforts to fulfil an obvious need for holistic approach and to manage the challenge in cooperation between all involved sectors: Health, Building, Environment and Energy (SOU 1989:76, Johnsen et al 1990, Nordisk Ministerråd 1991, Andersson & Setterwall 1996, SOU 1996:124, WHO 1999, 2000 a). This has so far not succeeded in Norway although the Norwegian Government have endorsed that the existing housing stock, the lifestyles of our population, the immediate environment of dwellings and the social conditions of the inhabitants should all be considered in developing healthy and sustainable housing policies by signing the declaration from the Fourth Ministerial Conference on Environment and Health, Budapest, Hungary, 23-25 June 2004. (Declaration. EUR/04/5046267/6 http://www.euro.who.int/document/e83335.pdf).

The Intergovernmental Panel on Climate Change (IPCC) has published "Climate Change 2007" (http://www.ipcc.ch/), reaffirming its previous conclusions and recommendations. Our societies must, as previously pointed out by IPCC and the Kyoto Protocol, face the huge and vital challenge of bringing the future societal development over to a sustainable track of living at a global level. Sustainability requires a reduction of energy use in our countries by a factor of four on short sight and 10 on a longer perspective (2050). The building sector must take a considerable part of this reduction. The EC Directive on Energy Performance of Buildings (Directive 2002/91/EC) requires buildings to meet minimum energy performance in order to comply with the Kyoto protocol. It is important that energy saving measures taken will improve indoor environment and not the opposite (WHO 1999).

Considerable improvement of indoor air quality is possible while maintaining or even decreasing ventilation and energy usage provided that present available knowledge being taken in use (Fanger 2006, Roulet 2006). This can be achieved by improving source control, air cleaning, personalized ventilation, deliver cool and dry air with low air enthalpy and the use of all these methods simultaneously. Good design, construction, operation and maintenance result in buildings using less than 25% of the building stock average energy use (Roulet 2006). Retrofit measures very often show a very good return on investment and may reduce the energy use by half.

The EU-project HOPE (Health Optimisation Protocol for Energy-Efficient Buildings, http://HOPE.EPFL.ch/), aimed to provide the means to increase the number of energy-efficient buildings that are at the same time healthy, thus decreasing the energy use by buildings and consequently resulting in a reduction of CO_2 emissions from primary energy used for ventilation, heating and humidity control (HOPE 2005). Analysis of health, comfort and energy use in 67 office buildings and 97 apartment buildings in nine European countries were carried out. Approximately 75% of the buildings audited were chosen for having energy saving measures in order to have good energy performance. On the average, low energy buildings in the HOPE sample were perceived as more comfortable than buildings with high energy use in both office and apartment buildings.

The main conclusions in the HOPE project were that healthy and comfortable buildings do not necessarily require much energy, and can have a limited impact on the environment. Smart managers, architects and engineers construct and operate buildings in a way that both good indoor environment and low energy consumption can be achieved. Good design is essential to achieve these objectives. By contrast, expensive measures to improve the indoor environment are sometimes counterproductive: even when technical requirements (temperature, air flow rates, etc.) are met, occupants do not feel well. Furthermore, including energy saving measures did not necessarily lead to an energy-efficient building.

Adjusted average specific annual energy consumption in Norwegian office buildings were lowest in the oldest buildings from before 1931 (214 kWh/m^2) and highest in the newest buildings erected after 1997 (292 kWh/m^2) (ENOVA 2006). This tendency was not observed for central heating but was limited to, and most pronounced, in buildings with direct electrical heat with 196 kWh/m^2 and 436 kWh/m^2, respectively. Newer buildings with direct electrical heating only and not central waterborne heating use more energy than the older.

1.4.3 Current building conditions in Norway

The Anticimex report.

This study was based on standardized reports from 8895 assessments of dwellings in connection with sale/handing over of the dwelling (Nilsen et al 2006). Buildings that are sold are older than average and might also have lower standard than average. The building parts were classified in four levels;

Level 0 (TG 0): perfect condition
Level 1 (TG 1): good condition, no need of action,
Level 2 (TG 2): no extensive damage, but need of repair within limited time
Level 3 (TG 3): bad condition with immediate need of repair.

The results presented in table 3 gives rise for concern. For instance many young families in Norway have their dwellings or sleeping rooms at basement level. Only 27% were in acceptable conditions (Table 3). It is a general assumption among professionals, although not documented, that occupied basement rooms generally are poorly ventilated.

Table 3. Findings by Anticimex ranged after percentage of need of immediate repair

1. Crawl spaces: 23% of about 1.5 million detached and un-detached residential houses. Moisture in the space during summer months cause mould growth and rot (Arfvidsson et al 2005). 77% were TG-classified. Of these; 27 % were in immediate need of repair (TG 3) and 59 % had damages, weaknesses or were in need of repair within limited time (TG 2).

2. Draining: 82% were classified of which 24 % were in immediate need of repair/renewal (TG 3) and 56% were in need of renewal within limited time (TG 2).

3. Bath rooms: The wall structure in a bathroom has a watertight and moisture proof inside, normally on a gypsum board. The exterior wall has another vapours tight membrane on the other side of the board (Arfvidsson et al 2005). This may trap moisture in the board between. The surfaces are often tiled which may hide any emergence of moisture damages. Of the 97 % classified, 20 % were in immediate need of repair (TG 3) and 54% had damages, weaknesses or were in need of repair within limited time (TG 2).

4. Cellar flooring: Of 89% classifies, 17 % were in immediate need of repair (TG 3). 69% had damages, weaknesses or were in need of repair within limited time (TG 2).

5. Cold-storage chambers: These are difficult to build in compliance with the requirements. The result is often hidden condensation damages. Of 84% classified, 17 % were in immediate need of repair (TG 3). 49% had damages, weaknesses or were in need of repair within limited time (TG 2).

6. Outer roofing: Of 96% classified, 15 % were in immediate need of repair (TG 3) and 30% had damages, weaknesses or were in need of repair within limited time (TG 2).

7. Water heaters: Old water heaters entail increasing leakage risk. Water heater should be openly situated over a water tight floor with drainage. Of the 78% classified, 12 % needed immediate repair (TG 3) and 49% had damages, weaknesses or were in need of repair within limited time (TG 2).

8. Basement level: Of the 90% classified, 11 % were in immediate need of repair (TG 3) and 62% had damages, weaknesses, or were in need of repair within limited time (TG 2).

9. Drainage: Of 78% classified, 10 % need repair immediately (TG 3), 56% were in need of repair within limited time (TG 2). Many owners “forget” that drainpipes need renewal.

10. Balconies and terraces: 94% were classified of which 8 % were in immediate need of repair (TG 3), 50% had damages, weaknesses or were in need of repair within limited time (TG 2).

11. Roof constructions (not outer roofing): Of 92% classified, 6 % were in immediate need of repair (TG 3). More than half were in need of repair within limited time (TG 2).

12. Water pipes: Of 76% classified, 6 % of the dwellings were in immediate need of repair (TG 3). 58% had damages, weaknesses or were in need of repair within limited time (TG 2).

13. Kitchen: Of 98% classified, 4% were in immediate need of repair (TG 3). Although 49% were classified as having damages, weaknesses or were in need of repair within limited time (TG 2). This is probably mostly due to old and worn fittings and installations.

Process induced building defects in Norway

Process induced building defects means failures performed in the new- or rebuilding process. A comprehensive review of process induced building defects investigated by

SINTEF Building and Infrastructure in the 10-year period 1993–2002 (2,423 cases registered and described in 2,003 assignment reports) has recently been presented (Lisø et al 2006). Defects related to the building envelope constitute 66% of the investigated cases. A bulk of the defects (76%) was related to moisture, and many types of building defects were recurring items, indicating a general lack of knowledge concerning fundamental principles of building physics. A wide range of classical problems were recorded, e.g. unfortunate design and use of materials, inaccurate craftsmanship, structure and composition of rendering layers and paint on porous, mineral building materials, inappropriate rendering layers on facade systems with rendering directly on thermal insulation, and insufficient efforts to protect against moisture in general (Lisø et al 2006). According to the authors, these findings support earlier investigations concluding that the construction industry is not able to learn from past experience and that the exchange of knowledge is not satisfactory. With an annual investment in refurbishment and new construction of NOK 130 billion (as in 2003), it is reasonable to estimate that at least NOK 15 billion is being spent on repairing defects or damage to buildings every year.

The extremely varied climate and topography in Norway puts great demands on the design and localisation of buildings and the correct choice of materials and constructions. A definitive minimum requirement for a building is that it should tolerate to be left outside (Lisø et al 2006).

Perceived indoor environment in Norwegian working life

Perceived indoor climate in Norwegian working life seem to have slightly improved in recent years according to the work environment surveys (Table 4-6). Still, a large number of persons are not satisfied with their indoor environment.

Table 4. Physical work environment for all employees in Norway, aged 16-66. Statistics Norway 2007. The table shows the percentage of employees who experience these factors for half of their working hours or more, all and by gender.

		1989	1993	1996	2000	2003	2006
Heat	All	7	7	6	4	4	4
	Men	7	7	6	5	4	4
	Women	7	6	5	4	4	3
Coldness	All	8	8	8	8	7	8
	Men	12	12	11	11	11	12
	Women	3	3	4	3	3	4
Bad indoor climate	All	:	:	:	34	32	28
	Men	:	:	:	25	23	21
	Women	:	:	:	43	42	36

There are also still huge differences between branches and trades. The revision of the Norwegian Tobacco Act June 1, 2004, banning indoor smoking in all public places including restaurants, bars etc seem to have had a positive effect, particularly striking in hotel and restaurants (Table 5) (SSB 2007).

Table 5. Physical work environment, by problem, selected industries and year. Statistics Norway 2007. The table shows the percentage of employees who experience bad indoor climate half of their working hours or more.

	2000	2003	2006
Total (among all industries)	34	32	28
Trade	34	29	27
Hotels and restaurants	40	33	26
Finance	20	22	19
Public administration	35	33	28
Education	52	43	36
Health and social work	42	48	39
Other community, social and personal service activities	31	18	24

The construct "bad indoor climate" was in 2000-2006 based on four questions about exposure to "draught", "dry air", "bad ventilation" or "other bad indoor climate" and the respondents were then asked about how much of the working time they were exposed. Table 6 shows the results for "dry air". The data was kindly provided by Trond Arild Ydersbond, Statistics Norway 2007. "Dry air" is of particular interest because it is often associated with low air quality and high air temperature.

Table 6. Percentage of employees reporting perceiving "dry air" and perceiving bad indoor climate more than half of their working hours. Statistics Norway 2007 (SSB).

Industries	2000 N=2536	2003 N= 2564	2006 N= 9961
Total among the displayed industries	18	20	17
Trade	24	22	17
Finance	18	19	19
Public administration	21	24	21
Public schools	27	28	20
Universities and high schools		18	14
Hospitals, medical staff, dentistry	29	43	35
Other	13	15	13

1.5 EG opinion report on risk assessment on indoor air quality

The European Commission requested the Scientific Committee on Health and Environmental Risks (SCHER) to prepare an opinion on risk assessment on indoor air quality. The report was finalised 29th of May 2007 after public consultation (SCHER 2007). The general conclusions and recommendations states that:

"Indoor air may contain over 900 chemicals, particles, and biological materials with potential health effects. Since their concentrations are usually higher than outdoors and people spend more time indoors than outdoors, the SCHER recommends that any studies to correlate outdoor air concentration with health effects need to consider the impact of indoor exposure.

The composition and concentrations of the different components in indoor air vary widely and are influenced by human activities. Since it is not feasible to regulate all possible scenarios, prevention from possible health effects and protection of sensitive populations is best achieved by reducing exposure. As a consequence the SCHER recommends that all relevant sources that are known to contribute should be evaluated. Such sources include tobacco smoke, any open fires including candles, building materials, furniture, pets and pests, use of household products, as well as conditions that lead to the growth of moulds. Constructers, maintenance personnel and inhabitants should also be aware that appropriate humidity avoids annoyances and sufficient air exchange reduces accumulation of pollutants".

1.5.1 Vulnerable groups. Asthma, allergy and other hypersensitivity

Increase of asthma, allergy and other types of hypersensitivity in the population also entails increase of hypersensitivity among young adults that are entering the work life and forming a population which might be particularly vulnerable to indoor environmental exposure. Asthma, allergy and other types hypersensitivity is the only group of diseases currently increasing among children in the Western and developed societies. Asthma is presently the most common chronic disease during childhood, and it is in most European countries the most common cause of admission to hospital in children, in many countries up to 20% of admissions to paediatric departments (Sennhauser et al 2005, EEA 2007). The burden of asthma consists mainly of a decreased quality of life for the patient and their family, as well as high costs for society; the healthcare expenditures for asthma in developed countries are 1-2% of the total healthcare costs (Sennhauser et al 2005).

Lifetime prevalence of asthma was 20.2%; current asthma 11.1%, doctor diagnosis of asthma 16.1% and wheezes ever 30.3% among 10 year old children in Oslo 2004 (Carlsen et al 2006) (Figure 18). This represents almost a two-fold increase in ten years. Allergic sensitization (29.3% overall) was more common among children with current (56.3%) compared to asymptomatic (last 12 months) (26.0%) or no asthma (27.6%).

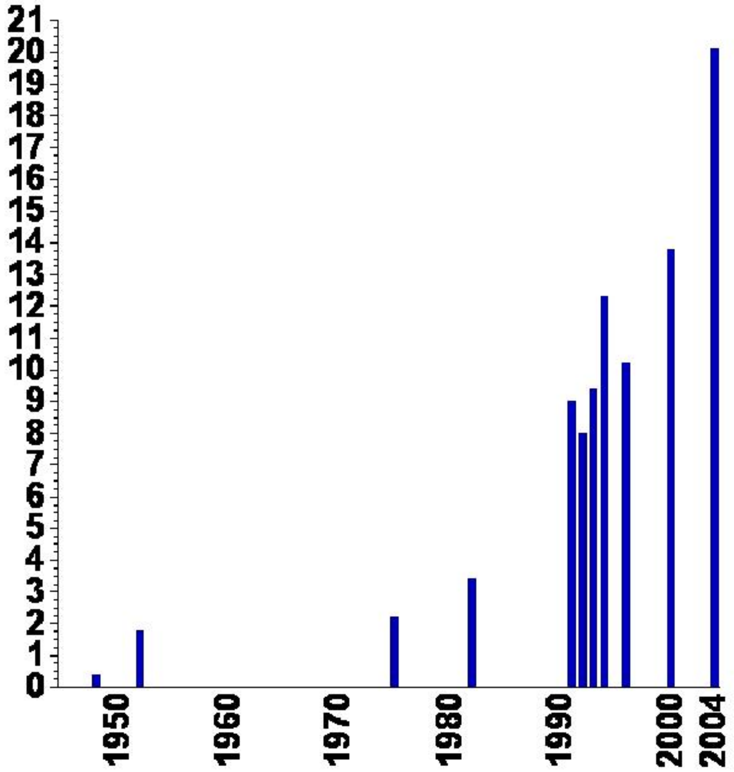


Figure 18. The figure is provided and with permission from, Kai Haakon Carlsen. Prevalence of asthma is given in percentages according to studies 1950-2004 among Norwegian school children. Figure from ERS 2003 supplied with data from studies 2000 and 2004 (Oslo) (Carlsen et al 2006).

Also in adults increase in asthma prevalence have been noted. The crude prevalence of ever having had a doctor diagnosis of asthma in Oslo and Bergen increased from 3.4% in 1972 to 9.3% in 1998-1999 (Brøgger et al. 2003). The increase in asthma was 50% greater in females than males. A 2.4 times increased risk to suffer from asthma among adults born in 1966 to 1971 as compared to being born in 1946 to 1950 was reported from studies performed in 15 industrialised countries (Sunyer et al. 1999). While for a pair of decennials ago the prevalence of asthma, rhinitis and sensitization seemed to be associated with high socioeconomic status, this tendency now seems to have changed to the opposite (Lewis & Britton 1998, Almqvist et al 2005). The causes of this increase and change is not clear, and may be related to better access to physicians and new diagnostic methods, however, environmental factor may to be of importance.

2. Modern Indoor Environment and Health with Emphasise on the Working Population. Current State-of-the-art

2.1 Indoor environment and health in general.

2.1.1 Building related illness (BRI)

In recent years, new knowledge has accumulated concerning the effects on health caused by exposure to agents present in indoor air (Indoor Air Pollutants = IAP) (Mølhave 1991, WHO 1983, 1999, 2000 b, 2006 a, ECA 2000). For some of these health effects, relationships with exposure to IAP have been reported. Among these are infectious and irritative respiratory diseases, respiratory allergy (for example, to house dust mites, animal fur and dander), asthma, and mucous membrane irritation. Such problems have particularly been linked to house dampness, however without clear establishment of causal mechanisms (Bornehag et al 2001, 2004 a, Gunnbjörnsdottir et al 2006). Indicators of dampness, as well as recently repainted interior surfaces, appear to be associated with recurrent infant wheezing, with a strengthened effect of combined indoor exposures (Emenius et al 2004). Intervention according to preventive guidelines including home dampness was associated with reduction of recurrent wheezing and asthma at 2 years of age (Wickman et al 2003).

Improperly vented, poorly ventilated or malfunctioning combustion appliances are associated with increased risk of respiratory diseases (WHO2000 a, b, 2002, 2004, 2007, Bousquet et al 2007). They also pose a real risk of acute poisoning by carbon monoxide.

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 10–15% of all lung cancers occurring in the population may be attributable to indoor radon exposure (WHO 1999, 2000 b). With regard to ETS, it has been estimated that non-smoking subjects living with smokers have about 30% increased risk of lung cancer when compared to the non-exposed population.

2.1.2 Sick Building Syndrome (SBS)

The impact of indoor work environment on health, well-being, and productivity has been increasingly acknowledged (Sundell 2004). Through the 1970ies there emerged an increasing awareness of symptoms and complaints on perceptions while staying in certain buildings or rooms, usually in non-residential buildings such as offices, educational buildings and hospitals. These experiences were summarised at a meeting within WHO in 1982 and this combination of symptoms were denoted as "Sick Building Syndrome", SBS (WHO 1983). These non-specific symptoms are usually perceived to be related to indoor environment in non-industrial buildings and improving, or disappearing, when being away from the indoor environment. Symptoms that have been associated with low quality of the indoor air are various non-specific symptoms from eyes, nose, throat, skin and general symptoms like headache and tiredness (Burge et al 1987, Burge 2004). The symptoms have been related to the central nervous system ("general symptoms"), the mucous membranes of the upper airways, eyes or skin symptoms (Andersson 1998). The mechanisms involved are largely unknown, but sensory reactions from both the olfactory and trigeminal nerves system might be involved as well as personal and psychosocial factors (Andersson 1998, Burge 2004).

Various factors in the indoor air environment, including dampness (Bornehag et al 2001, 2004 a) and temperature, (Reinikainen & Jaakkola, 2001) have been suggested to initiate and cause such symptoms. Also particle pollutants might be important when they contain bioactive components such as gram-negative bacteria or macromolecular dust (potentially allergenetic material) (Gyntelberg, 1994).

Other factors significant for the indoor environment includes thermal conditions (Wolkoff 1997, Fang et al 1998a, b, 1999, 2004, Reinikainen & Jaakkola 2001, 2003, Wyon 2004), ventilation rates (Wargocki 2002), environmental tobacco smoke (ETS), office equipment (Jaakkola and Jaakkola 1999), combustion products, formaldehyde and volatile organic compounds (WHO 2000 b). Interactions has been observed, e.g. between air temperature and air pollution (Norbäck et al 1990 b, Mølhave et al 1993).

SBS in residential buildings generally display lower symptom prevalence among occupants in single family houses, higher prevalence in multi-family houses and highest prevalence in big, multifamily houses in big cities (Andersson 1998). Epidemiology of SBS in residential buildings has not been extensively studied in Norway, but a large study has been performed in 609 multifamily buildings with 14235 dwellings in Stockholm, Sweden (Engvall et al 2000). Females, subjects with allergy, those above 65 years, and those in new buildings reported significantly more SBS than others. Subjects owning their own building reported less SBS. In adjusted analyses, 5% of person in all buildings build before 1961, 13% of those build 1976-1984, and 15% of those build 1985-1990 would have significantly more SBS symptoms than expected (Figure 19) (Engvall et al 2000).

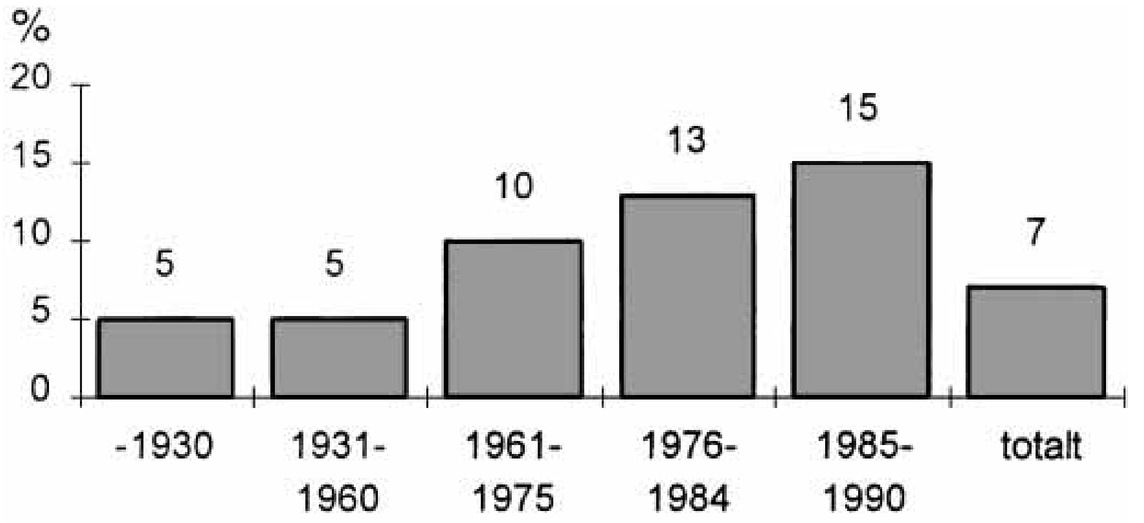


Figure 19. Proportion of residential buildings in Stockholm of different building periods, with ‘‘at least one weekly symptom higher than expected’’ (Engvall et al 2000, figure 1).

Many chemicals encountered in indoor air are known or suspected to cause sensory irritation or stimulation. These, in turn, may contribute to a sense of discomfort and other symptoms commonly reported in so-called "sick" buildings denoted “Sick Building Syndrome” (SBS) (WHO 1983, Mølhave 1991). Complex mixtures of organic chemicals in indoor air also have the potential to invoke subtle effects on the central and peripheral nervous system, leading to changes in behaviour and performance (Mølhave 1991). Toxicological and health hazard assessments are available only for a small proportion of these substances. Similar considerations apply to the transport and consumer products sectors. Indoor air pollution including volatile organic compounds (VOC) is most likely a cause of health effects and comfort problems in indoor environments in non-industrial buildings (Andersson et al 1997). However, the scientific literature is inconclusive with respect to assessment of total VOC (TVOC) as a risk index for health and comfort effects in buildings. Consequently, there is an inadequate scientific basis on which to establish limit values/guidelines for TVOC, both for air concentrations, and for emissions from building materials. TVOC might be used as an indicator for the presence of VOC indoors and can be used in relation to exposure characterization and source identification but for VOCs only, not as an indictor of other pollutants and their health effects (Mølhave 2003). In risk assessment the TVOC indicator can only be used as a screening tool and only for sensory irritation.

A recent review of the scientific literature found little support for the supposition that indoor chemicals by themselves possess important adjuvant effects for development of allergy in non-industrial indoor environment (Nielsen et al 2007). The observed precipitation of asthmatic symptoms with association to VOC exposures might either be caused by VOC levels considerably above typical indoor levels, or may be a surrogate for exposure to allergens, combustion products or dampness (Nielsen et al 2007).

The effects of IAP on reproduction, cardiovascular disease and on other systems and organs have not been well documented to date. 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.

An actual issue is plastic additives in the indoor environment including flame retardants and plasticizers from which exposure has increased dramatically since World War II (Bornehag et al 2004 b, Wensing et al 2005). Exposure to phthalate esters is an important issue because animal toxicity studies suggest that some phthalates affect male reproductive development (Calafat and McKee 2006). Concentration of phthalates in dust has also been associated with asthma, rhinitis and eczema with a strongly significant dose-response pattern and adjusted ORs in the range of 1.5-3 among those exposed to levels in upper quartile (Bornehag et al 2004 b). An association has also been observed between exposure to degradation products from damp PVC-floorings and incidence of asthma among employees with subsequent improvement after repair of the dampness and floorings (Tuomainen et al 2004). However, current evidence is not sufficient for risk assessment in terms of identifying possible causal effects of phthalates on allergy.

2.2 Indoor environmental exposures

2.2.1 Building dampness and health

The current scientific view is that dampness in buildings is a risk factor for health effects among atopic and non-atopic individuals both in domestic and in public environment (Bornehag et al 2001, 2004 a). Dampness in buildings appears to increase the risk for health effects in the airways, such as cough, wheeze and asthma. Relative risks are in the range of OR 1.4–2.2. There also seems to be an association between ‘‘dampness’’ and other symptoms such as tiredness, headache and airways infections. It is concluded that the evidence for a causal association between ‘‘dampness’’ and health effects is strong. However, the mechanisms are unknown. Several definitions of dampness have been used in the studies, but all seem to be associated with health problems. The literature is not conclusive in respect of causative agents, e.g. mites, microbiological agents and organic chemicals from degraded building materials.

This association has recently also been confirmed by the Respiratory Health in Northern Europe (RHINE) study (Gunnbjörnsdottir et al 2006). Moreover, a recent population-based incident case-control study of new cases of asthma aged 12-18 months also included careful home inspections and found that risk of asthma increased with severity of moisture damage and presence of visible mould in the main living quarter of the house (Pekkanen et al 2007).

The causal agents, although still poorly understood, may be linked to the complex interactions between bacteria and fungi with environmental growth substrates and other microorganisms which lead to a wide diversity of exposures (Nevalainen & Seuri 2005). Fungi and bacteria growing on building materials may produce toxic secondary metabolites, and the material appears to be a key determinant of metabolite production. Modern building technology has provided new ecological niches for microbes which readily exploit faults in moisture control.

Exposure to dampness and moisture has also been associated with the same effects in non-domestic, non-industrial indoor work environments such as schools and that repair of the damages has positive effect on health (Taskinen et al 1999, Ahman et al 2000, Savilahti et al 2000, 2001, Ebbehøj et al 2002, 2005, Rudblad et al 2004, Patovirta et al 2004, Meklin et al 2005). One intervention study indicated a dose-response relationship between exposure, asthma and respiratory infections (Savilahti et al 2000, 2001). Dose-response relations have been indicated in an observational study of dwellings, the severity of asthma was found to correlate with measures of total dampness and mould growth (Williamson et al 1997). However, this is by far not sufficient to conclude concerning causal relations and mechanisms (Eduard 2006).

Moisture in buildings can be in the form of water vapour or as free water. Measurements of relative humidity (RH) give information of the water vapour content in the air and/or in the building material. There are mainly four sources for ‘‘dampness’’ and moisture in buildings:

1. Leakage of rain and snow into the building construction or moisture from the ground.
2. Moisture from humans and indoor activities, e.g. cooking, bathing, human expiration, humidifiers, etc.
3. Moisture within building materials and constructions from the erection time due to lack of protection against rain and snow, or due to insufficient time for drying out, e.g. humidity in concrete floors.
4. Water leakage from e.g. pipes, flooding and other types of accidents.

More moisture and dampness than the building constructions and materials are dimensioned for, might entail damages due to chemical or microbiological decomposition of the construction, materials, organic dust or filth which may provide nutrition for microorganisms such as bacteria, moulds, amoebae and insects such as mites, cockroaches, flies and others. This can therefore cause exposure to

1. Allergens from house dust mites and other living or dead insects, germs, spores and other parts 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 forceful biological effects and some are used in medicine as antibiotics and agents used to modulate and suppress the immune system. Others are potent carcinogens such as aflatoxins,

however such effects has not yet been associated to indoor air exposures. Microorganisms use toxins in order to suppress other organisms in fight for survival and growth.

4. Endotoxins and glucanes as active abiotic agents originating from bacteria.
5. Emissions of chemicals e.g. formaldehyde from building materials often increases due to hydrolysis and decay of materials caused by water damage.

Although many potential mechanisms in this way theoretically are known to entail possible effect, most of these exposures are much too low in order to cause health effects within known and accepted dose-response relationship for single exposures. Known dose response relationships for mould exposure indicate effects at exposures several orders of magnitude higher than those observed under typical indoor environment conditions associated with dampness problems (Eduard 2006). However, the association between "dampness" and health effects is strong and it is no reason to believe that moisture or dampness as such is the cause. Obviously, the cause(s) must be looked for among the agents that occur due to the effects of increased humidity in the buildings and in combination with other factors such as temperature.

''Dampness'' is sometimes associated with mite growth that might induce mite sensitisation and allergic disease (Wickman et al 1991). Sensitisation to mites is far more common than sensitisation to moulds and most subjects sensitised to moulds are also sensitised to mites or other allergen. 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 evident (OR 3.4) after excluding subjects with positive mite findings in their homes (Nafstad et al 1998). Moreover, associations between ''dampness'' and health is also found in areas with little mite exposure, e.g. in northern Scandinavia with a dry indoor climate during winter-time. Several studies have showed that the prevalence of positive skin prick test to mites in these regions is less than 5 %, (Lindfors et al 1995, Norrman et al 1994) and 1% (Rönmark et al 1998). Nafstad et al (1998) found mite allergen in children's bed in 4.5% of 251 cases and in 1.2% of 251 controls.

The prevalence of sensitisation to mites is higher in countries with a more humid indoor climate. Verhoeff et al (1995) showed that the prevalence of sensitisation to mites among children aged 6– 12 years was 12.3% among 257 controls and 37.8% among 259 cases.

Airborne moulds and bacteria have also been shown to increase the risk for symptoms and signs related to indoor environment. However, the literature is not consistent on this point. Although moulds have been associated to allergy and asthma there is meagre evidence for any significant contribution by specific mould sensitization. A general adjuvant effect for specific sensitization by exposure to either moulds or any other exposure entailed by moisture might be a more probable cause than any specific sensitization to moulds. Garrett et al (1998) found that actual measurements of specific fungal spores predict health outcomes better than reported dampness. Asthma, atopy and respiratory symptoms were all significantly associated with exposure to one or more genera of fungal spores. However, the study might as well indicate that exposure to any fungi indoors could have the potential to increase the risk of allergic sensitisation to any allergen. Some support for this is also provided by other studies (Ruoppi et al 2003) and it is consistent with others (Burr et al 1988). These findings do not exclude the possibility that other and unknown mechanisms or exposures associated with building dampness can be more important causes of the associated effects. It can however be concluded that specific sensitisation to moulds do not play an important role in the development of allergy, asthma and atopy in relation to dampness in buildings. Testing for specific allergy towards mould has therefore little predictive value in the examination of individuals with suspected health effects from exposure to damp or mouldy indoor environments.

2.2.2 Ventilation and health

Sensory measurements using human panels were used to evaluate IAQ by Yaglou in the 1930ies forming basis for establishing ventilation requirements, and later by Fanger (Yaglou et al 1936, Fanger 1988). The impact of ventilation on health, comfort, and productivity in non-industrial indoor environment (offices, schools, homes, etc.) has been reviewed by a multidisciplinary group of scientists, called EUROVEN (Wargocki et al 2002). Based on the available data judged conclusive, the group agreed that ventilation is strongly associated with comfort (perceived air quality) and health (Sick Building Syndrome (SBS) symptoms, inflammation, infections, asthma, allergy, short-term sick leave), and that an association between good ventilation and high productivity (performance of office work) is indicated. The group also concluded that increasing outdoor air supply rates in non-industrial environment 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 ventilation rates above 0.5 air changes per hour (h^{-1}) in homes reduce infestation of house dust mites in Nordic countries. 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 may not be optimal for human productivity. Higher ventilation rates can increase energy costs in relation to building operation, but these can be reduced by lowering pollution loads on the air indoors, e.g., 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.

2.2.3 Heating, cooking, thermal indoor environment and health

A corresponding review on the impact of heating systems in the developed part of the world has not yet been performed and few studies have been done. However, the single most pervasive and harmful indoor air problem worldwide is still the oldest; smoke from fires (Samet & Spengler 2003). Increased risk of respiratory diseases associated with improperly vented, poorly ventilated or malfunctioning combustion appliances are well known (WHO1999, 2000, 2002, 2004, 2006b, 2007, Viegi et al 2004, Bousquet 2007). The almost daily exposure to smoke among about three billions of people in developing countries, primarily women and young children, is the 8th leading cause of disability-adjusted life years lost. This accounts for nearly 3% of the world's total burden of disease (WHO 2002). 36% of lower respiratory infections worldwide are attributable to solid fuel use alone, and 1% of all respiratory infections to outdoor air pollution (WHO 2006 b). More than 1.5 million deaths annually from respiratory infections are attributable to the environment, mostly in developing countries and among children less than five years of age. 700 000 occur as a result of chronic obstructive pulmonary disease and 120 000 are attributable to cancer in adults, particularly in women (WHO 2007).

Combustion products and pollution from heating systems and cooking using coal, wood, kerosene and gas, have also been associated to respiratory health effects in developed countries (Viegi et al 2004, Naeher et al 2007). Wood smoke at levels that can be found in smoky indoor environments caused an inflammatory response and signs of increased oxidative stress in the respiratory tract, especially in the lower airways in experimental short-term exposure of healthy subjects (Barregard et al 2007).

An Australian randomized, controlled intervention study (RCT) has been performed on heating is 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.

Use of gas stove and wood stove/fireplace was associated with shortness of breath, cough, nocturnal asthma and restrictions in activity among adult asthmatics in Denver, Colorado, USA, (Ostro 1994). Unvented gas space heaters were associated with episodes and days of wheeze among infants from households without smoking in Virginia, USA (Triche et al 2002). Wood stove and kerosene heater use was associated with cough.

Having 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 cough in siblings of previous child having asthma in USA (Belanger 2003). Exposure to freestanding wood burning stoves was associated with otitis among children in a case-control study from State of New York, Springville/ Buffalo USA (Daigler 1991). Lowest risk for eczema was found in households with central heating system and highest with the presence of a gas heater (Schäfer et al 1999). Emissions from fireplaces, gas space heaters, and kerosene heaters were associated with respiratory symptoms among non-smoking women (Triche et al 2005).

Electric heating has traditionally been considered as “clean energy”. However, electric heating has been associated with increased SBS symptoms (Engvall et al 2003) and asthma in children (Infante-Rivard 1993, Daigler 1991, Gent 2002). Asthma was also associated to “ducted air heating” (OR 8.9, CI 1.08-73) in a case-control study of atopic and non-atopic children in Plymouth and Dartmouth UK (Jones 1999). No other studies of health effects from “ducted air heating” have to our knowledge been published.

The need of keeping thermal comfort acceptable in the heating season and conserve energy at the same time might be challenging. Thermal comfort is dependent of operative temperature which in practice is the mean of air temperature and mean radiation temperature from surrounding surfaces. To reduce night temperature is a common way of conserving energy in office buildings in Norway. Air temperature is usually elevated to “acceptable level” when the work day starts in the morning. Mean radiation temperature can still be low at work start and might entail too low operative temperature and that employees are feeling too cold. This may entail compensatory actions in order to avoid freezing. Increased air temperature is the outcome of most of these actions, usually to a level well above the recommended max level of 22 ^{o}C in the heating season. The operative temperature might have been unacceptably low due to reduced radiant temperature from cooled indoor surfaces, particularly in buildings with heavy constructions and high heating capacity. Efforts to compensate this by increasing air temperature add to the enthalpy (energy contents) of the air and might then cause decreased air quality (Fang et al 1998 a, b). A high enthalpy of the air means a low cooling power of the inhaled air and therefore an insufficient convective and evaporative cooling of the respiratory tract, in particular the nose (Fanger 2006). This lack of proper cooling is closely related to poorly perceived air quality. The recommendation that the indoor air quality (IAQ) should be “dry and cool” is based on immediately perceived IAQ when entering the room (Fanger 2006). This notion should however be considered cautiously concerning continuous exposure through a work day (Wolkoff & Kjærgaard 2007). Their reviewed studies indicated that RH about 40% is better for the eyes and upper airways than levels below 30%.

There are relatively few field studies on health effects of thermal conditions (Gyntelberg 1994, Reinikainen and Jaakkola 2001, 2003, Mendell 2002), even though thermal factors are relatively easy to assess and comprehensive international standards are available (ISO EN 7730, Olesen 2004). High air temperature reduce air quality, increase perceived ”dryness” and irritation of the airways (Wolkoff et al 1997, Fang et al 1998 a, b, 1999, 2004, Reinikainen & Jaakkola 2001, 2003, Wyon 2004). Each 1^{o}C decrease in temperature within comfort range in public offices was related to a 19% decrease in severity of eye symptoms and to decrease in complaints on the complaints “stuffy” and “too warm” (19% and 25%) greatly exceeding the related increases in “draughty” or “too cold” (Mendell et al 2002).

Air velocity is required to be lower than the prevailing recommendation of max 15 cm/s (ISO EN 7730, Olesen 2004). This regulation of indoor air velocity is set in order to avoid draught. However, it is questionable whether this limit is set sufficiently low in order to avoid perceiving draught and feeling too cold, entailing need of higher operative and air temperatures. One mean to achieve good air quality combined with acceptable operative temperature in the heating season, is to keep mean radiant temperature high, air velocity low and air temperature as low as possible and well below 22°C. This might thus be an effective and important action to improve air quality and the same time save energy in the heating season (ECA 2003).

Heating sources might also contribute as pollution sources. Indoor heating in Norway is mostly provided by use of electric heaters. Electric heating has been associated with increased SBS symptoms (Engvall et al 2003) and asthma in children (Infante-Rivard 1993, Weichenthal et al 2007). Furthermore, experimental laboratory studies have confirmed the ability of electric heating stoves to emit a large number of sub-micrometer particles and VOCs that inhibit cell cultures (Pedersen et al 2003, Mathiesen et al 2004). Most of these problems can be avoided by keeping temperatures below 70-80 °C on all indoor surfaces that might be in contact with indoor air, including heater surfaces, halogen lamps, vacuum cleaners and other electric equipment with high surface temperatures cooled by air or brought in contact with indoor air. The most prevailing electric stoves in Norway are convection heaters that brings the indoor air in direct contact with surfaces heated up to several hundreds degrees centigrade.

Electric and other home cooking and heating systems contribute to formation of indoor ultrafine particles (UFPs) (Weichenthal et al 2007). Ultrafine particles 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 in 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, and particularly from heating and combustion in- and outdoors, has recently been associated to increased risk for ischemic heart disease (Torén et al 2007). The mechanisms behind might involve direct effects on the lung and cardiovascular system and indirect effect mediated through pulmonary inflammation and oxidative stress (Chuang et al 2007).

2.2.4 Particulate matter

Association between particulate matter PM_{10} and SBS-symptoms has not been reported until recently in field studies (Schneider et al 2003, Skulberg et al 2004, 2005, Simoni et al 2006), but few studies have been done. Findings from experimental chamber exposure studies of "office dust" among healthy subjects without hypersensitivity reactions indicate a threshold level for subjective symptoms and cough below 140 µg/m^3 TSP (Mølhave et al 2000 a). The size distribution of the dust was 50 weight percent (wt%) > 10 µm (Mølhave et al 2000 b). Hence, this would roughly correspond to a PM_{10} exposure of about 70 µg/m^3.

Three field studies found no association between SBS symptoms and exposure to dust at higher or comparable concentrations (Skov et al 1990a, Ooi et al 1998, Reynolds et al 2001). On the other hand, Skulberg et al 2004 found reduction of mucosal irritation symptoms in office workers after cleaning, entailing reduction of mean inhalable dust concentration from 67 µg/m^3 to 50 µg/m^3. Simoni et al 2006 found decreased nasal patency related to “elevated” PM_{10} (>50 µg/m3) among 547 pupils with mean age 10 years.

2.2.5 Organizational, mental and psychosocial work environment

SBS has been related to mental stress at work (Runeson et al 2004, 2005, Marmot et al 2006) and even shown to be more important than 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 public schools when comparing “water-damaged” and “non-damaged” schools (Ebbehøj et al 2005). Negative psychosocial work factors have been associated with the risk of various illnesses, especially psychosomatic disorders. The work situation is of importance to the individual, as the environment acquires its meaning through individual appraisal (Lazarus 1966, Cox 1994). The process functions as a mediating factor between the reality of the work environment and the individual’s mental and physiological reactions. High demands at work together with low social job control and low job support are a combination of factors that may cause various negative effects on health, such as heart disease and increased mortality (Kivimäki et al 2002) as well as anxiety, depression, mental distress, dissatisfaction and high rates for sickness absence and turnover (Michie and 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, 2005, Marmot et al 2006), the relationship to both physical and mental factors is of interest. Few studies have examined typical indoor air symptoms, indoor environmental factors and the psychosocial work environment at the same time (Marmot et al 2006).

2.2.6 University buildings

There are few studies on the indoor environment in University buildings. A few case studies have been published measuring microbial air quality in university buildings in Poland (Butarewicz 2005), Italy (Sessa et al 2002), China (Huang et al 1997) and indoor air pollution of 2-ethyl-1-hexanol in Japan (Kamijima et al 2005). Influence of number of students on the indoor level of coarse particle fraction (PM_{10}-$PM_{2.5}$) has been demonstrated in a university lecture room (Branis et al 2005). One study on university staff in Canada showed that they considered other features than air quality as important for their health, such as design of the university buildings, maintenance, funding cuts and socio-psychological factors (Bass et al 2003). One migration study in German university staff reported reduced well-being after moving to a new wide-spaced building, without any obvious relation to measured chemical or physical indoor environment (Neuner & Seidler 2006). There are no publications available on physiological signs from the ocular or nasal mucosa in relation to the indoor environment in university buildings.

2.3 Individual factors

2.3.1 Gender

Women tend to report more symptoms than men (Burge et al 1987, Skov et al 1989, Zweers et al 1992, Hall 1993, Burge 2004). Yaglou et al 1950 maintained that female workers, as a rule, prefer temperatures about 2^oC higher than those applying to men, because their metabolic rate is lower and their clothing is lighter than men's. This has not been supported in more recent studies forming basis for IS 7730 (ISO 1994). Griefahn & Künemund 2001 reported that women felt cooler and were more sensitive to draught than men. However, other studies did not identify an effect of gender on the perception of draught (Toftum 2004). The reason for gender difference in reporting symptoms from indoor environment is debated (Stenberg and Wall 1995, Brasche et al 2001). Gender differences have been observed in several other studies of subjective health symptoms. This has been found both in general population studies (Ihlebaek et al 2002, Ihlebaek & Eriksen 2003) as well as in studies of organ specific symptoms (Andersson et al 1992, Tollefsen et al 2007). Several suggestions are given concerning the possible causes of these differences in the articles. Different responses to stress, differences in coping style, different work situations, and different physical strength are mentioned (Ihlebaek et al 2002), as well as different traditions and thresholds for when and how to complain. In a study of airway symptoms, factors like hormonal fluctuations, airway calibre and bronchial hyper-reactivity are also mentioned (Tollefsen et al 2007). However, the real causes of these gender differences are not well understood, and several studies underline the importance of considering the gender issue in health studies (Messing et al 1994, Messing and Stellman 2006).

2.3.2 Atopy, allergy and other hypersensitivity

In the early 1920s, the term “atopy” was introduced to designate several phenomena of hypersensitiveness in man (Johansson et al 2001). This term changed as the scientific field developed and has acquired varying meanings. Today many scientists use the term synonymously with “IgE-mediated”, but particularly paediatricians and dermatologists also consider “atopy” a constitutional trait because IgE-mediated allergy is common in children and young adults and often runs in families. Typical symptoms include asthma, rhinoconjunctivitis, gastrointestinal symptoms and characteristic skin lesions.

“Atopy” has recently been defined as a tendency to become sensitized and produce IgE antibodies in response to ordinary exposure to allergens implying that the term can not be used until an IgE sensitization has been documented (Johansson et al 2004). This can be performed by means of testing allergen-specific IgE with a mixture of common inhalant allergens such as in Phadiatop® (Johansson et al 2005). The presence of IgE antibodies does not necessarily mean clinically active disease but have clinically predictive value for developing characteristic symptoms and to react on allergens corresponding to the specific IgE antibodies (Johansson et al 2004).

It is generally believed that “atopic” individuals are particularly vulnerable to inferior indoor environment. However, this has been shown only in few studies and even fewer have used definitions of atopy based on clinical tests. Atopy defined as a positive prick test to any allergen was a significant independent risk factor for reporting at least one SBS-related symptom (Björnsson et al 1998) although another study using the same definition did not find any association (Muzi et al 1998). Also, total serum IgE $\geq$ 100 kU/L has been used as atopic marker when studying association between asthma, chronic bronchitis and exposure to irritant agents in occupational domestic cleaning (Medina-Ramon et al 2005), although the diagnostic sensitivity of this test is low (Simoni et al 2001, Carosso et al 2007).

Moreover, compared to non-allergic, a higher percent among allergic persons may suffer from SBS-symptoms and complain about perceived annoyances in the indoor environment (Lundin 1999).

It is of interest to assess the associations between Phadiatop, total IgE, and other subjective and objective markers that are believed to be associated with atopy and to validate definitions of atopy. Also associations with mucosal inflammatory markers, symptoms and complaints on perceived indoor climate are of interest in this context.

2.3.3 Impact of home environment

Employees in non-industrial indoor environment in Norway usually spend not more than about 20% of their time at work, as opposed to often 65% of their time in their dwellings. Home environment might therefore have significant impact on environmental symptoms and signs among employees. Type of dwelling, pet keeping, and building dampness might have effects that can be associated with airway infections, SBS, tear film break up time (BUT), total and specific IgE, nasal patency, and selected nasal lavage biomarkers. These exposures and effects may constitute potential confounders in the work environment study that ought to be controlled for. Most indoor studies using physiological investigations of the ocular and nasal mucosa have been investigating health effects of the school (Norbäck et al 2000 a, Wålinder et al 1998, 2001 a, Hirvonen et al 1999, Rudblad et al 2004), hospital (Wieslander et al 1999 a, Smedbold et al 2002) or the office environment (Wieslander et al 1999 b, Wålinder et al 2001b, Skulberg et al 2004, 2005). There are relatively few studies on SBS in relation to the home environment (Engvall et al 2001, Norbäck and Edling 1991, Norlen and Andersson 1995). Even less studies are available on physiological signs from the ocular and nasal mucosa in relation to exposure at home. One study demonstrated that children exposed to environmental tobacco smoke (ETS) at home had less nasal patency (Zavras et al 1997). Various factors in the dwelling such as type of building, building age, ventilation, pet keeping, and wall-to-wall carpeting have been shown to influence the prevalence of SBS-symptoms (Apter et al 1994, Hodgson 1995, Mendell 1993). In addition, SBS is also influenced by personal factors, such as female gender, psycho-social work conditions, and allergic disorders (Mendell 1993, Apter et al 1994, Hodgson 1995).

Building dampness is associated with different home indoor exposures such as dust mite allergens, bacteria, mould, and increased emission of certain volatile organic compounds. A large number of studies have shown that subjects in damp dwellings have a significant increase of different types of symptoms, including ocular and nasal symptoms (Bornehag et al 2001, Bornehag et al 2004 a). The general scientific view is that we do not know which exposure in the damp building is responsible for the observed health effects (Bornehag et al 2001). Building dampness in the dwelling has been associated with increased levels of eosinophilic cationic protein (ECP) in serum, an indication of eosinophilic inflammation (Norbäck et al 1999). We have found no publications on health effects of dampness in dwellings, investigating physiological signs from the ocular or nasal mucosa.

2.4 Methods used for objective examination of health and well-being in studies of indoor environments.

2.4.1 Physiological effects and biomarkers

Most studies on health effects of the office environment have used self-administered questionnaires to collect data on exposure, health effects, or both (Apter et al 1994, Burge 2004).

Physiological investigations of the ocular and nasal mucosa have also been used to study health effects of occupational and environmental exposure (Franck 1986, Wålinder et al 1998, 99, Muzi et al 1998, Kjærgaard and Hodgson 2001, Norbäck & Wieslander 2002). A few studies have applied these methods to study health effects of the office indoor environment (Wålinder et al 2001b, Skulberg et al 2004). Recently, new objective methods have become available to study physiological effects of the indoor environment on the ocular and nasal mucosa (Norbäck & Wieslander 2002). Building dampness in workplace buildings have been associated with reduced tear film stability (Wieslander et al 1999 a), reduced nasal patency (Wålinder et al 2001a), and increased concentration of certain biomarkers in nasal lavage (Hirvonen et al 1999, Purokivi et al 2001, Wieslander et al 1999 a, Wålinder et al 2001 b).

A relatively large inter-individual variation has been observed for these methods, both for measurements of tear film stability as tear film break up time (BUT) (Kjærgaard & Hodgson 2001), nasal patency by acoustic rhinometry (Fisher 1997, Corey et al 1998, Wålinder et al 1999), and biomarkers in nasal lavage (Wålinder et al 1999). Since the conventional fluorescein method for BUT may give incorrect results, because fluorescein itself has an effect on the tear film stability, a non-invasive tear film break up time (NIBUT) has been developed (Mengher et al 1985).

Relatively little is known about influence of personal factors on ocular and nasal biomarkers, e.g. age, gender, smoking and atopy. In office workers, a reduced BUT was observed for females, older subjects (> 40 y), and for those with a history of eye disease (Brasche et al 2005). In two review articles on ocular effects of the office environment, female gender, allergic rhinitis, Sjögrens syndrome, contact lenses, eye-makeup and certain medication, e.g. antihistamine products, antidepressants and hormonal treatment were found to cause eye irritation (Wolkoff et al 2003, Wolkoff et al 2006).

In a Swedish study of white collar workers, males had larger nasal dimensions and higher nasal airway lavage (NAL) concentrations of ECP (eosinophilic cationic protein), MPO (myeloperoxidase) and albumin (Wålinder et al 2000). Moreover, there was a weak correlation between anterior nasal dimensions and nasal obstruction symptoms. In subjects aged 4-61 years without nasal symptoms, minimum cross-sectional area (MCA) showed weak positive correlations to weight, body mass index, height and age in that order (Millqvist & Bende 1998). In a randomly selected adult population, symptoms of allergy, frequent infections, small anterior nasal dimensions, and a large degree of swelling of the nasal mucosa were related to nasal obstruction symptoms (Grymer et al 1997). Influence of individual and seasonal variations of biomarkers in NAL was investigated in ten healthy volunteers during one year. Men had higher NAL-levels of nitrite, tumor necrosis factor (TNF)-alpha, interleukin (IL)-4, and IL-6. Seasonal differences were detected, with highest TNF-alpha and IL-6 in winter and highest IL-5 in summer. It was concluded that individual variation of the basal level of inflammatory markers is low, while difference between individuals are considerable (Roponen et al 2003). Besides these studies, there is little information on the significance for personal factors such as age, gender and life style, on ocular and nasal biomarkers. Such knowledge is of major interest in order to interpret the results from these tests.

Among the research needs are to describe how ocular and nasal symptoms and biomarkers depend on age, gender, atopy, smoking, airway infections and type of occupation. How nasal and ocular symptoms, BUT, total IgE, atopy, nasal patency, and lavage biomarkers are interrelated is also of interest. Also the associations between occupation, indoor environmental perceptions, ocular and nasal biomarkers, and atopy should be further elucidated.

Increased exhaled nitric oxide (eNO) levels are increased in bronchial asthma (Alving et al 1993). The diagnostic accuracy of eNO measurement is superior to that of the standard diagnostic spirometry in patients with symptoms suggestive of asthma (Fortuna 2007). Atopy seems to be associated with increased levels of eNO (Ricciardolo 2003, Spanier et al 2006). It seems not to be associated with same level of pulmonary inflammation among non-allergic asthmatics (Ludviksdottir et al 1999). In non-sensitized children eNO levels were associated with respiratory infections and home window pane condensation (Janson et al 2005). Experimental exposure of healthy adults to *Aspergillus fumigatus* and to wood smoke showed association to eNO (Stark et al 2005, Barregaard et al 2007). Exhaled NO was also increased in shoe and leather workers exposed to solvents at the end of work shift, while it did not change in unexposed subjects of the same factory. This indicates that eNO may be a sensitive biomarker for subclinical inflammatory effects of occupational exposure (Maniscalco et al 2004). However, eNO was a poorer sensitive marker for effects of PM10 and PM2.5 exposure among subjects with asthma and COPD (chronic obstructive pulmonary disease) than spirometry (Jansen et al 2005). Exhaled NO is useful in distinguishing atopic from non-atopic asthma and to identify and monitor patients who do/do not require treatment with inhaled steroids (Taylor et al 2007). However, it is still unclear whether eNO is a feasible biomarker for irritative effects among a general population in non-industrial work environment.

2.4.2 Methods based on blinded exposure, perceived air quality and objectively assessed human performance

Sensory measurements using human panels were already used to evaluate IAQ by Yaglou in the 1930s forming basis for establishing ventilation requirements (Yaglou et al 1936). Based on controlled and standardized exposure of judges entering a ventilated room to bio effluents from occupants in the room, PO Fanger introduced the olf and decipol unit in 1988 (Fanger 1988). The olf was introduced in order to quantify pollution sources based on perceived acceptability of the air by a panel of judges not adapted to the indoor air. One olf is the emission rate of air pollutants (bio effluents) from a standard person. Any other pollution source is quantified by the by the number of standard persons (olfs) required to cause the same dissatisfaction as the actual pollution source. The decipol was introduced to quantify the concentration of air pollution as perceived by humans. One decipol is the pollution caused by one standard person (one olf), ventilated by 10L/s of unpolluted air. The percentage of dissatisfied as a function of the perceived air pollution in decipols was presented, based on bio effluents from more than one thousand occupants, judged by 168 subjects. The aim was to provide a rational basis for calculation of ventilation requirements and for the prediction of and measurements of air quality based on human perception. Results from field studies in 20 randomly selected offices and assembly halls in Copenhagen were presented based on 54 judges visiting each space three times (Fanger et al 1988). Ventilation rates, carbon dioxide, carbon monoxide, particulates, and total volatile organic compound were measured, but did not explain the large variations in perceived air quality. For each occupant in the 15 offices there were on average 6-7 olfs from other pollution sources; 1-2 olfs from the room, 3 olfs from the ventilation system and two olfs causes by tobacco smoking. Ventilation rate was 25 L/s per occupant, but only 4 L/s per olf. This could explain why an average of 30% of the judges found the air quality unacceptable. The obvious way to improve indoor air quality was to remove the pollution sources in the spaces and ventilation systems. This would at the same time improve air quality, decrease required ventilation and energy consumption, and diminish the risk of draughts.

These methods have since then been validated and used in many settings. They have been used in experiments demonstrating and quantifying sensory effects of different pollution sources at varying ventilation rates The results have also been used in setting ventilation requirements and guidelines, e.g. in Norway.

Experimentally controlled and blinded exposure has been performed in office work conditions simulated in laboratories and in field when performing office work at different pollution loads and ventilation rates (Wargocki et al 1999, 2000, 2004). Perceived air quality improves, SBS-symptoms decreases and human performance increases when pollution load is decreased. When performing office work; increasing ventilation between 3 and 30 L/s decreased the percentage of persons dissatisfied with the air quality and the intensity of odour, and increased the perceived freshness of air (Wargocki et al 2000). It also decreased the sensation of dryness in mouth and throat, eased difficulty in thinking clearly and made subjects feel generally better.

Similar results have been reproduced in field (Wargocki et al 2004). A 2 x 2 replicated field intervention experiment was conducted in a call-centre providing telephone directory service. Outdoor air supply rate was adjusted to be 8 % or 80% of the total airflow and supply air filters were either new or had been in place for 6 months. The 26 operators were blind to the conditions. Increasing outdoor supply rate reduced talk-time with a new filter but increased talk-time with used filter in shape. Replacing a used filter with a new one at high ventilation rate caused the air to feel less dry, skin to feel less dry, the air to feel fresher and the operators to feel less tired. Replacing a new filter with a used one at the low outdoor supply rate caused operators to feel that the air quality was less acceptable and that the call-centre was darker and dirtier. Perceived dryness of air and skin were affected although the relative humidity was nearly the same.

3. AIMS OF THE STUDY

The main objective of this project was to study the associations between subjective symptoms, objective signs, physiological effects, and perceived and measured indoor environment among employees in University buildings (figure 20).

Subsidiary aims were to

- Compare subjective symptoms, indoor environment and physiological signs from the ocular and nasal mucosa among staff in university buildings with suspected indoor problems (problem buildings) to similar buildings with no indications of impaired indoor air quality (control buildings)(art 1).
- Study associations between the home environment and selected physiological signs (art 2).
- Assess associations between and gender differences in self-reported symptoms, psychosocial, subjective and objective physical environment (art 3).
- Assess the associations between on one side mucosal symptoms and perceived environments, and on the other side traditional measures for hypersensitivity such as different atopy definitions and new measures in terms of biomarkers (art 4).

More knowledge in this area is important in order to promote health, comfort and sustainability and prevent adverse effects from indoor environment at work.

3.1 Ethics

The study was approved by the Regional Medical Research Committee of Western Norway. The Ministry of Health and Care Services gave permission to establish a bio-bank and to transfer the biological material abroad for analysis. Both oral and written information was given and all participants gave written informed consent. Individuals displaying any possible pathology were individually informed and offered personal consultations and advice.

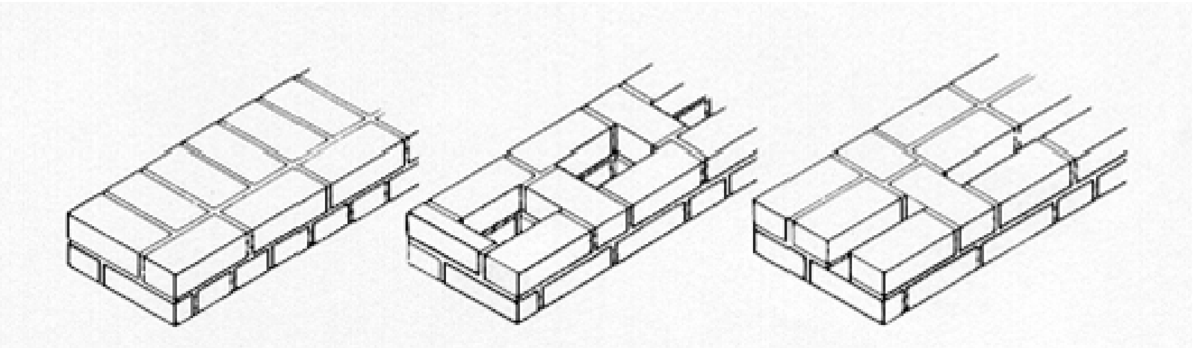
Figure 20. Pictures of the University buildings studied in the project

4. Materials and methods

4.1 Buildings

In 2004, a cross-sectional study was performed in four approximately 100 years old brick buildings erected in “Bergen cavity walls” (Figure 20 and 21). They had previously been refurbished from apartment houses to serve as offices and lecture rooms for the university, and were further redecorated and equipped with mechanical supply exhaust ventilation in 1999-2000.

Figure 21. Brick wall constructions used in Norway 1860 - 1940



Massive brick wall Bergen Cavity wall Trondheim Cavity Wall

Bergen, and the Jugend town of Aalesund, has a huge building stock of corresponding buildings erected in “Bergen cavity walls” (Figure 22) (Olsen & Monsen 2003). Similar technical and physical properties and possible risks connected to modernization seem to occur in this building stock (Grytli 2004). Corresponding problems might also occur in other modernized brick apartment town buildings in Norway erected in 1860-1940. “Trondheim cavity walls” were used in the same time period as “Bergen cavity walls” but are slightly different in construction. Brick buildings from the same time period in other Norwegian towns, especially Oslo, are often erected in compact brick walls, but have much of the same risks connected to modernizations with insulation inside and change of air pressure conditions in the buildings (Geving & Thue 2002, Grytli 2004). Distortion of the original building physics by internal insulation or changing air pressure conditions might convey condensation and dampness problems.

In 2001-2003, workers from two buildings complained to their Occupational Health Service (OHS) about various health problems during the work day. Several sources of dampness and mould were identified by inspection and verified by indoor air sampling of microbiology. The workers were evacuated. Improvements were made and verified by assessing normalised air microbiology. Complaints on indoor climate however remerged after moving in for the second time summer 2003, giving the buildings status as "problem buildings" in our study. As "control" buildings, two similarly refurbished buildings of same construction were chosen. There were no recent health complaints reported to the OHS among the workers in the control buildings before the study period.

Figure 22. Jugend buildings in Ålesund probably erected in Bergen cavity brick walls. Pictures from Globalnytt 3, Norsk nettskole: http://www.av-senteret.no/nettskolen/globalnytt/3/jugend.htm

4.2 Study period and participants

The study was performed in the Norwegian winter season February – March 2004, after the influenza season and before the main pollen season. Four specific weeks were chosen for environmental measurements and two of these for examinations of the participants. All employees and master students working in the buildings during the study period were invited to participate. They were all informed in meetings, one for each building, where the researchers, the safety deputies and head of the department were present.

In total, 173 (86.1%) of 201 eligible workers participated in the study. 97 of 115 workers (84%) participated from the problem buildings and 76 of 86 (88%) from the control buildings, altogether 81 men and 92 women. The problem buildings had a higher proportion of females ($p = 0.03$). Mean age of all workers was 43 years. They had a mean of ten years of education after primary school and had been working nine years at the University. There were no significant differences between the groups in terms of proportion of professional or administrative positions, education level, years at work at the University, working hours, atopy measured as a positive Phadiatop, or private housing conditions.

4.3 Health examinations

All health examinations of the employees were performed in an office in their own University building. We wanted to collect both subjective and objective data at the same time and in a way that minimised the risk that knowledge of any other result among the researchers could influence their own assessments. The subjects were required to be present at their working place at least one hour before the examination in order to assure a minimum exposure time in the work premises before performing studies of tear film, nasal patency and nasal lavage (NAL).

4.3.1 Questionnaire

The participants filled in an extended and modified MM040NA questionnaire (Andersson, 1998). The symptom questionnaire included five questions (yes/yes sometimes and not at all) on general symptoms (fatigue, feeling heavy-headed, headache, nausea/dizziness and difficulties concentrating), four questions on mucosal irritation (itching, burning or irritation of the eyes, irritated, stuffy or runny nose, hoarse, dry throat and cough), and three on skin symptoms (dry or flushed facial skin, scaling/itching scalp or ears, hand dry, itching, red skin) during the last three months. The symptoms were for some analyses, dichotomised and classified as general (0-5), mucosal (0-4), or dermal (0-3). A total symptom index was constructed by summing up the number of symptoms for each subject. The symptom index was also subdivided in scores for general, mucosal and dermal symptoms. The questionnaire also included twelve questions about subjectively perceived indoor environment during the last three months. All questions were answered by yes (weekly), yes sometimes and not at all.

Questions about job demands (six items), control (five items) and social support (six items) in the past 3 months were based on the Swedish Demand–Control–Support Questionnaire (Theorell & Karasek 1996, Karasek et al 1998). Each item is scored on a four-point scale; “Yes, often” = 1, “Yes sometimes” = 2, “No, seldom” = 3 and “No, almost never” = 4 (Sanne et al 2005 a). The scores were totalled, giving subscale scores from 5 to 20 for demands and latitude and from 6 to 24 for support. The three indexes were mathematically transformed to give values in the range of 0.00–1.00 by first subtracting from each score the number of items included and then dividing by the same number. Job demands and control were combined as the factor “strain” (demands divided by control), giving a range of 0.00–1.40.

The participants also answered questions about gender, age, years of education, scientific position at the university (yes/no), dampness and domestic animals in their home (yes/no), work hours daily, current chronic diseases (yes/no) (cardiovascular diseases, chronic lung diseases, cancer or serious mental disorders), daily medication (yes/no), absence from work due to infectious airway disease in the past year (days), physical fitness (scale 1–5), current smoking (yes/no) and number of cigarettes smoked daily.

The aggregated frequencies from each symptom and each complaint in both problem buildings and the other university buildings were compared with a Swedish reference population from workplaces in nine “healthy” buildings with 319 respondents (Andersson 1998). These buildings consisted of seven offices and two schools and have been used as a general reference population in studies of indoor climate at workplaces. Comparable external reference populations for university buildings are to our knowledge not available.

4.3.2 Blood samples

A blood sample was taken of all participants in the study. The samples were drawn from the cubital vein with the subject sitting in a chair. The blood was clotted in the tube at room temperature. After a maximum of two hours the blood was centrifuged. The serum samples were brought to the laboratory and frozen to - 25 ^{O}C. Serum samples were analysed at the Laboratory of Clinical Biochemistry at Haukeland University Hospital for serum IgE and IgE antibody levels by the Immuno-CAP FEIA system (Phadia, Uppsala, Sweden). Allergen-specific IgE was tested for the main inhalation allergens using Phadiatop® (*Dermatophagoides pteronyssinus* (d1), *D. farinae* (d2), birch (t3), timothy (g6), mugwort (w6), cat (e1), dog (e2), horse (e3), and *Cladosporium* (m2)). Results were assessed as negative when the concentration of IgE antibody was <0,35 kU$_A$/L (kU$_A$ = kilo units of specific antigen) or positive when concentration was $\geq$ 0,35 kU$_A$/L (Johansson et al 2005).

4.3.3 Tear Film examination

Tear film stability was studied by assessing non-invasive break-up time (NIBUT) by ocular microscopy (Keeler TearScope®, Keeler Instruments, Clewer Hill Road, Windsor, Berkshire SL4 4AA, UK), based on a grid of equidistant circles of light that are blurred by tear film break up (Mengher et al 1985). Contact lens wearers were not assessed. “Self-reported Break Up Time" (SBUT) was assessed by recording the time the subject could keep the eyes open without blinking, when watching a fixed point at the wall. This method has been previously used (Wyon & Wyon 1987, Wieslander et al 1999 a), and has been shown to correlate well with the fluorescine method for BUT (Wyon & Wyon 1987). Recording of SBUT was stopped at 30 seconds. The average of three tests was registered for both NIBUT and SBUT. Contact lens wearers were included when assessing SBUT.

4.3.4 Acoustic rhinometry

Acoustic rhinometry (Rhin 2000; SR Electronics, Denmark) with continuously transmitted wideband noise was applied to measure nasal patency (Wieslander et al 1999 a) (figure 23). This method measures internal dimensions of the nasal cavity at different distance from the nose opening, by means of reflection of ultrasound.

Smaller nasal volumes or cross-sectional areas indicate swelling of the nasal mucosa and nasal congestion. The first measurement was after five minutes of rest (sitting); the second after nasal lavage by isotonic saline solution, the third was performed ten minutes after decongestion (two douches of 140 microgram xylometazolin-hydrochloride each, five minutes apart (Otrivin, Novartis Consumer Health AG, Nyon, Switzerland)). By means of acoustic reflection the minimum cross-sectional areas (MCA) on each side of the nose were measured from 0 and 22 mm (MCA1) and from 23 and 54 mm (MCA2) from the nasal opening. The volumes of the nasal cavity on the right and the left sides were also measured from 0 and 22 mm (VOL1) and from 23 to 54 mm (VOL2). The mean values were calculated from three subsequent measurements on each side of the nose. Data on nasal dimensions in the present study are presented as the sum of the values recorded for the right side and the left side. The volume changes after decongestion were calculated by subtracting the values of VOL1 and VOL2 before decongestion from the values after decongestion. The respective percentages of increase after decongestion were calculated. Total volume change (dVOL) was assessed as the mean of the percentages increase of VOL1 and VOL2.

Figure 23. Performing acoustic rhinometry and nasal lavage.

4.3.5 Nasal lavage

Lavage of the nasal mucosa was made with a 20 mL plastic syringe attached to a nose olive (Wieslander et al 1999 a). The subjects were standing, with their head flexed ca 30˚ forward. The room-tempered (20-22 ˚C) sterile 0.9% sterile saline solution was introduced into the nasal cavity. Each nostril was lavaged with 5 mL solution, which was flushed back and forth five times via the syringe at an interval of a few seconds. The fluid was transferred into a 10 mL polypropylene centrifuge tube. Samples were kept on ice and within 300 minutes the solution was centrifuged at 800 g for five minutes. The supernatant was re-centrifuged at 1,400 g for five minutes and immediately frozen to -20 ˚C. Lysozyme was analysed by radioimmunoassay (Venge et al 1979). The concentrations of ECP, MPO and lysozyme were measured by means of a double-antibody radioimmunoassay (Pharmacia Diagnostics AB, Uppsala, Sweden) (Peterson et al 1991, Griffin et al 1991, Schmekel & Venge 1991). The intra- and inter-assay coefficients of variation for all three tests were less than 11%. Albumin was measured by the rate nephelometry on an Array protein system (Beckman Instruments: Beckman Coulter Inc, Fullerton, CA, USA). All analyses were performed at the Department of Clinical Chemistry, University Hospital, and Uppsala, Sweden.

4.4 Exposure assessment

The technical installations in the buildings were inspected including outside air inlets and outlets, technical rooms, all ventilation aggregates, which were stopped and opened for inspection inside including filters. Ducts and shafts where they were accessible, air inlets, outlets and local heating systems in all rooms were inspected. All rooms with working places had their internal floor, walls and roof surfaces characterized and net area controlled.

Indoor climate measurements were performed in a number of representative rooms that were categorised according to location, size and function. In total, 56 logging points were covered of which 48 were in offices. All logging points were situated 110 cm above floor level. In total, 14 logging points were in small offices (< 15 m^2), 31 in medium sized offices (15-30 m^2), 3 in large offices (> 30 m^2) and 8 in meeting rooms/lecture halls. Air temperature, relative humidity, CO_2, and air velocity were monitored. PM_{10} was assessed as time point measurements. The results gave rise to the exposure variables that were included in the analyses (Table 2, paper 1). Outdoor CO_2 measurements were taken near the ventilation inlets. Outdoor temperatures and meteorological data were obtained from the Norwegian Meteorological Institute.

Data were logged continuously by use of the following instruments and software:

- Temperature (air): Q-TRAK Plus IAQ Monitors Model 8552/8554 (TSI, Shoreview, MN 55126-3996 U.S.A.), Kistock with KILOG soft ware (KIMO Instruments, MONTPON, France), Klimalog 7, SenseAir CO_2 monitor (SenseAir® AB, Delsbo, Sweden), Mitec AT40g (Universal), Mitec SatelLite-T, Mitec Satelite-TH (Mitec Instrument AB, Säffle, Sweden)
- CO_2: Q-TRAK Plus IAQ Monitors Model 8552/8554, SenseAir CO_2 monitor, Mitec AT40g (Universal)
- Relative humidity: Q-TRAK Plus IAQ Monitors Model 8552/8554, Klimalog 7, Mitec AT40g (Universal), Mitec Satelite-TH
- Air borne dust (PM_{10}): SidePack dust monitors, with soft wear TrakPro (TSI)
- Air velocity: SWA 03 draught sensor (Swema, Stockholm, Sweden)

Lighting and noise were screened for all areas:

- Luminance and illumination: Hagner Universal Photometer which is a combined luminance and illumination meter (B.Hagner AB, Solna, Sweden)
- Noise: Brüel & Kjær 2237 integrating Sound Level Meter (Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark)

The instruments were calibrated according to stated procedures from the instrument suppliers. Parallel loggers were calibrated with each other in the relevant measurement ranges. A final calibration was performed by adjustments in the data sets. The logging periods were typically set to two days (9 am to 4 pm) and one night (4 pm to 9 am) in each room. Measurements were collected every fifth minute through the monitoring period. Airborne dust (PM_{10}) was assessed at specific time points.

Mean daytime room air temperature (9.00-16.00), mean night time air temperature during the coldest part of the night (2.00-6.00), mean daytime relative humidity (RH %), carbon dioxide (CO_2) and airborne dust (PM_{10}) were modelled according to building and office size (small offices < 15 m^2, medium sized offices 15-30 m^2, and large offices > 30 m^2) for office room with no measurements. The modelling was based on data from the 48 logging points inside rooms with work places. Each room with work places were attributed one data set, either modelled or measured, which was attributed to all subjects working in that particular room.

4.4.1 Air microbiology

The microbiological assessments included viable microbiological sampling in air aiming to compare microbial flora composition between outdoor air, air intakes and indoor air. Air samples were collected from:

- Outdoors near the actual air inlet grid
- Main plant area – between the filter and the fan
- User area – in rooms supplied with air by the ventilation systems
- Technical rooms, central parts and inside corners and angles of the building
- Near a shaft in Problem building 1

Samples were collected using the Biotest Standard RCS Centrifugal Air Sampler (Biotest AG, Dreieich, Germany) which has been validated and compared with other methods (Lee et al 2004 a, b). Sampling volume was 320 Litres with 40 L/min in eight minutes. Tryptic Soy Agar was used for determination of total airborne microbial count, and Rose Bengal Agar for selection of moulds and yeasts. Incubation temperatures were 22°C and 37°C. Evaluation of microbial flora was based on flora composition and not on numbers. Each agar strip was semi-quantified (few, moderate, rich), and specified within three levels: *Specific dominance* for moderate or rich growth of one genera, at incubation 22°C, and *thermo tolerant*, if genera was found at incubation 37°C. Absence of a specific dominance or thermo tolerant activity was specified as a *normal flora.*

191 air samples were taken (Table 7). 6 samples were from outdoor air near ventilation inlets, 6 samples from inside ventilation plants, and one sample inside one technical room for the ventilation aggregate due to observed moisture problems. 169 samples were taken from 124 rooms, of which 45 samples were from room supply air and 124 from room air. 77 of the rooms were offices, classified as small (18), medium (53) and large (6). 54 samples were taken from other rooms and locations, 6 samples were taken in problem building 1 from near a shaft in order to assess whether pollutions could spread from a source to occupied areas.

Table 7. Number of air samples for microbiology collected (in number of rooms) in two problem buildings and two control buildings

	Problem build 1	Problem build 2	Problem build 1+2	Control build 1	Control build 2	Control build 1+2
Outdoors	1	1	2	3	1	4
Ventilation plant	1	1	2	3	1	4
Technical room	1	-	1	-	-	-
Offices	19 (12)	28(19)	43 (31)	48 (30)	22 (16)	70 (46)
Other rooms	24 (19)	10 (10)	34 (29)	9 (7)	13 (11)	22 (18)
Near shaft	6	-	6	-	-	-
Total samples	51	40	91	63	37	100

4.5 Statistics

SPSS version 12.0 was used for the analysis, and the significance level was set at 0.05. Categorical values were tested with Pearson chi-square tests, and continuous variables were compared using Students t-test. Associations were studied with Pearson's correlation coefficient or with Kendall's tau when non-parametric analyses were needed. Mann Whitney U-test was used for comparison of continuous variables that were not normally distributed.

Multiple linear regressions were used for analyses of associations between continuous variables of exposure and health effects and adjusted for gender and age. Stratifications were performed for upper and lower median of mean day air temperature in order to study possible differences in associations and patterns between those exposed to high air temperatures versus those exposed to low. Logistic regression was performed for dichotomized responses concerning symptoms and perceived indoor environment, both crude and when adjusting for gender, age, scientific position, current smoking, atopy, moisture and pets at home. Adjustment was also performed for strain in the analysis of environmental perception. The analyses were also stratified by gender. The most prevalent complaints in the pooled study group "stuffy air" and "dry air", and the complaints about too low and too high temperature, were dichotomised in yes weekly and yes sometimes, versus not at all, and separately analysed in multiple logistic regressions adjusted for age and gender, studying the relation to exposure variables.

For the comparisons of the impact on symptoms of subjectively and objectively assessed physical and psychosocial environment, linear regression analysis was performed using scores as dependent variables, adjusting for age, gender, scientific position or not, atopy, current smoking, moisture and pets at home. Unadjusted and adjusted betas (partial regression coefficient) were calculated.

5. Results

5.1 Symptoms, complaints, ocular and nasal physiological signs in university staff in relation to indoor environment - temperature and gender interactions

All environmental exposures were within prevailing requirements and recommended standards. Exposure differences between problem buildings and controls were small, variations between rooms were greater. Workers in the problem buildings had more general and dermal symptoms, but not more objective signs than the others. All symptoms were more prevalent in the pooled study population than in external Swedish references and the study population had twofold higher levels of MPO and Lysozyme NAL-biomarkers compared to Swedish white collar workers.

NIBUT and SBUT were shorter at lower night temperature. Adjusted day NIBUT and SBUT increased at higher night air temperatures with B; 95% CI: 0.6; 0.04-1.2 and 1.3; -0.02-2.5, respectively. Higher relative humidity at mean day air temperature $< 22.1^{o}$C was associated with increased adjusted NIBUT and SBUT; B; 95% CI: 0.16; 0.03-0.29 and 0.37; -0.01-0.75, respectively.

Perceiving temperature too low was associated with increased difference in air temperature between day and night, between 06 and 10 o'clock a.m., high temperature at 10 o'clock a.m., and increasing air mean velocity in the range lower than 12 cm/second. Reduced tear film stability was associated with lower mean night air temperature and lower air temperature at 06 a.m., but not with air temperature at 10 a.m. and all these associations were stronger among those exposed for upper median of mean day air temperature.

Lower RH% in the range of 15-30% was associated with perceiving "dry air" in the whole group, and higher RH% with increasing tear film stability among those exposed to day air temperature $< 22.1^{o}$C. Air velocity was positively associated with complaints on stuffy air. Perception of dry air was also associated with higher air velocity up to 12 cm/second which was the highest mean air velocity assessed on the working places in the buildings and well below the prevailing winter requirements on air velocity in non-industrial buildings.

5.2 Pet keeping and dampness in the dwelling: associations with airway infections, symptoms, and physiological signs from the ocular and nasal mucosa.

Totally 21%, 21%, 18%, 11%, 27% had weekly ocular, nasal, facial dermal symptoms, headache and tiredness, respectively. One third of the staff lived in apartments in multi-family buildings, one fourth in detached houses and another fourth in single-family houses. Half of the houses were made of bricks and 43% were wooden buildings. Wall-to-wall carpets were very rare (3%), one fifth had a cat or dog at home, 15% reported signs of dampness in the dwelling, and 54% reported any airway infection the last month. Multiple linear or logistic regressions were applied, controlling for age gender, smoking, exposure at work and environmental factors.

Any respiratory infections last month was three times more common in subjects living in a damp building (OR=3.14: p=0.04), but there was no association between dampness and any type of weekly symptoms Building dampness was also associated with increased NAL-lysozyme (p=0.02).

Pet keeping was associated with difficulties to concentrate (OR=5.10; p= 0.001), heavy headedness (OR=4.35; p=0.004), four more days with tiredness per month (p=0.04), and less airway infections (OR=0.32; p=0.02). There were no significant association between pet-keeping and depression the last month.

There were no significant associations between type of dwelling (apartment v.v. other type of building) or type of material used in the wall construction (wood/vs. brick house) and respiratory infection, or any symptoms or physiological signs.

5.3 Gender and the physical and psychosocial working environments are related to indoor air symptoms.

The study showed an association between symptoms and experienced mental strain (P=0.02) in the work environment among university staff. Also the physical work environment was related to these symptoms (P=0.01), both for perceived physical environment and objective assessments such as air velocity and RH. Women reported more often health symptoms than men and complained more on physical but not psychosocial factors. Women had more symptoms and complaints than men although men's symptoms and complaints were stronger associated than women's to strain, air velocity and relative humidity. Men's but not women's complaints about stuffy or dry air were significantly associated with lower RH. Lower relative humidity in the range of 15-35% was associated with perception of too low temperature among both genders.

5.4 Atopy, symptoms and indoor environmental perceptions, tear film stability, nasal patency and lavage biomarkers in university staff

Data on Phadiatop, total IgE, NIBUT, SBUT, nasal patency and nasal lavage biomarkers were obtained from 168, 164, 148, 173, 168, and 166 subjects, respectively. Six nasal patency assessments were excluded due to technical reasons. Mean age was 43 years (SD=13), men were older than women, more women used contact lenses. SBUT was not different among contact lenses users compared with the others. In total, 55% had allergy in the family, 37% had a positive Phadiatop, 20 % had total IgE ≥ 100 kU/L, 26% had ever had hay fever, 20% had ever had asthma, 41% had ever had eczema, 28% were current smokers and 15% used contact lenses.

In total, 57% reported ocular, 65% nasal and 50 % laryngeal symptoms and 41 % reported cough weekly or sometimes. 52 % reported complaints on environmental perceptions about “dry air”, 63 % about “stuffy air”, 32 % about “temperature too high” and 43% about “temperature too low” weekly or sometimes. Women reported more complaints on perceived indoor environment than men.

21% had weekly ocular, 21% nasal, and 17% laryngeal symptoms. Women had more complaints on environmental perceptions, shorter BUT and less nasal patency. Neither atopy (Phadiatop), Total IgE or allergy in the family, but asthma and hay fever was associated with mucosal symptoms or perceptions. Subjects with positive Phadiatop had higher levels of all NAL-biomarkers. Those with ocular symptoms had shorter NIBUT and SBUT. Nasal symptoms were related to respiratory infections, laryngeal symptoms to NAL-lysozyme. Perceiving dry air was associated with lower BUT and nasal volume difference before and after decongestion. Older subjects had greater nasal patency, and less atopy. All NAL-biomarkers were positively correlated. Higher lysozyme level was associated with less nasal patency and greater nasal decongestion.

6. Discussion

6.1 Methodological discussion

6.1.1 Design

This study has a cross-sectional design. Lack of longitudinal observations of the population and the exposure strongly limits the possibility to draw conclusions on causal relationships. However, this design made a detailed study of the workers possible and also to observe immediate and transient physiological changes in about the same time period as the independent exposure assessments were performed.

6.1.2 Validity, internal

Selection bias
The study population was all employees in four buildings, of which two were problem buildings and two were control buildings. Selection bias can occur particularly in cross-sectional studies due to selection mechanisms of participants in to the population or out of the population previous to the study.

We do not know any selection mechanism that would recruit different populations into the two University populations. The buildings were similar in age, construction, technical installations and modernization methods. Moreover, both “problem” and “control” populations were very similar in terms of organizational position, age, gender and atopy. However, some individuals might have moved out of the “problem buildings” due to health or comfort problems before our study started. We do not know the size of this “healthy worker problem” but such effects will tend to reduce the associations found between exposure and effects and the differences in health between the workers in the two types of buildings. However, it will not impair the validity of the associations found.

The response rates were high (86.1%) and relatively similar in both the problem and control populations (84% and 88% respectively). Low response rates and differences in response rates between “problem” and “control” buildings may introduce differences in selection effects among responders and non-responders in the two populations. We have not sufficient data available to characterize and control whether the non-responders differs from the others. However, such differences can only have limited impact due to the high response rates.

Information bias

An advantage with our study is that we have both questionnaire data as well as objective measurements of both exposure and effects. One type of information bias is recall bias due to an awareness of exposure and possible effects or symptoms caused by such exposure. In cross-sectional studies, misclassification of exposure and health status may be related. For instance some subjects may tend to over report both exposure and effect. Measurement errors in two variables are dependent when the degree of error in one of them correlates with the degree of error in the other (Kristensen 2005). When dependent error affects measured exposure and measured outcome, the estimated association between the two is likely to be falsely inflated. Such information bias is not uncommon in cross-sectional studies providing data on both variables from questionnaires. The major precaution in order to eliminate bias from dependent error is to break the bond between information on exposure and outcome by gathering data from separate sources like we have done in the present study.

Both participants and researchers knew whether they were situated in “problem” or “control” buildings when the study was performed. The need of performing the study at the work place made it impossible to blind the participants and the researchers. However, several markers both for exposure and effects were assessed by objective methods. Assessments of BUT and nasal patency might, to a limited extent, have been unconsciously influenced by the researchers expectancy of outcome due to the lack of blinding of building and participants in terms of belonging to problem or control groups. However, the expected results in terms of differences between problem and control buildings were not found. The associations found to exposure indicators are explainable in terms of known mechanisms, but they were not expected. Hence, it is not probable that the validity of the outcome has been impaired by information bias among the researchers.

The laboratories assessing the blood samples and markers in nasal lavage were not aware of which groups the participants belonged to. Only one laboratory was used for analysis of the blood samples and the analyses were performed for a short period. Another laboratory was used for the nasal lavage assessments and all samples were delivered frozen to the laboratory at the same time. Hence, the risk of information bias or any internal systematic source of error from the laboratories should be minimal.

Confounding (age, gender, education etc)

Confounding can be thought of as a mixing of effects (Rothman 2002). A confounding factor, therefore, must have an effect and must be imbalanced between the exposure groups to be compared. This implies that a confounding factor must have two associations:

- It must be associated with the disease, either as a cause or as a proxy for a cause, but not as an effect of the disease.
- It must be associated with the exposure

A third property is that it must not be an effect of the exposure.

We tried to avoid confounding by selecting control populations as similar as possible to those in the problem buildings and within very similar buildings. The problem buildings had a higher proportion of females. There were no significant differences between the groups in terms of proportion of age, professional or administrative positions, education level, years at work at the University, working hours, atopy measured as a positive Phadiatop, or private housing conditions. Furthermore, all linear and logistic regressions were controlled for gender and age. It is thus not probable that the validity of the study has been affected by any known confounder.

Statistical analysis

When performing a number of statistical tests, there is a risk for mass significance. In our studies a high number of statistical tests were performed, but we found mostly similar results using different types of statistical methods. Furthermore, our main results were relatively stable through confounder adjustments and they were also biologically and physiologically reasonable.

Power calculation, concerning symptoms, showed a statistical power of 99-100% for all general symptoms, for two dermal and one mucosal symptom (hoarse, dry throat). However, power was 26% for one mucosal symptom (cough) and 83% and 91% for two other mucosal symptoms. The power for the dermal symptom “dry or flushed skin” was 39%.

The statistical power for the physiological tests (lysozyme and nasal patency) performed with the actual number of persons participating in the two groups of this study varies and is as low as 30-50 with significance level of 0.05, but increases to 60-70 with significance level of 0.10. This might explain why no difference was found between the groups for these tests. However, the power for tear film and the blood tests were higher.

6.1.3 Validity, external

Buildings

The results are valid for employees in offices that have their work place in old apartment brick buildings erected in “Bergen cavity walls” or similar constructions modernised, refurbished and equipped with mechanical supply and exhaust ventilation in order to serve as offices, lecture rooms or similar use.

Particularly Bergen, and the Jugend town of Aalesund, has a huge building stock of corresponding buildings erected in “Bergen cavity walls” (Olsen & Monsen 2003). Some of the same technical and physical properties and possible risks connected to modernization are probably similar in this building stock (Grytli 2004). Our findings may also be applicable to other modernized brick apartment town buildings in Norway erected in the time period 1860-1940. “Trondheim cavity walls” were used in the same time period as “Bergen cavity walls” but are slightly different in construction (Figure 21). Brick buildings from the same time period in other Norwegian towns, especially Oslo, are often erected in compact brick walls, but have much of the same risks connected to modernizations with insulation inside and change of air pressure conditions in the buildings (Geving & Thue 2002, Grytli 2004). However, these issues are best covered by scientists mastering the complex topics of building physics, material and building research. This also emphasizes the need of multi- and interdisciplinary cooperation in this research area. It is important to puzzle out how these buildings can be modernized and conserved in order to provide good indoor environment by acceptable use of energy and at the same time preserve as far as possible valuable and beautiful architectural heritage and built environment.

Population

The population of University employees was relatively similar in both problem and control buildings confirming that we achieved the aim of recruiting a suitable control population with no known increase of complaints about indoor environment.

The study population including both “problem” and control groups differed significantly from an external Swedish reference population in “healthy buildings” with a higher prevalence of symptoms (Andersson 1998) This reference group of 319 persons has been used in previous studies to assess effects of indoor environment, and have been compared to other office workers with no obvious difference (Lindgren et al 2002). The differences might be due to the higher prevalence of atopy in the more educated part of the population (Lewis & Britton 1998).

Another possibility might be a special “culture” in our population, where it is normal to complain about health and environmental issues. However, the psychosocial factors; strain and social support were similar in our population and in the general working population of Hordaland (Sanne et al 2005 b). On the other hand, such “culture” might not be measured by this instrument.

But these results may also be compatible with a situation where both problem and control buildings have inferior indoor environments. A local university population collected from many different “healthy” University buildings without known problems would have been preferred, but was not available.

It is difficult to evaluate whether the findings from this study will be the same in other occupational groups. It might be the case; both for university employees and other office workers, but additional studies are needed to confirm our findings.

6.2 Main discussion

6.3 Associations between subjective symptoms, objective signs, biological effects, and perceived and measured indoor environment among employees in University buildings (Paper 1).

6.3.1 Comparing problem buildings with control buildings

The problem buildings had more general symptoms and perceived more “stuffy” and “dry” air” but had not any differences in physiological signs compared to the control buildings. The problem buildings had on average 0.6 ^{o}C higher daytime temperature, 0.4 ^{o}C greater day-night time temperature difference, 2% higher RH, 65 ppm higher CO2, and 6 µg/m3 higher PM_{10}. These differences were significant, but the magnitudes of the differences were small, and the variations between rooms were greater. Whether such small differences between the buildings have practical impact is questionable, we cannot conclude in this respect. However, it would not be an unexpected finding if the differences between rooms might seem to have more impact on effects of exposure than the differences between problem and control buildings.

The problem buildings had a history of suspected indoor environmental problems, including suspected dampness problems. Symptoms and signs of hypersensitivity and hyperreactive mucosa have been reported to persist for several years after renovation of damp buildings (Rudblad et al 2004). This might be an explanation of the difference in symptoms found in our study. However, our differences were found mostly for general symptoms, not mucosal, although this may also be due to lower power for mucosal symptoms. We did not find any clear indication of remaining indoor environmental problems in occupied areas of the problem buildings when our study started and no aberration in air microbial measurements from normal flora in any occupied areas. However, it is important to be aware of the limitations of air measurements of microbial exposures in damp buildings (Wieslander et al 2007). We have not analysed biological components in settled dust.

Both localised and general lighting as well as noise were well within acceptable conditions (Paper 1). Perceiving noise and unpleasant illumination were significantly lower in the study group compared to the Swedish referents. Hence, it is little reason to consider noise and illumination as significant causes of indoor symptoms, signs or perceptions in the study population.

Ventilation rate per person was good with a mean CO_2 concentration of 497 ppm. 500 ppm corresponds to a ventilation rate of about 35 L/s/person which is not more than about 115-120 ppm higher than mean outdoor concentration (Paper 1). This is well above the highest set requirements or recommended standards for clean outside air ventilation rate per person in non-industrial indoor environments. Thus, low ventilation rate can in practice be excluded as a possible causative factor for indoor symptoms, signs or perceptions.

Experts in building physics from the Norwegian Building Research Institute strongly recommended further characterization of the buildings, including thermo photography and air pressure assessments. Analyses of sedimented dust from the buildings might also have provided information about possible exposure to bioactive abiotic components. Such analyses were not performed.

Hence, we can not exclude that unknown conditions in terms of building physics and abiotic, but biologically active dust might have influence on the indoor environments of the buildings.

6.3.2 Comparing the pooled study population with external referents

The study population had higher prevalence of symptoms than an external Swedish reference population in “healthy buildings” (Andersson 1998). When comparing with the Swedish referents, ORs for symptoms in our population ranged from 2.2-8.1. However, “stuffy air” and “unpleasant odour” were the only perceptions that were significantly more prevalent in the study population with OR 2.1 and 2.0, respectively. Perceiving noise and unpleasant illumination were significantly less in our study population compared with the Swedish referents.

Interestingly, when comparing our data on NAL-biomarkers with mean levels in 411 Swedish white collar workers, the university staff from Bergen had twofold higher levels of MPO and Lysozyme (Wålinder et al 2000). Also, 37.2% of the participants were Phadiatop positive, higher than the prevalence of 25.2% of Phadiatop positive subjects in a population of 500 blood donors in the same region in Norway (Johansson et al 2005). This might be due to the higher prevalence of atopy in this population as shown for other high educated populations (Lewis & Britton 1998). Also general differences in climate or possible private building conditions between the humid west coast of Norway and the drier Swedish areas might be an explanation. However, this might also indicate that both “problem” and “control” buildings have some unknown indoor environmental or other problems that we have not been able to identify.

Furthermore, tear film stability (NIBUT median 8.3 seconds, SBUT: median 15.2 seconds) was lower than expected considering values reported from other studies using the same methods. Reference values among normal individuals have not been established in Norway. It was originally reported by Mengher 1985 as means of 48 seconds on right and 35 seconds on left eye. Guillon et al 1997 reported that NIBUT can range in time from very poor (<10 seconds) to very good (>30 seconds). Median

BUT was 11.9 seconds among 182 non-allergic, non-smoking Danes using the fluorescein method (Kjærgaard et al 2004). NIBUT was 16 seconds before exposure to moisture damaged office environments an 8 seconds after exposure (Wieslander et al 2007). Employees in 36 nursing departments in geriatric hospitals in the municipality of Trondheim had similar results as in our population (median 8.0 seconds) (Smebold et al 2001). Adjusted analyses of the results showed association between BUT and dust settlement rate and urban vicinity of work place. They were exposed to low RH % (17-26%) and high air temperatures (23.0-23.7^{o}C). The high percentage of females might altogether partly explain the low tear film stability. Also results from air crew showed similar or even lower results being exposed to RH% in the range of 10-12% and mean air temperatures of 23 ^{o}C but showed improvement with 2-3 seconds by a slight increase of RH% of 3-10% (Norbäck et al 2006).

BUT assessed at the work place among 814 German office workers in 14 "non-problem buildings", by means of slit lamp and fluorescein staining, was less than 10 seconds among 24 % (Brasche et al 2005). 71 % of our study population had NIBUT less than 10 seconds although NIBUT is believed to have less irritative effect on the eyes than the fluorescein method.

Median SBUT was 17 seconds among Swedish hospital employees, 12 seconds among those who were exposed to visible building dampness and 25 seconds when not exposed (Wieslander et al 1999 a) .

We found no associations between atopy (Phadiatop positive) and reduced BUT. However, SBUT, not PBUT, was higher among those with atopy when adjusting for age, gender, current smoking and number of days with respiratory infections (Paper IV). BUT among women was lower than among men with NIBUT; median 8.3 seconds, men 9.0 seconds, women 8.0 seconds and SBUT; median 15.2 seconds, men 17.4 second and women 12.1 seconds.

Whether our findings of comparably low BUT in the study population are due to indoor environmental exposures, other population characteristics or environmental aspect can probably best be assessed by recruiting other representative control groups in order to compare, e.g. with employees in old wooden University or other buildings in Bergen or other relevant sites.

6.4 Associations between measured indoor parameters, environmental perceptions and physiological signs from the ocular and nasal mucosa (Paper 1).

6.4.1 Relative humidity (RH) and air temperature

We found lower perception of dry air and improved self reported tear film stability (SBUT) at higher relative air humidity (RH) in the range of 15-30%, which is in agreement with a previous experimental air humidification study in cabin airline crew, exposed to very low relative humidity at 10-15% RH (Norbäck et al 2006). In a previous experimental air humidification study at higher RH (30-35%), no effects on tear film stability was observed (Norbäck et al 2000 b). Among hospital employees, air humidification which increased RH% to 40-45% in the heating season improved as compared with a control group with no humidification and RH% in the range of 25-35% (Nordström et al 1994). A recent review concludes that current data indicate that RH about 40% is better for the eyes and upper airways than levels below 30% (Wolkoff & Kjærgaard 2007). High RH might protect the pre-corneal tear film against desiccation and sensory irritating pollutants which is particularly relevant for intensive computer work and high air temperatures (Wolkoff et al 2006).

Low RH% was associated with a sensation of temperature being too low, in accordance with field experiments in Finland (Palonen et al 1993).

Indoor day air temperature was relatively high for the winter heating season with mean 22.2 ^{o}C, median 22.1 ^{o}C. The higher temperatures were seen in the small rooms as expected due to generally more heat sources per net area square meter and room ventilation rate as total added effect from local heater, lighting, technical equipment and humans. High room temperature is well known to cause several symptoms (Skov et al. 1990 b, Jaakkola et al 1991, Mendell 1993). Occupants' perceived acceptability of air quality has been shown to decrease as temperature and humidity increase in the range between 18^{o}C, 30% RH and 28 ^{o}C, 70% RH (Fang et al 2004). One cross/over study in public office buildings reported that a 1^{o}C decrease in temperature (within 22-26 ^{o}C) correlated with 19% decrease of the mean value in severity of eye complains (dry, itching, irritated) (Mendell et al 2002). A finding from the Danish Town Hall study was that temperature rise during work day was associated with general symptoms with OR of 1.75 per 1 ^{o}C (95% CI: 1.10-2.77) (Skov et al 1990 b). A rise in temperature of 3 ^{o}C in the office during a work day increased the risk of general symptoms among the office workers by three (OR=3.06). However, in our study, we found no significant association between mean daytime room temperature, symptoms, perceptions or any physiological signs in the adjusted results.

6.4.2 Air temperature differences

We found that a lower night time temperature, and a larger difference between mean daytime and mean night time temperature, was associated with impaired tear film stability in the adjusted analyses. Also anterior nasal patency, MCA1 and VOL1, were associated with the difference between mean day and night temperatures the crude, but not in the adjusted analyses. The effects on tear film were strongest for those with the highest mean day air temperatures. To our knowledge, this has not been previously reported.

Complaining on too low temperature was associated with increasing air temperature differences between night and day, between air temperatures 06 and 10 o'clock and to air temperature at 10 'clock. It is not probable that high air temperature, as such, is a cause for perceiving temperature as low, but rather that perceiving temperature as low, entails actions in order to increase temperature by using local stoves or other means. The operative temperature might have been unacceptably low in the morning due to reduced radiant temperature from cooled indoor surfaces. We do not know this for certain, but efforts to compensate this by increasing air temperature might have added to the enthalpy (energy content) of the air and decreased air quality (Fang et al 2004).

Furthermore, if electric convector or fan heaters have been used, this might in addition have contributed to formation of indoor ultrafine particles (UFPs) (Weichenthal et al 2007). UFP has increased ability to cause oxidative stress and inflammation. Electric heating has traditionally been considered as "clean energy". Less attention had been paid to electric stoves as potential IAP sources although electric heating has been associated with increased SBS symptoms (Engvall et al 2003) and asthma in children (Infante-Rivard 1993). 26.7% of the asthma cases among children 0-10 years and 16.7% of the control group had electric baseboard heat in State of New York (Daigler 1991). Although not mentioned by the authors, this difference is significant (P=0.02). In Connecticut and Western Massachusetts, infants at high risk of developing asthma living in homes that were heated with an electrical baseboard had higher rates of wheeze than those in homes with other system (p<0,01) (Gent 2002). This tendency was however reduced when adjusting for other factors, with RR for wheeze 1.30 (CI: 0.93-1.82).

6.4.3 Air velocity

Air velocity was significantly associated to perceiving "dry air" and "too low temperature", even though all air velocities were well below the prevailing (winter) recommendations of max 13-15 cm/s according to ISO EN 7730 and newer recommendations (Olesen 2004). Regulation of indoor air velocity is set in order to avoid draught and we found no associations between perceiving draught and measured air velocity. However, the findings might indicate that even lower maximal indoor air velocity requirements should be considered in the heating season in order to improve both thermal climate and air quality. Lower air velocity might allow for providing lower air temperature without entailing perception of “too low temperature”. Lower air temperature also increases RH% which might have beneficial effects on tear film stability and the perception of “dry air”.

Air velocity was also positively associated with perception of stuffy air. We cannot explain this finding, although one can speculate whether more sedimented dust might be airborne with increasing air velocity. As a matter of fact; air velocity was correlated with PM_{10}, Pearson correlation: 0.352, $p<0.0005$, Kendall’s tau 0.329, $p<0.0005$ (not previously reported). However, PM_{10} was not associated with “stuffy air”.

6.4.4 Ventilation rate

Ventilation rate per person was high with a mean CO_2 concentration of 497 ppm. 500 ppm corresponds to a ventilation rate of about 35 L/s/person according to CEN technical report CR1752 (CEN 1998), cited from Olesen 2004. This was not more than about 115-120 ppm higher than mean outdoor concentration in the area which was assessed in the study period as about 385 ppm (range 375-395 ppm). A ventilation rate of 35 L/s/person is well above the highest set requirements or recommended standards for clean outside air ventilation rate per person in non-industrial indoor environments. 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/person or CO_2 lower than about 600 ppm in non-industrial indoor environments (Wargocki et al 2002, Seppänen & Fisk 2004). Higher ventilation rates might reduce RH to a level that can entail other problems (Norbäck et al 2006). Thus, it is an interesting question whether this ventilation rate might be too high.

Experimental 7-h exposures in a simulated aircraft cabin tested four conditions of increased RH% from 7% to 28%, by lowering fresh outside supply from 9.4 L/s to 1.4 L/s per person. This corresponded to an increase of CO2 from 900 ppm to 2500 ppm (Strøm-Tejsen P et al 2007). However symptoms increased rather than improved, indicating that increased RH% could not compensate for the reduction of ventilation.

In field studies on intercontinental aircrafts, slightly increase of RH% by humidification, without reducing ventilation, reduced sensation of dryness and improved sensation of cabin air quality (Lindgren et al 2007). Increasing mechanical ventilation in 7 Swedish classrooms reduced mean CO2-level of 1050 ppm to 780 ppm entailed reporting of less asthma symptoms among the pupils (Smedje & Norbäck 2000).

This might indicate that reducing ventilation rates below about 10 L/s reduces IAQ is too much in order to benefit from increasing RH%. On the other side, considering these findings together with ours, it is possible that some reduction of ventilation from 35 L/s to i.e. 20 - 25 L/s per person could have improved the conditions in our study buildings.

6.5 Associations between factors in the home environment, airway infections, and symptoms compatible with the sick building syndrome (SBS). (Paper 2).

6.5.1 Dampness at home

Dampness at home was reported by 15%, which is a lower prevalence than in many western countries (Bornehag et al. 2001), but similar as in other population based questionnaire studies from Nordic countries (Engvall et al. 2001, Gunbjörnsdottir et al. 2006, Norbäck and Edling 1991, Skorge et al. 2005). Prevalence of current home dampness in Trondheim in 2000 was 21 % and 50% of the responders reported that their dwelling had one or more sign of dampness ever (Jon Jenssen, personal information). Dampness during the last two years confirmed by inspection was observed in 27% of cases and 14% of controls in a children asthma case control study in Oslo (Nafstad et al 1998).

Dampness at home in our population was associated with decreased nasal patency, increased secretion of lysozyme from the nasal mucosa, and increased risk for airway infection. Lysozyme is a secretory and inflammatory enzyme with an antimicrobial function, mainly directed against gram-positive bacteria but also towards other microorganisms (Ibrahim et al 2002). An increased secretion of lysozyme in nasal lavage fluid (NAL) has been reported after experimental exposure to rhinovirus (Yuta et al 1998) and influenza virus (Doyle et al 1996). Moreover, an increase of NAL-lysozyme has been reported in hospitals, schools and office buildings with building dampness (Wieslander et al 1999a, b, Wålinder et al 2001a, b), and one study has found an association between NAL-lysozyme and airborne concentrations of fungi in schools (Norbäck et al 2000 b). The association between building dampness, indoor moulds and airway infections was well known in the 19th century (Holst 1894), but modern epidemiological data on this topic is limited. Two studies reported an increased prevalence of respiratory infections in adults living in damp dwellings in Finland, with OR=1.3 and OR=1.5, respectively (Pirhonen et al 1996, Kilpeläinen et al 2001). One study in children reported an association between lower respiratory infections first year of life, and measured fungal concentrations in the home environment (Stark et al 2003). Moreover, an association between respiratory infections in school children and mould problems in the school have been reported (Taskinen et al 1999), and the sum of respiratory infection periods in teachers decreased after remediation of a mould damaged school (Patovirta et al 2004). It has also been proposed that a more efficient spreading of respiratory infection viruses in damp indoor climate can be a “missing link” between allergen exposure and onset of asthma and allergic disease (Hersoug 2005).

6.5.2 Pets at home

20% had a cat or a dog at home, similar as the prevalence of cat keeping (15%) and dog keeping (13%) in the general adult population in Bergen, and somewhat lower than the prevalence of cat (22%) and dog keeping (19%) in Europe (Svanes et al 2003). Subjects with a pet at home had more often CNS-symptoms such as heavy-headedness and difficulties concentrating, more often headache, and more severe tiredness. On the contrary, they had less often respiratory infections, and the infections were reported to be less severe. It is not possible to conclude concerning cause and effects in a cross sectional study. It is possible that the propensity of having non-specific symptoms may cause increased tendency to keep pets as well as the opposite. Health aspects of pet keeping have mainly been focused on allergen exposure in relation to asthma and allergy, and we found few studies on pet keeping and other types of symptoms. In one population based study in mid-Sweden, no association was found between pet keeping and any type of SBS-symptoms (Norbäck and Edling 1991). We can only speculate on the mechanisms behind our findings. It could be possible that the extra work related to pet keeping can lead to stress at home. Another explanation could be "reverse causality" i.e. that subjects with more CNS-symptoms choose to have a pet, but we found no difference in reports on depression between pet keepers and non-pet keepers. In addition, both dog and cat keeping has been associated with increased levels of endotoxin in house dust (Heinrich et al 2001), with possible microbial stimulation. One experimental study could demonstrate that pre-exposure of epithelial cells to bacterial lipopolysaccharides inhibited the level of cellular infection with respiratory syncytical virus (Foster et al 2003). Moreover, dog keeping may also be related to a more active life with respect to outdoor exercise walking the dog and give more social contact, which could be beneficial for the airways as well as for general human health (Larsen and Lingaas 1997). On the contrary, pet ownership was associated with poor rather than good perceived health among a randomly selected population aged 20-54 years in Finland (Koivusuilta & Ojanlatva 2006). BMI was the risk factor most strongly associated with pet ownership. Pet ownership did not either confer any health benefits among 60-64 years aged Australians (Parslov et al 2005). Instead, those with pets had poorer mental and physical health and used more pain relief medication. More research is needed in terms of longitudinal or intervention studies in order to assess mechanisms or causality behind these patterns.

6.6 Associations and gender differences in self-reported symptoms, psychosocial, subjective and objective physical environment (paper 3).

6.6.1 Gender

Gender was a major factor associated with various physiological signs (Paper 2 and 3). Females had shorter BUT as assessed by both methods and they had smaller anterior and posterior nasal dimensions, and greater nasal decongestion by adrenergic spray. Shorter BUT in females has been observed in other studies (Wolkoff et al 2003, Wolkoff et al 2006, Brasche et al 2005). Smaller nasal volumes among women, both anterior and posterior have previously been reported in a study in 411 white collar workers from Sweden (Wålinder et al 2000).

Women had the highest symptom prevalence, in accordance with several studies (Paper 3) (Runeson & Norbäck 2005, Brasche et al 2001). Men and women reported psychosocial work factors similarly but perceived physical factors differently. This might indicate that women are more sensitive to environmental factors, they tend to perceive their health problems more intensely and to report more than men (Verbrugge 1985). This might be due to differences in hormonal levels, giving different physiological thresholds for observing symptoms (Ihlebaek et al 2002). For instance, among women, progesterone and estradiol have been postulated to have importance for asthmatic symptoms (Zimmermann et al 2000). Also, it might be caused by a difference in reporting tradition between the genders (Mendoza-Sassi & Beria 2007). It is suggested that women have a more health-seeking behaviour for perceiving and reporting health problems than men.

On the other hand, the differences found may also be due to an actual gender difference in the physical work environment, as supported by our data. In our population, the women had different types of work than men, as more men had scientific positions. This might mean that the women spent more of their work time in their offices, as the scientists at the university often teach and participate in activities outside the office buildings. Unfortunately, this was not registered in our study. Stenberg & Wall (1995) indicated that gender differences in working conditions, entailing different hierarchical positions in the office, might influence the physical indoor environments that affect the symptoms. We suggest that future studies of office workers register the time the participants spent in the offices to be able to evaluate such differences better.

Associations between relative humidity, air velocity and symptoms as well as complaints were more pronounced among men than among women, although women had both more SBS symptoms and complaints than men. Few studies have stratified for gender in the analyses of associations between exposure and effects. Significant relations between a high number of symptoms and exposure to environmental parameters including temperature, carbon monoxide, noise, aldehydes, endotoxin, and particulates were found for males in US commercial office buildings (Reynolds et al 2001). Relative humidity and endotoxin were the only parameters associated to symptoms among females, endotoxin being the only parameter associated to symptoms in both genders. Contrary to our findings, they found a strong association between increased number of symptoms and scores on psychosocial scales for women, but not for men. Our results might give support to the hypothesis that differences in illness perception and reporting bias may contribute to women's tendency to perceive and report symptoms more freely than men and for men to underreport symptoms. Rather than adjusting for gender, in future studies, the differential influence of gender on exposure, symptoms and perceptions in indoor environments should be a specific and separate target of investigation.

6.6.2 Relationship with psychosocial and indoor climate factors

In our study, exposures to factors in both the psychosocial and physical work environments seem to be important for the symptoms to occur (Paper 3). This may fit with a theoretical model postulating that occupational stress (or strain) may function as a modifying factor between the environmental factors and symptoms, increasing the individual's sensitivity to factors in the physical work environment (Baker 1989, Rollins & Swift 1998). The mental stress can also result from exposure to factors in the physical work environment causing anxiety and thus enhancing the symptoms. As our study was cross-sectional, we cannot conclude on causality, but the study indicates that some aspects of this theory might be present, which is supported by findings from a previous study in Finland (Lahtinen et al 2004). Other models also include the influence of personality factors in the model of development of indoor air symptoms (Crawford & Bolas 1996). Several personality factors have been shown to be related to high occurrence of indoor air symptoms (Runeson et al 2004, Runeson & Norbäck 2005). However, we had no information about the personality of workers in our study, and could not evaluate this aspect.

The relationship between symptoms and strain was mainly found for general health symptoms and was not as clear for skin and mucosal symptoms. Social support did not seem to affect any of the associations studied.

A few previous studies have examined indoor air symptoms, psychosocial factors and physical environmental factors at the same time. Attention has been given to psychosocial factors and indoor air problems, but this has generally been related to the sick-building syndrome (Skov et al 1989, Runeson & Norbäck 2005, Nordström et al 1995, Ooi & Goh 1997). A study of workers in buildings in Finland with three types of indoor environmental problems examined aspects of the psychosocial work environment by interview and by questionnaire (Lahtinen et al 2002). This study concluded that increased mental strain and stress at work influenced the perceived symptoms, supporting our findings. A study in Sweden (Runeson & Norbäck 2005) supports the hypothesis that psychosocial work factors expressed such as work satisfaction, work stress and work cooperation are important in studying symptoms related to indoor environment problems. Results from the Whitehall II study (Marmot et al 2006) showed that the physical environment appeared to be less important than the psychosocial work environment in explaining differences in symptom prevalence.

6.7 Associations between atopy, symptoms and indoor environmental perceptions, tear film stability, nasal patency and lavage biomarkers (art 4).

6.7.1 Associations between biomarkers, symptoms and perceived environments

Tear film break up time (BUT), nasal patency, nasal volume difference before and after decongestion and NAL-lysozyme were predictors for ocular, nasal, laryngeal symptoms and environmental perceptions. Perceiving “dry air”, having ocular symptoms and lower BUT were strongly associated. The prevalence of ocular and nasal symptoms was similar to other studies in office and hospital workers using the same symptom questionnaire (Wieslander et al 1999 a, Wieslander et al 2000). We found that ocular symptoms were associated with reduced tear film stability, measured by two different methods. This is in agreement with previous studies (Franck 1986, Wieslander et al 2000, Brasche et al 2001). In contrast, nasal symptoms were not significantly associated with physiological signs from the nasal mucosa, neither nasal patency nor NAL-biomarkers. Poor correlation has previously been reported between measured nasal patency and nasal obstructive symptoms (Roithmann et al 1994, Kim et al 1998). The association between laryngeal symptoms and increased NAL-lysozyme is interesting and should be followed up in future studies.

6.7.2 Associations between atopy markers, symptoms and perceived environments

Our findings does not support that atopy defined by Phadiatop, total IgE, hereditary allergy or previous eczema is predictive for airway symptoms or perceived air quality in terms of “dry” or “stuffy” air in non-industrial indoor occupational environments. However, current or previous asthma was associated with symptoms and current or previous hay fever was associated with perceiving “dry air” suggesting that current hyperreactive and hypersensitive airways might be a more important predictor for increased symptoms and perceptions than Phadiatop, IgE or hereditary allergy. This is consistent with a recent finding in Norway that indoor climate at the workplace was stated as the most frequent provoking factor among employees 18-55 years, who had been on sick leave > 16 days due to asthma in the years 2000-2003 (Leira et al

2006). This might also be consistent with findings of association between SBS and atopy defined as past or present asthma, hay fever or atopic dermatitis (Stenberg et al 1994). Also “atopic manifestations” (any prior history of allergic rhinitis, atopic dermatitis or bronchial asthma) was associated with SBS (Jaakkola et al 1991). Graudenz et al 2002 found building related associations between respiratory symptoms, symptoms of rhinoconjunctivitis and aging ventilation systems, but this was not associated to familiar atopy or previous diagnoses of asthma or rhinitis. Graudenz et al 2006 found that individual with allergic rhinitis had different IAQ perceptions compared with controls and perceived more “dry air” particularly at lower indoor temperatures. Individuals with a history of atopy, defined as a history of asthma, hay fever or eczema in childhood, reported a higher prevalence of Sick Building Syndrome (SBS) symptoms including airway symptoms in the general population (Norbäck and Edling 1991). Like in our study, this association was not found among employees in primary schools (Norbäck et al 1990 b) or among employees in 11 consecutive sick buildings referred for investigation (Norbäck et al 1990 a) although “hyperreactivity” in terms of “easily irritated eyes or respiratory tract during exposure to non-specific irritants (tobacco smoke, exhaust gases, organic solvents)” were associated in both studies. Atopy defined by reporting an allergy to tree or grass pollen or to furry animals, or a history of eczema in childhood was on the other hand associated with SBS among airline crew (Lindgren & Norbäck 2005).

The association between “ever hay fever” and perceiving “dry air” suggest that nasal inflammation increases the sensitivity to irritating effects of indoor air. In particular the symptom “dry eyes” and related ocular-surface effects has been associated to indoor environmental exposure in office building (Wolkoff et al 2006). Increased air temperature has also been shown to worsen eye irritation symptoms which also are of interest in view of the association found between “ever hay fever” and both “dry eyes” and perceiving “temperature too high”.

“Ever eczema” was associated with perceiving “temperature too high”. Skin symptoms may be alleviated by lowering room temperature which increases relative humidity (Reinikainen & Jaakkola 2003). A clear-cut inverse correlation was found between aggravating atopic eczema and increasing air temperature in the Swiss high-mountain area (Vocks et al 2001). This might give some support for avoiding high indoor air temperature in the winter season when the relative humidity is low in order to reduce skin symptoms generally and particularly for person with atopic eczema.

6.7.3 Unexpected findings

The associations between ocular and laryngeal symptoms and increased posterior nasal volume (VOL2) and between complaining about “dry air” and decreased nasal volume difference before and after decongestion were unexpected and are difficult to explain. These findings should be further examined in future studies.

6.7.4 Atopy defined as positive Phadiatop

We found that 37% had atopy assessed as positive Phadiatop, as compared to 25% in a population of 500 consecutive blood donors from the same region in Norway (Johansson et al 2005). This might be due to higher prevalence of atopy in the more educated part of the population (Strachan 1996). Among 126 Phadiatop positive blood donors from the same region, 46.8% were positive to timothy, 50.8% to birch, 21.4% to cat and 11.6% to mite (Johansson et al 2005).

Positive Phadiatop has not previously been used as atopy definition in studies of occupational non-industrial indoor environmental effects. Atopy defined as a positive prick test to any allergen was significant independent risk factor for reporting at least one SBS-related symptom (Björnsson et al 1998) although another study using the same definition did not find any such association (Muzi et al 1998). Phadiatop was strongly associated with all four NAL biomarkers, but not related to nasal patency or nasal decongestion. Moreover, all nasal biomarkers were associated with each others, and a higher level of lysozyme was associated with decreased anterior nasal patency and increased nasal decongestion. Challenge studies with allergens in sensitised subjects have showed effects on nasal patency (Fisher 1997) and increase of ECP (Beppu 1994, Wilson 1998) and albumin (Wilson 1998) in nasal lavage after exposure. Since the present study was performed in late winter, off pollen season, it is unlikely that the strong effect of atopy on nasal biomarkers was caused by pollen allergen exposure in sensitised subjects. This is supported by self-reported hay fever not being associated with physiological ocular or nasal signs. One possible explanation could be allergic reactions to indoor allergens, such as furry pets, house dust mites or moulds. In future studies, a more detailed allergen testing should be performed.

7. Conclusions

1. Employees in the problem buildings had more general and dermal symptoms, but not more objective signs than the control population.

   It might be difficult to identify the exposure behind, and find the reason why, some buildings are defined as “problem buildings”.

   Thermal climate in university buildings may affect both perceptions and physiological signs. Reduced night time air temperature, increased difference in air temperature between day and night and fast changes in air temperature, might impair indoor environment. Air velocity less than 15 cm/s and variations in relative humidity in the range of 15-35% might affect the perception of indoor environment in the heating season.

2. Pet keeping was associated with more CNS-symptoms and less airway infections, but no physiological signs.

   Dampness in the dwelling may have inflammatory effects on the airway mucosa, possibly mediated via increased infection proneness.

3. Psychosocial factors, physical environmental factors and gender differences are related and all factors ought to be considered in the evaluation of an indoor environment.

4. BUT and NAL-lysozyme was associated with ocular, nasal, laryngeal symptoms and indoor environmental perceptions.

   Ever having had asthma and ever having had hay fever were predictors for symptoms and perceived air quality respectively.

   Phadiatop, Total IgE, familiar allergy and ever eczema were not associated to symptoms or perceived environments.

   Age, gender and Phadiatop were main predictors for ocular and nasal biomarkers.

7.1 Implications

Managing indoor environmental problems and performing indoor environmental research are complicated tasks that require sufficient resources in order to perform all the necessary examinations of the occupants and the environmental exposures. A holistic approach seems to be needed in order to get valid results of research when multiple factors interact and to examine both health and exposure parameters. It is important to control for many factors at the same time and understand how they interact.

Modernisation and rebuilding of old buildings might entail unintended, although inherent risks, for unfortunate changes in building physics which might cause condensation, dampness and risks of causing bad indoor environment and health. All the multiple aspects of such processes must be taken care of simultaneously in terms of indoor environment, health, productivity, and energy-conservation as well as architectural and aesthetic values. This also affects huge economical values and possible costs. Cross- and multidisciplinary cooperation is necessary. More research and development is needed in order to puzzle out the principle problems and solutions connected to these challenges.

Thermal climate impact both perceptions and physiological signs. Temperature control is of importance for the health of workers. For instance

- Lower ventilation in the heating season might increase RH%, reduce air velocity and thereby allowing supplying air with lower temperature without entailing unacceptable thermal conditions with perception of “too low temperature”, increase IAQ “freshness”, quality and acceptability and at the same time consume less energy.
- Reducing air velocity even under 15 cm/s in the heating season also improves thermal comfort and allow lower air temperatures which in itself might improve air quality and reduce ventilation needs in the heating season. This will also increase the relative humidity in the range of 15-35% and may improve perceived air quality.
- It might be possible to reduce energy consumption in buildings and at the same time improve indoor environments. One step would be to develop indoor climate requirements based on a season or outdoor climate by applying a multidisciplinary holistic approach in research and development and based on human physiological needs and perceived environment.

Those who have experienced asthma or hay fever seem the most sensitive to the indoor environment in terms of typical indoor environment symptoms and perceptions.

- Testing for Phadiatop or total IgE have little if any association to indoor symptoms or perceived environments in university staff.
- Self reported respiratory “allergy”, “hypersensitivity” or “hyperreactivity” symptoms might be a better predictor of indoor symptoms and complaints on perceived environments in university staff.

The general impact found of home dampness on infection proneness support the view that measures should be taken in order to reduce building dampness in dwellings. This is an important public health issue.

Need to improve methods in order to study impact of gender
Future studies of office workers should register the time the participants spend in the offices in addition to work hours in order to be able to better evaluate and control for differences between hierarchical positions, gender, work hours and time spend at work.

Rather than adjusting for gender, in future studies, the differential influence of gender on exposure, symptoms and perceptions in indoor environments should be a specific and separate target of investigation.

Need to improve methods in order to study impact of home environment
It is of importance to control for home environmental exposure when performing studies of effects of exposure in occupational indoor environment. Future studies of office workers and indoor environment are strongly recommended to adjust for pets and dampness at home.

7.2 Research Needs

In the buildings and population studied
Further characterization of building physics seems needed in all buildings studied in our project, including thermo photography and air pressure assessments in order to discover possible differences between the problem buildings and control buildings.

Characterisation of sedimented dust seems needed in order to assess whether it might have any capability of exerting abiotic biological effects on humans and to test for any possible associations with studied health effects among the employees.

The association found between laryngeal symptoms and increased NAL-lysozyme is interesting and should be followed up in future studies.

It is recommended to recruit other representative control groups in order to compare with the university staff, e.g. from old wooden buildings in Bergen.

National and general research needs
A scientifically based characterisation of Norwegian residential and non-residential buildings is needed in terms of construction, indoor environments, including ventilation, dampness, energy use, heating systems etc. as well as health outcomes among the users. Large groups are required in order to get sufficient statistical power in the studies and provide scientifically valid data.

Establishment of an external Norwegian reference population for symptoms and perceptions in “healthy buildings” corresponding to the Swedish sample (Andersson 1998) is needed in order to compare with the university population as well as to cover national needs in indoor climate assessment and research. Also a reference groups concerning ocular and nasal biomarkers is needed and should be established in terms of NIBUT, SBUT, nasal patency and nasal lavage biomarkers.

Ventilation requirements in non-industrial indoor environments should be tested and evaluated in field studies which might provide foundation for suggesting season or outdoor climate based requirement for indoor ventilation rates in line with principles now applied by other countries. This might provide better indoor environments at lower energy consume. As emphasized by WHO: “Cooperation between those responsible for healthy indoor air and the energy, building and outdoor environment sectors should be encouraged to identify, analyse and propose solutions to existing and potential conflicts between the sectors. Public health and energy policies should be coordinated” (WHO 2000a).

Cross- and multidisciplinary research is needed in order to puzzle out the principle problems, risks and solutions connected to modernisation and rebuilding of old buildings in Norway.

Cross-, multi- and interdisciplinary research is needed in order to puzzle out how brick apartment town buildings in Norway erected in the time period 1860-1940 can be modernized and conserved in order to provide good indoor environment by acceptable use of energy and at the same time preserve as far as possible valuable and beautiful architectural heritage and built environment.

The observed increase of energy consumption in the most modern office buildings in Norway (ENOVA 2006) might be caused by lack of holistic understanding of indoor environments as well as lack of adequate season adapted indoor environmental standards and requirements.

The potential role played by electric heating on health, indoor environment and energy use should be of particular interest in Norway from both a environmental health point of view as well as for future energy politics and energy conservation solutions.

Generally, longitudinal, follow-up and intervention studies are needed in order to better characterise exposures and outcomes as well as identify the most effective means for improving the indoor environmental conditions in terms of cost, energy use and other environmental impacts.

In future studies, a more detailed allergen testing should be performed. More studies are needed in order to assess the association between pet keeping, indoor environment, health and well-being.

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