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# A Sociological Approach to Indoor Environment in Dwellings

*Risk factors for Sick Building Syndrome (SBS) and  
Discomfort*

BY

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#### **Abstract**

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The principal aim was to study selected aspects of indoor environment in dwellings and their association with symptoms compatible with the sick building syndrome (SBS). A validated questionnaire was developed specifically for residential indoor investigations, using sociological principles and test procedures. The questionnaire was mailed to 14,243 multi-family dwellings in Stockholm, selected by stratified random sampling. Females, subjects with a history of atopy, those above 65 y, and those in new buildings reported more symptoms. Subjects owning their own dwelling had less symptoms. A multiple regression model was developed, to identify residential buildings with a higher than expected occurrence of SBS. In total, 28.5% reported at least one sign of building dampness in their home (condensation on windows, humidity in the bathroom, mouldy odour, water leakage). All indicators of dampness were related to symptoms, even when adjusting for demographic data, and other building characteristics (OR=2.9-6.0). Associations between symptoms and other building data was evaluated in older houses, built before 1961. Subjects in older buildings with a mechanical ventilation system had fewer symptoms. Heating by electric radiators, and wood heating was associated with an increase of most types of symptoms (OR=1.2-5.0). Multiple sealing measures (OR=1.3), and major reconstruction (OR=1.1-1.9), was associated with an increase of symptoms. The effect of seasonal adapted ventilation (SAV) was studied in a small experimental study. A 20% reduction of ventilation flow from 0.5-0.8 ac/h to 0.4-0.5 ACH during the heating season increased the perception of poor indoor air quality in the dwelling in general, and in the bedroom. In conclusion, low building age, and building dampness in the dwelling are associated with SBS. In older houses, mechanical ventilation is beneficial. The thesis did not support the view that energy saving measures in general is an important risk factor for SBS, but major reconstruction and multiple sealing measures can be risk factor for symptoms. Reducing the outdoor ventilation flow below the current Swedish ventilation standard (0.5 ACH) may increase the perception of impaired air quality.

*Keywords:* Indoor environment, Questionnaire, Atopy, Building age, Indoor air quality, Sick building syndrome (SBS), Validation, Dwelling, Energy conservation, Mechanical ventilation, Building dampness, Building reconstruction, Wood heating, Electric heating, Heat pump, Thermal Insulation, Sealing

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## List of papers

This thesis is based on following papers, which are referred to in following numerals I-V

- I Engvall K, Norrby C, Sandstedt E. The Stockholm Indoor Environment Questionnaire (SIEQ): A sociological based tool for assessment of indoor environment and health in dwellings. *Indoor Air* 2003 (in press).
- II Engvall K, Norrby C, Bandel J, Hult M, Norbäck D. Development of a multiple regression model to identify multi-family residential buildings with a high prevalence of sick building syndrome (SBS). *Indoor Air* 2000; 10: 101-110.
- III Engvall K, Norrby C, Norbäck D. Sick building syndrome (SBS) in relation to building dampness in multi-family residential buildings in Stockholm. *Int. Arch. Occup and Environ Health* 2001; 74: 270-278.
- IV Engvall K, Norrby C, Norbäck D. Ocular, nasal, dermal and respiratory symptoms in relation to heating, ventilation, energy conservation, and reconstruction of older multi-family houses. *Indoor Air* 2003 (in press)
- V Engvall K, Wickman P, Norbäck D. Sick building syndrome (SBS) and perceived indoor environment in relation to energy saving by reduced ventilation flow during heating season: a one year intervention study in dwellings. (Submitted)

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## Abbreviations, units and terminology

ACH	air changes per hour
Bq/m <sup>3</sup>	measurement for radon gas (Bequrel) per cubic metre
CNS	Central Nervous System
CI	confidence interval
CO <sub>2</sub>	carbon dioxide
DEHP	di-ethyl-hexyl-phtalate
ECRHS	European Community Respiratory Health Survey
ETS	environmental tobacco smoke
H <sub>0</sub>	null hypothesis
H <sub>1</sub>	alternative hypothesis
HVAC	Heating, Ventilation and Air-Conditioning System
ISAAC	International Study of Asthma and Allergy in Children
k	kappa-value
L/s	Litre per second
MVOC	microbial volatile organic compounds
NO <sub>2</sub>	nitrogen dioxide
NS	not significant
OR	odds ratio
p	probability
ppm	parts per million
PVC	poly-vinyl-chloride
RH	relative humidity
SAV	Seasonal Adapted Ventilation
SBS	Sick Building Syndrome
SIEQ	Stockholm Indoor Environment Questionnaire
SOC	The Sense of Coherence Scale
TWh	Terawatt per hour
TVOC	total volatile organic compounds
VOC	volatile organic compounds
WHO	World Health Organisation
y	year

multi-family residential buildings  
or multi-family houses

public owned dwelling

private landlord

owned by the inhabitant

buildings with more than  
one-or two dwellings

rental dwellings owned by  
municipal housing companies

rental dwellings owned by a  
private landlord

tenant-owned flat (apartment)  
by housing co-operative

# Introduction

The home is an indoor environment in which the population both children and adults spends considerable time, usually 15–16 hours per day<sup>1</sup>. It is an important social environment, where the population keep contacts with family and friends, the most important members of the social network. Furthermore, for many people, the home reflects their major financial and personal investment<sup>2</sup>. Residential houses are important investments for the society, the urban infrastructure and the home environment may have great significance for public health. “My home is my castle” is a familiar quotation originated from a rule of law stated in the 1600 century by the English jurist Edward Coke<sup>3</sup>, when he maintained the right to armed defense of private homes. Today there are new threats in the homes, which must be defended by more sophisticated methods. One such threat is exposure related to poor indoor environment, which could have pronounced effects on our health<sup>4-5</sup>.

Exposures in the home-environment have been in focus since ancient time and different authorities and stakeholders have set the tone on the subject. One of the oldest descriptions of microbial growth in buildings, including measures that should be taken to improve the home environment is found in the Old Testament.

...”If the mildew reappears in the house after the stones have been torn out and the house scraped and plastered, the priest is to go and examine the house and if the mildew has spread in the house, it is a destructive mildew; the house is unclean. It must be torn down...”

Levictus 14:44 (3<sup>rd</sup> Book of Moses)<sup>6</sup>

A general practitioner in Sweden produced a reference book for doctors in 1921 describing the health risk for poor housing conditions as a consequence of tight buildings.

“Wild native people have exceedingly simple houses: caves, tents, huts made of limps etc. That which is common for these houses that they are very airy. Our modern houses have solid walls with just some holes for air and

light (“windows”). They do but grant us warmth. But do they give us even health? Often not.”...

“The doctors’ book” 1921, Henrik Berg, GP<sup>7</sup>

A social writer, aiming to improve the hygienic conditions in Swedish, gives the following description of poor home environment in the lower classes in Sweden in the 1930’s:

...” A smell of pickled-herring brine and stale air, combined with odors from decayed wood, mildew, the chamber-pot, old wet clothes, wet shoes and dirty socks filled the cottage.” ...

“Dirty Sweden” 1938, Ludwig Nordstöm, social writer<sup>8</sup>

The increase of asthma and allergies in the western countries resulted in a concern about possible effects of the indoor environment during the 1990’s. At a large meeting concerning this arranged by the National Institute of Public Health in 1996, the following statement were presented:

...”Allergies and other hypersensitivities like the sick building syndrome (SBS) are reported by almost 50% of young Swedes. Asthma now or in the past is reported by 10% of 14-year-old children. Something seems to have initiated an upward trend in allergies 30-40 years ago and they are still increasing.”

Professor Max Kjellman 1996, National Institute of Public Health<sup>9</sup>

In parallel to the health issue there has been a discussion about thermal comfort and poor indoor environment in buildings expressed through the tenants association as:

...”Does one have to be ill to be taken seriously, perceiving discomfort in the dwelling?”

Solveig Larsen 1989, co-worker of tenants association<sup>10</sup>

Since then, debates about the indoor environment have continued in many countries, including Sweden. The following statement focus on the economical aspects of low quality of newly constructed buildings:

...” You are paying jerry built houses! Newly built houses with cracks, newly applied floors like waves and occupants getting mysterious illnesses. The widespread jerry built houses cost society a terrific amount of money - six millions of Swedish crowns a year!

The Swedish Magazine ”Our House 2002”, Per Jernberg editor-in-chef<sup>11</sup>

In Sweden, there have been government commission reports on issues related to the indoor environment in dwellings during the latest century. Some reports have been dealing with public health issues related to the home environment<sup>12-13</sup>, rules and standards for the building designer<sup>14-15</sup>, measures to avoid environmental problems in residential buildings<sup>16-17</sup>. In addition, the Swedish Government have been giving interest subsidies to owners of multi-family houses as well as single-family houses, that needed major reconstruction because of health-related complains<sup>18-19</sup>.

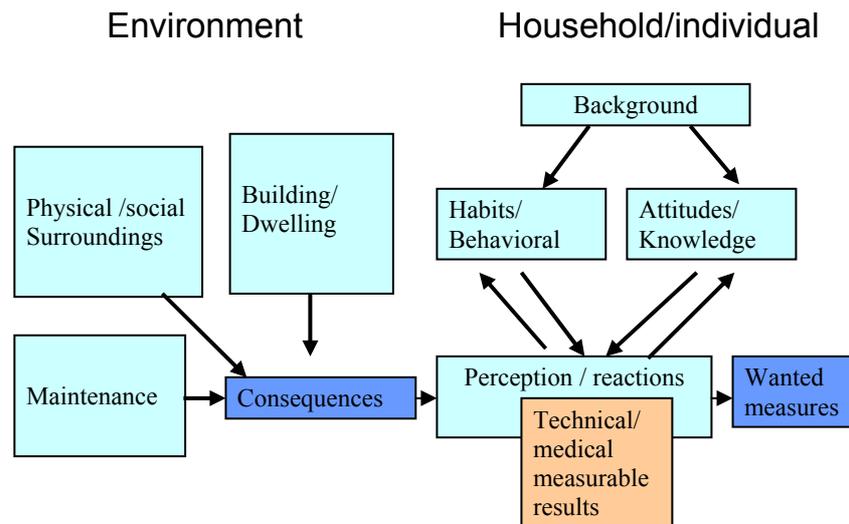
The significance of the residential environment, with respect to health status in a general sense have been investigated in different countries, including Great Britain<sup>20</sup>, Germany<sup>21</sup>, Austria<sup>22</sup>, the Netherlands<sup>23</sup>, Japan<sup>24</sup>, Russia<sup>25</sup>, USA<sup>26</sup>. Some investigators have focused on the health consequences of residential segregation<sup>26</sup>, and the increased risk for environmental exposure, ambient, occupational, and residential exposure in lower social groups<sup>27</sup>. One investigator developed an aggregate public health indicator, "loss of healthy life years", to represent the impact of multiple environmental exposure. They concluded that among environmental factors, ambient air pollution and ambient noise had the largest impact on public health in the Netherlands, but indoor air pollution had some impact and contributed to about 6% of total loss of healthy life years<sup>23</sup>.

Building technology is constantly changing, new building materials and new constructions are introduced. In a temperate climate, heating of residential houses is a large proportion of the total use of energy for heating, and in Sweden the consumption for multi-family buildings have increased between the year of 2000 and 2001, from 27.0 TWh to 28.3 TWh<sup>28</sup>. The issue of energy conservation and demands on a sustainable development of society is now influencing the home environment in many different ways. Concepts such as "healthy" and "sick" buildings have emerged<sup>29</sup>. In the mid 80's, WHO<sup>30</sup> estimated that between 10-30% of all new buildings, or newly reconstructed buildings in industrialised countries could be classified as "sick" because of excessive health complains from building occupants. In Sweden, one governmental commission report estimated that about one third of buildings constructed or reconstructed after 1960, were affected by "sick" building problems<sup>13</sup>.

## Perspectives on the indoor environment in residential buildings

The residential environment is a complex issue. The indoor environment is influenced by interaction between buildings, building service maintenance systems, and the occupants<sup>31</sup>. There can be a very close interaction between the behaviour of occupants, and the indoor exposure, e.g. concerning ventilation habits, cleaning habits, pet ownership, building dampness, emissions from smoking, cooking and the use of chemical products. Moreover, the occupants feel that the home environment is their own responsibility, but have limited possibilities to influence aspects of this environment and also to understand how their own behavior is linked to the building design, or maintenance of the building and its rented apartments. Traditionally, technical data from buildings have been compared with technical standards, e.g. for ventilation<sup>32-33</sup> and thermal comfort<sup>34</sup>. In many cases, technical investigations and exposure measures have been performed without taking the response of the inhabitants into account. Medically orientated investigations have mainly used self-administered questionnaires to collect information about health effects and residential exposure, e.g. building dampness<sup>35</sup>, furry pets<sup>112</sup>, passive smoking<sup>36</sup>. The sociological perspective focus on the interaction between the building and its inhabitants individual data is transferred from an individual to a collective level. Lifestyle and handling of technical installations may influence the function of building installations and the indoor air quality. The perception of different aspects of the indoor environment is a key issue, since it may influence both the behaviour and the comfort of the occupant. In one study from Germany, subjective perceptions of health impairment in relation to indoor air quality in the dwellings was compared with objective measurements, e.g. indoor NO<sub>2</sub>, CO<sub>2</sub>, fungal spores, and indoor temperature. The perceptions were significantly related to technical measurements, and the authors concluded that people suspecting a connection between the home environment and health should be taken serious<sup>22</sup>. Moreover, environmental perceptions and medical symptoms can be influenced by social and cultural impacts<sup>37</sup>, organizational aspects<sup>38-39</sup>, stress<sup>40</sup>, personality aspects<sup>41</sup>. The opinion that the building is unique and has to be evaluated together with its population both on a group level and an individual level is in agreement with both the building technician's and doctors perspective<sup>31,42,43</sup>. An overview of interaction between occupants and environmental factors in dwellings is given in figure 1.

**Figure 1.** Description of the interaction between occupant's perception and reaction on indoor environment in dwellings.



## Indoor environment in residential building

The indoor environment in buildings depends both on climate screens, heat stores, absorbers and emission source of chemical substances to the indoor air. It is also relational to the climate/occupational system- consisting of some physical aspects, with the addition of heating and ventilation systems, electrical systems, water- and drainage systems<sup>31</sup>. The building and its installations are there to serve the occupants and their need for good indoor environment influenced by thermal conditions, air humidity, noise, illumination, ventilation. Indoor sources of pollutants in dwellings may come from the building or its surroundings, heating systems, building material and construction but also from the occupant's metabolism and activities such as shower habits, washing clothes, preparation of food,

cleaning, tobacco smoking, furnishing, and pets. Building dampness and microbial growth in the dwelling is also an important issue. An overview of important environmental factors and exposures in the home environment in a temperate climate is summarised below, major health effects of residential exposure in adults is reviewed.

### Thermal climate

Indoor thermal environment in residential buildings in Sweden are regulated by the Swedish building regulation code<sup>15</sup>. The general recommendation is that the lowest directional operative temperature is 18°C in habitable rooms that the floor surface temperature should not be below 16°C, the air velocity in the occupied zone of a room should not exceed 0.15 m/s. Besides the direct effect on thermal comfort, room temperature in dwellings may influence both chemical and biological exposure, as well as airflow in dwellings. There are few epidemiological studies on effects of thermal climate in residential buildings, on medical symptoms compatible with the sick building syndrome. In one experimental exposure chamber study, an interaction between high room temperature and sensory effects from chemical emissions (VOC) was demonstrated<sup>44</sup>.

### Indoor air humidity

In well-ventilated workplace buildings, low relative air humidity may cause an increase of symptoms compatible with the sick building syndrome<sup>45,46</sup>. In dwelling, the focus has been on health risks related to high air humidity. According to the Swedish National Board on Health and Welfare<sup>47</sup>, the dampness load on the indoor surfaces should not exceed 3 g/m<sup>3</sup>, and the absolute indoor air humidity should not exceed 7 g/kg dry air during heating season. The main health risk of high relative air humidity in dwellings is growth of house dust mites in the mattress, condensation causing microbial growth on cold surfaces. Studies in Denmark have shown that if the absolute air humidity is increased above approximately 7 g/m<sup>3</sup> there is an increased risk for house dust mite infestation<sup>48</sup>. This corresponds to relative air humidity above 40-45% at normal room temperature. In modern houses in cold temperate regions, a mechanical ventilation system increases the possibility to reach an air exchange rate above 0.5 turnovers per hours, and indoor humidity levels below 7 g/kg, which protects against mite survival in winter<sup>49</sup>.

## Noise

Noise in residential buildings can come from traffic, neighbours, the ventilation system, the heating system, or the water- and drainage system. In one study from London, noise appeared to be the greatest indoor traffic related nuisance, but smoke, fumes and odors from traffic was also a common problem<sup>50</sup>. In a large national survey in Sweden, it was found that 23% of occupants in multi-family buildings were dissatisfied with the soundproofing of the building, 18% stated that they had sleep disturbance due to noise from external sources<sup>51</sup>. There are many studies on road traffic noise and various kind of discomfort<sup>52,53</sup>, sleep disturbances related to environmental noise<sup>54</sup>, noise effects related to personal factors, stress and other mental factors<sup>55,56</sup>. There are few studies on health effects of noise from the building service systems in dwellings.

## Illumination

In Sweden, the building regulation code<sup>15</sup> prescribed that, “Rooms where people are present other than occasionally shall have satisfactory access to direct daylight”. Moreover, the building code prescribes that “Dwellings shall have access to direct sunlight”. There are few studies of the relationship between illumination, indoor daylight, and health effects in dwellings.

## Ventilation

The primary function of ventilation is to dilute pollutants that are emitted into the interior space, by supplying the building with outdoor air. The quality of the indoor air depends on the outdoor air in the surroundings. A mechanical ventilation system in dwellings may increase the indoor exposure to outdoor air pollutants. Because of chemical reactions, ozone and nitrogen dioxide (NO<sub>2</sub>) from outdoor sources is decreased when entering the indoor environment. Typically, a mechanical ventilation system in dwellings can give a reduction of 30% for NO<sub>2</sub> indoors compared with outdoor levels<sup>57</sup>. The dilution of indoor pollutants with outdoor air can be achieved by either a mechanical ventilation system, by window opening, or by thermal differences between the indoor and outdoor environment. General ventilation system conventionally categorises into natural ventilation, mechanical exhaust systems, mechanically supply and exhaust systems and mechanical supply and exhaust system with heat exchangers. The ventilation of the building is linked to the year the building was constructed or reconstructed, as newer dwellings in Sweden have a more complex mechanical ventilation system<sup>58</sup>.

General ventilation guidelines in USA specify a minimum air exchange of 0.35 air exchanges per hour (ACH), or minimum personal outdoor airflow rates of 7.5 L/s<sup>32</sup>. Swedish building code for dwellings prescribes a minimum outdoor airflow of 0.35 L/s, m<sup>2</sup>, corresponding to 0.5 ACH<sup>14</sup>. In Scandinavian dwellings, an outdoor airflow below this ventilation standard increase the risk for infestation of house dust, due to increased air humidity<sup>59</sup>. The relationship between building ventilation and bio-effluent levels, as determined by CO<sub>2</sub> measurements, is well established, and is the foundation for most existing ventilation standards. Already in the 1850's, it was shown experimentally that at CO<sub>2</sub>-levels above 1000 ppm, the indoor air quality is perceived as impaired by non-adapted visitors<sup>60</sup>. There are two review articles on the associations between airflow, and health effects in non-industrial buildings. Some studies on the relationship between ventilation rate and health have shown that a personal ventilation rate up to 10 L/s may reduce symptoms and occupant dissatisfaction. Other studies measuring CO<sub>2</sub> could demonstrate that the risk for sick building syndrome is decreased at CO<sub>2</sub> levels below 800 ppm<sup>61,62</sup>. Very few studies on health effects of building ventilation have been performed in dwellings<sup>48,64,65</sup>.

### Building age, construction and energy saving

Both building technology and building service systems have changed over time. In Scandinavia, older buildings were wooden constructions, stone buildings, or brick buildings. The ventilation was ensured by wood heating in the homes, which helped to create sufficient ventilation by thermal forces. Modern residential buildings are becoming more and more complex, with many different materials in each part of the dwelling, with its own particular purpose. Examples of such materials are thermal insulation, wind barriers, air sealant, internal and external surface coverings. There are some indications that newer dwellings have more symptoms compatible with the sick building syndrome. In the large ELIB-study complains and symptoms were more frequent in multi-family houses than in single-family houses and most frequent in bigger multifamily houses. Complains and symptoms were also more frequent in new buildings, constructed after 1975, than in older buildings<sup>66,125</sup>. Moreover, it has been shown that moving from old to new buildings resulted in an increase in SBS-symptoms<sup>67</sup>. Finally, subjects living in newer dwellings reported more dermal symptoms<sup>68</sup>. Building age is linked to many different building factors, may also be linked to social and demographic differences. None of the studies mentioned above have been

able to explain the observed association between low building age and symptoms.

Since the 1970's, increased energy-prices have made energy conservation issues more and more important. Energy-saving building technology has been suggested as a cause of building-related symptoms<sup>69</sup>, the discussion about health risks of energy saving has continued<sup>70,71</sup>. In former Eastern Germany, increased energy prices after the unification in 1990 resulted in energy-saving measures. After thermal insulation of dwellings, an increase in health problems was reported<sup>72</sup>. After installation of insulated windows and central heating systems in German dwellings, the air exchange decreased, and indoor temperature increased from 13 to 18°C, absolute indoor air humidity increased from 4.6 to 6.2 g water/kg air<sup>73</sup>.

In Sweden, energy conservation issues were first addressed in the building regulation code of 1975<sup>74</sup>. The Building Regulation Code from 1980<sup>75</sup> had requirements for thermal insulation, air tightness of buildings, an upper limit of airflow rate to limit heat loss through the ventilation system. The consequence was increased use of mechanical ventilation systems with heat exchangers<sup>76</sup>, use of heat pumps to extract energy from the surroundings<sup>77,78</sup>, sealing of window frames, installation of triple glassed windows, and thermal insulation of roof, attic or building facade. Due to energy-saving measures, Sweden's energy use in residential houses has been constant during the latest decades, despite an increase of the country's gross heated floor area by more than 40%<sup>31</sup>. Despite the economical and ecological implications of energy saving, there are few studies on health effects of energy saving measures.

## Chemical and particle exposure

Indoor nitrogen dioxide (NO<sub>2</sub>) from gas stoves has been reported to increase the risk for asthmatic symptoms<sup>79</sup>. Chemical pollutants such as NO<sub>2</sub> may enhance the effect of allergens<sup>80,81</sup>. Another source of indoor air pollution can be burning of wood, coal, other organic material for heating and cooking. This can be a severe source of indoor air pollution in developing countries<sup>5</sup>. It has been estimated that globally, 2 million subjects in the world die every year from particle pollution from indoor combustion sources<sup>82</sup>. In Sweden, this problem is expected to be less severe since we are mainly heating our houses with district heating, cooking our food on electric stoves. In Stockholm, gas appliance for heating are rare, whereas gas stoves for

cooking are mostly used in some older buildings with in older part of the urban area.

Many different types of volatile organic compounds can be detected in residential buildings<sup>83,84</sup>. Formaldehyde can be emitted from building materials, e.g. chipboard, is a well known irritant<sup>85</sup>. An association between formaldehyde concentrations in dwellings, respiratory symptoms in adults has been reported<sup>63</sup>. There has been concern about possible health risks linked to emission of VOC, other than formaldehyde, in dwellings. Volatile Organic Compounds (VOC) may be higher in new buildings compared to established dwellings due to long-term emissions from building material<sup>83,84</sup>. Besides the building structure, indoor VOC emissions appear to be dominated by furnishings, textiles and household products used by occupant's<sup>86</sup>. In epidemiological studies, mass summation of individual VOC (TVOC) has been used as a crude exposure variable. The TVOC-concept does not consider different irritative properties of different VOC's, and have failed to predict health effects, as recently reviewed<sup>87</sup>. There are few epidemiological studies on associations between chemical exposure in dwellings and symptoms compatible with the sick building syndrome. Some studies have shown an association between newly painted indoor surfaces in dwellings, asthmatic symptoms<sup>88</sup>, SBS-symptoms in adults<sup>89</sup>. Moreover, one study found an association between some groups of VOC's in dwellings, asthmatic symptoms in adults<sup>63</sup>. During recent years, it has been suggested that chemical reactions may occur in indoor air, e.g. that ozone and NO<sub>2</sub> react with some VOC to formaldehydes and other oxygen containing reactive compounds<sup>90</sup>. There are, however, few studies on this topic in dwellings.

### Environmental tobacco smoke (ETS)

Exposure to environmental tobacco smoke in dwellings is a well-known risk factor for both lung cancer<sup>91,92</sup> and asthma and asthmatic symptoms<sup>36</sup>. There are few studies on the association between residential exposures to ETS, symptoms compatible with the sick building syndrome. In one questionnaire study from mid-Sweden, childhood exposure to environmental tobacco smoke from smoking mothers was related to SBS symptoms in adult population<sup>68</sup>.

## Radon

Radon, a colourless, odourless, radioactive gas coming from either the ground or some types of building material<sup>93</sup>. Exposure to radon is known to cause lung cancer<sup>95</sup> and is estimated to be the second leading cause of lung cancer, after cigarette smoking<sup>93-94, 96</sup>. It has been estimated that radon exposure in Swedish homes may result in 400-900 extra cases of lung cancer every year. The government has decided that all homes expected to have more than 400 Bq/m<sup>3</sup> of radon in the air shall have radon measurements performed before 2010<sup>16</sup>.

## Building dampness and microbial growth

Building dampness is common in residential buildings, and related to an increase of both asthmatic symptoms and SBS-symptoms, as concluded in four literature reviews<sup>35,97-99</sup>. Most of these studies been on asthmatic symptoms in children in relation to dampness in dwellings, there is little information on SBS-symptoms among adults in dwellings with building dampness and microbial growth<sup>100-104</sup>. Information on symptoms compatible with SBS, e.g. nasal and ocular symptoms, are available in some studies on asthmatic symptoms in adults in relation to building dampness in dwellings<sup>102,103,105</sup>. Despite the large number of studies suggesting health effects of building dampness, the possible biological mechanism are poorly understood<sup>97</sup>. Building dampness comprise different aspects of the indoor environment facilitating growth of moulds and bacteria<sup>97,106</sup>, house dust mites<sup>107</sup>. Conditions in dwellings facilitating microbial growth include high air humidity, condensation on cold surfaces, permanent dampness in the building construction, episodes of water leakage<sup>98,108</sup>. Building dampness may also increase the emission of volatile organic compounds (VOCs) due to degradation of building materials. One example is degradation of phthalate esters, used as plasticizers in poly-vinyl-chloride (PVC) floor coatings or glues<sup>109</sup>.

## Allergens

On a global level, house dust mite allergens is the most significant indoor allergen in dwellings<sup>110,111</sup>, associated with both asthma and allergic sensitization<sup>48</sup>. Allergens from furry pets can be found in high levels in homes with furry pets, this exposure is common in Scandinavia<sup>112,113</sup>. Pet allergen is transported on the clothes of pet owners and may contaminate homes without furry pets. It is yet unclear if early childhood exposure to pet allergens has a protective effect, or is a risk factor for atopic sensitisation<sup>114</sup>. In the adult population, however, it is well-known that subjects sensitized to

a particular allergen may react when exposed to this allergen in the home environment. In Sweden 7-14% of the adult population is sensitized to mite allergens, and 13-15% are sensitized to cat allergen<sup>115</sup>. There are methodological problems to study health effects of allergen exposure in the home environment, due to selection effects, causing sensitized subjects to get rid of their pets. In the ECRHS-study, an association was found between the proportion of cat owners in different cities in Europe, and the proportion of adults sensitized to cat allergen<sup>116</sup>. Other allergens in the home environment may include cockroach allergen, and pollen allergens transported to dust in the home environment when opening windows during pollen season.

## Risk factors for sick building syndrome (SBS)

The concept sick building syndrome (SBS) was introduced in the mid-1970. At this time, there had been increasing awareness of an association between some medical symptoms and exposure to the indoor environment in some office buildings<sup>117,118</sup>. These non-specific symptoms have sometimes been referred to as the sick building syndrome (SBS)<sup>118-120</sup>. During the 90's the concept of SBS has been criticized as unspecific, mixing different types of symptoms, a sub classification of SBS depending on the type of symptom has been suggested<sup>119,121</sup>. One suggestion is that the sick building syndrome should be thought of as a figurative concept of everyday language, rather than a single disease entity. This is because the phenomena consists of several types of relations between different environmental determinants and health<sup>38</sup>. Despite these well justified objections, the term Sick Building Syndrome is still used. Some investigators have restricted their studies to symptoms perceived to be related to the indoor environment<sup>122</sup>. Others have restricted their studies to symptoms improving, or disappearing, when being away from the indoor environment<sup>123</sup>. Many Scandinavian authors have studied the general prevalence of SBS-symptoms, without such restrictions<sup>64,68,124</sup>. In this thesis we have used the term SBS-symptoms to describe symptoms, which may be related to the indoor environment in dwellings. Initially, we studied both total prevalence of symptoms and building-related symptoms.

Most epidemiological studies on SBS-symptoms have dealt with office workers<sup>119-120</sup>, there are few studies on SBS-symptoms among adults in relation to domestic exposures<sup>68,122,125-126</sup>. Previous research has found that SBS is influenced by personal factors, such as female gender<sup>118-120</sup>, allergic disorders<sup>68,124,127</sup>. Age is another such personal factor, but the evidence

concerning its direction is not consistent, one study age had a negative association to SBS<sup>128</sup> while another study reported a positive correlation<sup>129</sup>. In addition there are studies that demonstrate no relation between age and SBS. Burge<sup>130</sup> found that those between 21 and 40 years of age reported more symptoms than either younger or older individuals. Brasche<sup>131</sup> found that age is a significant risk factor for SBS but only for men. Some studies found a relationship with smoking and SBS<sup>89,127,132</sup> but there are others that did not find such a relationship<sup>133-134</sup>. There are few published studies on the relationship between social- economic status or social class and SBS in homes. In one study<sup>68</sup> there was no relationship between marital status, education level, obesity, regular physical exercise with SBS-symptoms. Residents living in single-family houses reported lower levels of complaints and symptoms than those living in multi-family buildings, although the technical measurements suggested a less favourable indoor climate in single family houses<sup>66</sup>.

## Questionnaires for indoor environmental research in dwellings

Questionnaires are commonly used in epidemiologic studies to obtain information about exposure to risk factors, confounders, effect modifiers, and disease outcome<sup>135</sup>. Questionnaires can either be used to identify individuals with particular diseases, or to provide a comparative estimate of the prevalence of the disease between different population samples. Standardized questionnaires have been developed for the assessment of asthma and asthmatic symptoms, such as the ECRHS-questionnaire for adults<sup>136</sup>, the ISAAC-questionnaire for children<sup>137</sup>. These questionnaires have been translated to different languages and have been used in large international studies on respiratory effects in relation to different environmental factors in dwellings<sup>79,137-138</sup>.

In Scandinavia, self-administered questionnaire studies on SBS-symptoms and environmental perceptions are commonly used as a first step in investigations of indoor environments with suspected problems<sup>139</sup>. Self-administered questionnaires have been used to study ocular, nasal, throat and facial dermal symptoms in relation to the indoor environment, mainly in office workers in different parts of the world<sup>38,64,123,140-145</sup>. These questionnaires also include symptoms from the central nervous system, such as headache, tiredness and difficulties concentrating.

There can be different philosophy behind the development of indoor questionnaires. One approach is to develop a set of general questions that can be used in many types of indoor environments (e.g. offices, schools, hospitals, dwellings). This approach was used in the development of the MM 040 questionnaire<sup>139</sup>, originally developed for non-industrial workplace buildings. This questionnaire is widely used in the Nordic countries. Later versions of the questionnaire have been developed to be used among children and adults in dwellings, among both pupils and school personnel. The general approach has some advantages. The questionnaires can be used in different types of indoor environments, and comparisons between different environments can be made. The general approach has, however, certain limitations related to the validation process. Different indoor environments are used for different purpose, attitudes, as well as linguistically expressions of perceptions or reaction to factors can be different<sup>146</sup>.

By developing a questionnaire specifically designed to be used in dwellings, one can obtain more detailed and precise information about specific factors causing annoyance, discomfort and symptoms. This may facilitate technical investigations and improvements in the building. In multi-family houses there are sometimes only 10-20 households in one building. This means that there is a need to develop multivariate statistical models, which can be used to calculate expected prevalence of symptoms controlling for significant demographic and personal risk factors. In addition, there is a need for multidisciplinary approach to indoor environment research, particularly in dwellings. One way to collect people's responses is to construct a questionnaire concerning both the technical, medical and behavioural aspects. The occupant's response to the indoor environment is a complex issue. Lifestyle and handling of technical installations may influence the function of building installations and indoor air quality. The perception of different aspects of the indoor environment is a key issue, since it may influence both the behaviour and the comfort of the occupant. The sociological perspective focuses on the interaction between the building and the inhabitants. Individual data is transferred from an individual to a collective level. To our knowledge, sociological methods have not previously been applied to construct and validate a standardised questionnaire to be used in residential buildings.

## Aim of the investigation

The principal aim was to develop a tool and method to study indoor environment in dwellings, including perception of the indoor environment and the inhabitant's symptoms together with a personal, behavioural and social dimension. The aim was also to study associations between selected aspects of the indoor environment in dwellings and the adult occupant's health, in terms of symptoms compatible with the sick building syndrome.

The specific aims were:

- To develop and validate a standardized questionnaire-the Stockholm Indoor Environment Questionnaire (SIEQ), designed to be used in dwellings. The validation procedure was based on sociological principles and test procedures. The questionnaire covered medical symptoms, perception of the home environment, individual behaviour, and selected personal factors.
- To develop a multiple logistic regression model to identify multi-family houses with an increase of symptoms compatible with the sick building syndrome (SBS)
- To study associations between selected personal risk factors and symptoms
- To study associations between symptoms and different indicators of building dampness in multi-family dwellings
- To study associations between symptoms and type of heating and ventilation system, energy saving, and major reconstruction in older dwellings, built before 1961
- To evaluate the effect of an alternative operational principle for mechanical ventilation in dwellings, using a reduced ventilation flow during the heating season, to save energy. The evaluation included symptoms, perceived indoor environment, and measured indoor climate and ventilation.

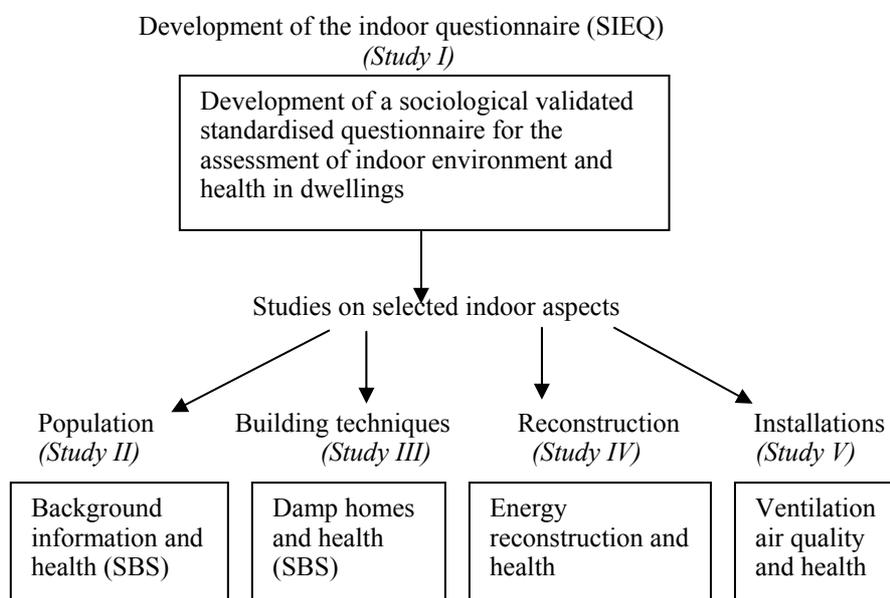
## Material and methods

The thesis comprises the development of a validated questionnaire (study I), the Stockholm Indoor Environment Questionnaire (SIEQ), and use of SIEQ in prevalence studies among adults in multi-family houses (II-IV). One study (V) was a longitudinal experimental study, with cross-over design. Information on symptoms and perception of the indoor environment, as well as individual and household factors, was collected by a postal questionnaire answered by one adult ( $\geq 18$  y) in each apartment, during the heating season (November – March). Information on number of apartments in housing blocks, building age, total reconstruction, ownership was obtained from the central building register in Stockholm. Parallel to the questionnaire study, a telephone interview was made with the building owners to collect information on building characteristics, reconstruction, energy saving measures.

### Overview of the studies

The first part of the thesis included the development of a questionnaire to collect empirical data on perception of the indoor environment and health together with personal, behavioural and social dimensions. The questionnaire is designed to be used in epidemiological studies, as well as in practical work, to identify technical investigations and measures that could be taken to improve the indoor environment in dwellings.

**Figure 2.** The structure of the thesis



*Study I Development of a validated indoor questionnaire for dwellings*

A standardised postal questionnaire for registration of indoor environment and SBS among adults in relation to the home environment was developed. The validation was performed in four steps, following common sociological principles. The questionnaire is named “Stockholm Indoor Environment Questionnaire” (SIEQ).

*Study II A statistical model to identify multi-family buildings with increase of SBS*

A cross-sectional study was performed among inhabitants in 609 multi-family buildings selected by stratified random sample in Stockholm, using the SEIQ-questionnaire. A multiple regression model was developed to identify multi-family residential buildings with a high prevalence of sick building syndrome (SBS). Analysis was applied, adjusting for building related factors, personal factors, and demographic data. The association between building age and significant increase of SBS was studied.

*Study III Associations between symptoms and indicators of building dampness in dwellings.*

From the same study population as in Study II, the relationships between symptoms, different indicators of building dampness was studied, adjusting for age, gender, population density in the apartment, type of ventilation system, ownership of the building, by multiple logistic regression analysis.

*Study IV Reconstruction and energy saving measures in relation to SBS*

A cross-sectional study was performed in Stockholm in 231 multi-family buildings built before 1961, selected by stratified random sample. This population is a sub-sample of the study population in Study II and III. The relationship between symptoms, type of heating and ventilation system, energy saving and reconstruction was studied by multiple logistic regression analysis, adjusting for age, gender hay fever, current smoking, population density and co-variation between different building factors.

*Study V Seasonal Adapted Ventilation and air quality in relation to SBS*

This is an experimental intervention study on effects of changes of outdoor ventilation flow, in two parts of a multi-family building (A, B). Two different operational principles for the mechanical ventilation were compared (seasonal adjusted ventilation vs. constant flow operation). The study compared symptoms and perception of the indoor environment during heating season, technical measurements of indoor climate and ventilation during all parts of the year. The study started with constant flow ventilation in building A, seasonally adapted ventilation in building B. After one year, there was a shift of the two ventilation principals without inhabitant's knowledge. Technical measurements were done in a separate part of the building (C). The seasonally adapted ventilation is programmed to reduce the outdoor airflow by 25-30% during the heating season, to reduce energy cost.

## Study population

In *study I*, the initial qualitative interviews were performed among 21 occupants with different sex, age and martial status living in seven multifamily buildings. In the following validation steps, one adult who had lived in the apartment at least one year was randomly selected from each dwelling in seven buildings (N=287). In the last validation step, three multi-family buildings in different parts of Sweden were selected, with different prevalence of complains (N=82). Reliability testing on the area level was performed by two repeated random surveys performed in the same local area

within two years ( $N_1=935$ ,  $N_2=3241$ ). Reliability testing on the building level was performed in the same building within two years ( $N_1=36$ ,  $N_2=37$ ), reliability testing on the individual level was performed with the same individuals within two years ( $N_{1+2} = 138$ ).

In *study II and III*, 609 out of 11.808 (5%) multi-family buildings in Stockholm were selected by stratified random sampling. The stratification was based on building age, to achieve a sufficient number of buildings in each age class. The division of the buildings into age classes was based on major changes in building technology. The main sampling, of 378 buildings, was done in November-February 1991/92. An additional sampling of 231 buildings built before 1960 was done in November-February 1993/94, to obtain a sufficient number of older buildings in the total sample. All dwellings ( $N=14\ 235$ ) in these 609 buildings were selected for the study. In larger buildings with more than 29 apartments ( $N=250$ ), 30 apartments were randomly selected for the study. In buildings with less than 30 apartments ( $N= 347$ ), all apartments were included. Finally, all buildings ( $N=84$ ) with less than 10 respondents were excluded.

In each included apartment ( $N=14\ 235$ ), one randomly selected adult person ( $\geq 18$  y) was drawn by combining the building register with the civil registration register, irrespectively of the number of inhabitants living in the apartment. The Stockholm Indoor Environment Questionnaire (SIEQ-questionnaire) was sent to these subjects. In total, 9 808 out of 12 667 with correct addresses answered the questionnaire (77%). Similar response rates were obtained in 1991 and 1993 (78% and 77%, respectively). In the statistical analysis, further restrictions were made, excluding those who reported in the questionnaire that they had lived in the current dwelling less than one year. The proportion of participants were similar in all age classes of buildings (74-80%), moreover the response rate was similar for publicly owned buildings, buildings owned by the inhabitant and privately owned buildings (69%-72%).

In *study IV* 231 out of 7 987 (3%) multi-family buildings in Stockholm, built before 1961, were selected from the study population in study II and III. Building built before 1930 were mainly larger stone buildings, building built in 1930-60 were smaller brick houses. Among these, 32 buildings had been totally rebuilt and were classified as new buildings in the building taxation register. All dwellings ( $N=4\ 815$ ) in these 231 buildings were selected for the study. In each included apartment, one randomly selected adult person ( $\geq 18$  y) answered the SIEQ-questionnaire. In total, 3241 out of 4224 still living at the same address answered the questionnaire (77%).

*Study V* is a one year “cross-over” intervention study in 44 subjects in a multi-family building in Gothenburg, Sweden. The building was constructed at the end of the 1960’s it was totally reconstructed in 1992 and the occupants moved in 1993. All parts of the building had the same type of exhaust ventilation system, but it was operated by two different ventilation principles. One part of the building (A) had an airflow regulated by the outdoor temperature (seasonally adapted ventilation), giving less flow (0.35 ACH) during heating season (November-March) higher airflow (0.6 ACH) during the rest of the year (April-October). The other part (B) had a conventional ventilation principle with a constant airflow of approximately 0.5 ACH during the whole year. When the occupants had lived one year in their dwellings (March-April 1994), the SIEQ- questionnaire was sent to all adults ( $\geq 18$  years). Then the operation principle was shifted without inhabitant’s knowledge between part A and B, in April-May 1994. One year after the first questionnaire (March-April 1995), the same questionnaire was sent to those now living in part A and B of the building. In total, 18 out of 26 persons in building A (69%) and 26 out of 32 persons in building B (81%) participated both years, and comprised the study population in our longitudinal study.

## Methods for validation and reliability tests of the questionnaire

The development of a structured validated self-administrated postal questionnaire- The Stockholm Indoor Environment Questionnaire (SIEQ) - was carried out as follows:

- **The first step** was to identify expressions in the every day language describing characteristics of the building and its function, from the occupants’ perspective. This was done in order to achieve a good content validity. A pilot interview study was performed in 1985, among 21 occupants with different sex, age and marital status, in seven different multifamily houses with different building technology related to energy saving measures. Each individual had qualitative interviews during a period of 1-2 hours for each individual, with non-standardised questions and open answers.

- **The second step** was to select significant aspects of the indoor environment in dwellings, based on information obtained from the qualitative interviews. This enabled us to construct a standardised interview questionnaire with both open and closed questions. In this questionnaire, we tested different expressions for each issue as well as different types of scales.

The interview questionnaire contained totally 250 questions was tested in 1985-86 by professional interviewers in 350 households (one adult in each dwelling) in multifamily houses. The answers for some of the environmental factors obtained from the inhabitants were compared with observations made by the interviewer.

- **The third step** was to transform the standardised interview questionnaire into a reduced postal questionnaire, by selecting the most effective questions. Questions were reduced and specified open questions were transformed into questions with fixed alternatives. The selection procedure was based on correlation analyses, keeping specific questions that were most closely correlated to the relevant general questions (e.g. on air quality, thermal climate, acoustic perceptions and illumination). The original 250 questions were reduced to 45. From these three steps we could obtain a good correspondence between the theoretical and empirical concept of indoor climate i.e. content validity.

- In **the fourth step**, the standardised self-administered questionnaire was tested in 75 dwellings in three multifamily buildings in different parts of Sweden, with different degree of complaints according information from the building owners. The number of questions was further reduced from 45 to 33 questions, by selecting specific questions with the highest correlation with the general question on the indoor environment by omitting questions that did not add significant information. This was done to get a good internal validity. On the other hand some specified questions that did not correlate to the general question, but obviously related to technical functions, were kept in the questionnaire.

The reliability of the questionnaire was tested on area level, building level on individual level by comparing prevalence of symptoms and complaints when applying the questionnaire twice after one or two years, during the same season (winter).

## Assessment of building characteristics and indoor environment

Information on building age, type of ownership, and number of apartments in the building was obtained from the central building register in Stockholm. This register also contained information on which buildings had been totally reconstructed were classified as renewed (new) buildings in the latest building taxation register (1976).

Information on type of ventilation and heating system, including use of additional energy saving heat pump was gathered from each building owner by telephone interviews. In addition, information on reconstruction and energy saving measures during the latest 10 year period was collected. This information included exchange of heating or ventilation systems, sealing of window frames, change to double or triple glassed windows, external insulation of the building, insulation of the roof or attic. Detailed information about changes of heating or ventilation system was not collected. The information was coded by an experience building engineer, with no information on symptoms reported by the inhabitants.

Information on signs of building dampness was collected from the selected inhabitant, when answering the SIEQ-questionnaire. There were four indicators of building dampness; episodes of water leakage latest 5 years, condensation on windows, slow drying of damp towels in the bathroom, perception of mouldy odour in the dwelling.

In study V, technical measurements were performed by an experienced, independent technical engineer in cooperation with Chalmers University of Technology, Gothenburg, Sweden. The measurements were done in a separate part of the building (C), not included in the questionnaire study, shifting between the two operational principles every week. Long term measurements were performed in 8 dwellings and short-term measurements in 4 representative dwellings, during one year in different parts of the dwellings. Measurements included temperature, relative air humidity, air exchange rate (ACH), personal outdoor rate (L/s), ventilation efficiency, inlet air temperature ( $^{\circ}\text{C}$ ), air velocity (m/s) and velocity profile in the vicinity of the air inlet. Indoor temperature, relative air humidity (R.H) and carbon dioxide concentration ( $\text{CO}_2$ ) were measured as the mean value for every hour during the whole period and compared to measured outdoor temperature.

To evaluate energy saving during the heating period, the consumption of electricity by the ventilation fans were measured by the two operational principles. In addition, the loss of thermal energy by the ventilation system was calculated. These measurements were related to type of operational principle, outdoor temperature, by linear regression.

## Assessment of personal- and household factors

Information on age, gender, current smoking, time spent in the dwelling was obtained from the SIEQ-questionnaire as well as information on asthma, hay fever, eczema. In the initial version of the questionnaire, there were no questions about smoking habits, only one “allergy“ question, covering both asthmatic symptoms, hay fever or eczema. This question was used in *study II*, to define a history of atopy. The later version of the questionnaire, used in the sub-sample of older houses (*study IV*) and in the experimental study V, contained separate questions on asthmatic symptoms, hay fever, eczema, as well as a question on current smoking habits. This enabled us to adjust for both smoking and hay fever in *study IV*.

Information on number of subjects living in the dwelling and the number of rooms was obtained from the postal questionnaire; population density (number of subjects/room) was calculated.

Ventilation habits in the apartment were also obtained in terms of “how often” and “for how long time” the windows are open during the heating season. In *study V*, the management staff visiting the apartments noticed how the occupants of each apartment set their ventilation in number of open and closed air inlets. The observations were classified as “all air inlets closed”, “most inlets closed“, “equal open and closed inlets”, “most inlets open“, “all air inlets open”.

## Assessment of subjective indoor environment

Information about perceived air quality was obtained from questions on “annoyance from dry air”, “yes, often”, “yes, sometimes” or “no never”, different odours with linguistic expressions as “pungent”, “mouldy”, “musty” and “stuffy”. Finally ending up in a general question on the air quality in the living room, bedroom and the apartment as a whole. The SIEQ-questionnaire also contained questions on the general opinion of thermal comfort in the living room, bedroom and the apartment as a whole.

## Assessment of medical symptom

Besides questions on the perception of the indoor environment in the dwelling, the questionnaire contained seven questions on symptoms compatible with the sick building syndrome. These were; one on eye

symptoms "itching, burning or irritation of the eyes", one on nasal symptoms "irritated, stuffy or runny nose", one on throat symptoms "hoarse, dry throat", one on "cough", one on facial skin symptoms "dry or flushed facial skin". There were also two questions on CNS-symptoms "headache" and "fatigue". The seven symptom questions were identical to those in the self-administered MM 040-questionnaire commonly used in Sweden<sup>139</sup>. Five other questions from the MM questionnaire on more uncommon symptoms were omitted. There were additional questions about the respondent's opinion if the symptoms are related to their home environment or not, used in study II. A recall period of 3 months was used for the symptoms. For each symptom, there were three alternatives to answer "no, never," "yes, sometimes," and "yes, often." Often means every week. The prevalence of weekly symptoms was calculated for each symptom. In addition, the prevalence of home-related symptoms was calculated in study II.

In the statistical regression model (Study II) to identify buildings with an increase of SBS-symptoms, the CNS-symptoms (headache and fatigue) were excluded from the analysis. These symptoms were included in later epidemiological studies (III-V). The information if the respondents attributed the symptoms to the indoor environment in the dwelling was not used in study III-V, which covered symptoms irrespectively of the inhabitant's opinion about causes.

## Statistical methods

The selection procedures keeping the most relevant questions in SIEQ (study I) was partly based on correlation analyses, but other non-statistical aspects were also considered when including questions in the final questionnaire. The Chi-2-test was used when testing the reliability of the questionnaire on area level and building level, when comparing the prevalence of symptoms and complains and when applying the questionnaire twice. Cohen's kappa value was calculated when testing the reliability on individual level.

Relationships between symptoms, personal factors and home environment (Study II-V) were analysed by means of multiple logistic regression using the SAS-statistical package (Statistical Analysis System). Weekly symptoms were assigned "1" and both "yes, sometimes," and "no, never" was assigned a zero value. In study II, a stepwise regression model was used, initially including all factors, keeping factors with highest explanatory value excluding non-significant factors (two-tailed  $p < 0.05$ ). Based on ten separate

models, a final classification model was constructed, aiming to identify "risk buildings" with a significant increase of at least one of the five included symptoms. In this model, a "risk building" was defined as a building with an occurrence of symptoms above the 99% upper confidence interval limit, in at least one of the ten models.

In the epidemiological studies (III and IV), multiple logistic regression was used to analyse associations between different symptoms and different exposure variables, adjusting for possible confounders adjusted odds ratios with 95% confidence intervals were calculated. In these studies, different personal factors and building characteristics were included in the models. The inclusion of a particular factor was based on available information about risk factors and possible associations between different building characteristics, irrespectively of the statistical associations in the current studies (III and IV). A dose-response relationship between symptoms and dampness exposure was evaluated by constructing a dampness index, in study III by counting the number of dampness. In a similar way, an insulation index was constructed in study IV.

In study V, differences in mean exposure between two operational principles were calculated by Student's t-test. Changes of symptoms and environmental perceptions between the first and the second questionnaire study were calculated for each individual participating. Differences in changes of symptoms or perceptions were compared between the two groups, using the Mann-Whitney U-test.

In all the statistical analyses, two tailed test and significance level of 5% were used except in study II, when a significance level of 1% was used in the statistical definition of a "risk building".

## Hypotheses tested

Study I was a methodological study, no formal hypotheses testing was applied. The other studies included hypotheses testing about statistical associations between occupant's symptoms (Study II-V), perception of indoor environment (study V), building factors, the home environment, or personal and household factors. The null hypotheses,  $H_0$ , in the different studies can be formulated as follows:

- There is no relationship between symptoms, home-related symptoms, and building related factors, personal factors, household factors (study II).
- There is no relationship between symptoms, and indicators of building dampness (study III).
- There is no relationship between symptoms, and heating and ventilation system, reconstruction and energy saving measures (study IV).
- There is no relationship between symptoms and perceived air quality and thermal comfort, and a reduced airflow during heating season by seasonally adapted ventilation (study V).

The concept of “**personal factors**” includes; a history of allergy, asthma or eczema (atopy), hay fever, age and gender, current smoking and time spent in the dwelling.

The concept of “**home environment**” includes;

**-building related factors:** age of the building, type of ventilation and heating system, number of apartments, ownership of the building

**-household factors:** population density (subjects/room), window opening habits

**-building dampness:** condensation on or between windows, high humidity in bathroom, mouldy odour, history of water damage

**-reconstruction:** total reconstruction (renewal) new value in the taxation register, exchange of ventilation, exchange of heating system

**-energy saving measures:** additional insulation of phased, insulation of roof or attic, additional sealing of window frames, exchange of windows, additional heat pump

**-seasonally adapted ventilation:** exhaust airflow regulated by outdoor temperature, giving less flow (0.35 ACH) during heating season (November-March), higher flow (0.6 ACH) during the rest of the year (April – October).

The research hypotheses  $H_1 \neq H_0$

## Results

### Development of a validated indoor questionnaire (SIEQ) -Study I

A standardised questionnaire for dwellings – the Stockholm Indoor Environment Questionnaire (SIEQ) was developed, based on sociological principles and test procedures for validation. The indicators of indoor environment are air quality, thermal climate, noise and illumination. The indicators of health are symptoms comprised in the sick building syndrome (SBS). The questionnaire also contains questions about the apartment, individual behaviour, personal- and household factors. The everyday language describing the building and its function was first obtained by qualitative personal interviews, then by standardised questions. The interview questionnaire was transformed into a postal self-administered questionnaire. The reduction of the questionnaire was based on correlation analysis. It was found that to obtain a good validity, general questions are not sufficient, but specific question on perceptions and observations are needed. Good test-retest agreement was found both on an area level, building level, individually. The response rate has been good when the questionnaire has been used, mostly over 75%, often 85-90% and the partial loss of answers on individual questions is usually less than 6%. An overview of the different variables covered by the questionnaire is given in figure 3. The questionnaire will be available in 2003 at the home page of the publishing journal ([www.indoorair.com](http://www.indoorair.com)).

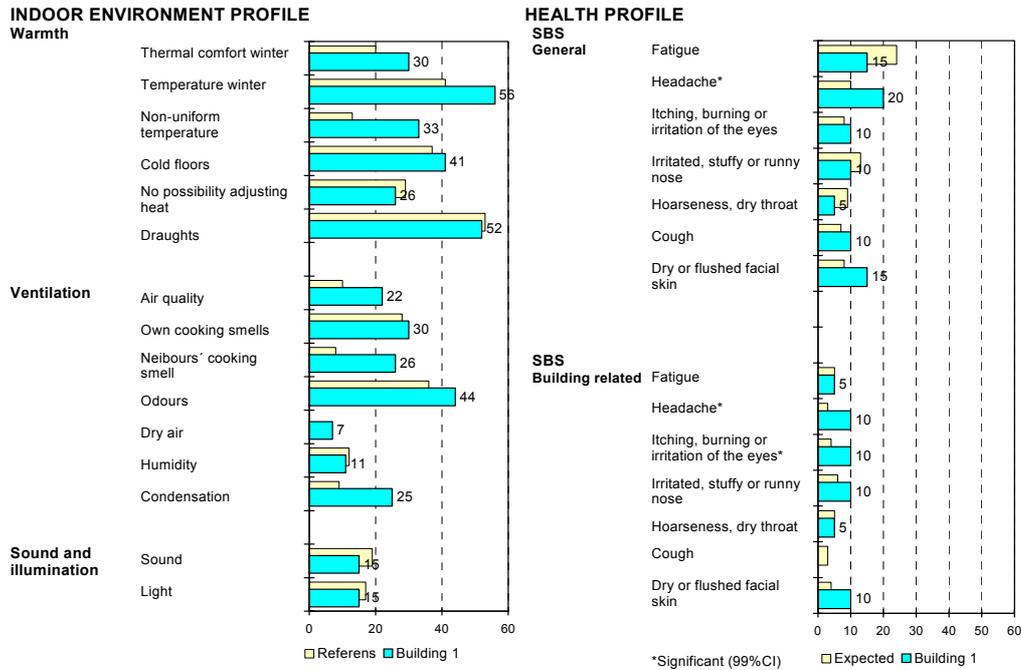
**Figure 3.** Variables in the Stockholm Indoor Environment Questionnaire (SIEQ).

Building	Population	Indoor environment	Health
<ul style="list-style-type: none"> <li>-ventilation</li> <li>-heating</li> <li>-building age</li> <li>-building size</li> <li>-ownership</li> <li>-rebuilding</li> </ul>	<p><b>personal factors:</b></p> <ul style="list-style-type: none"> <li>-age</li> <li>-gender</li> <li>-atopy</li> <li>-current smoking</li> </ul> <p><b>household :</b></p> <ul style="list-style-type: none"> <li>-size</li> <li>-marital status</li> <li>-sum of children</li> </ul> <p><b>behaviour:</b></p> <ul style="list-style-type: none"> <li>-airing habits</li> <li>-cleaning habits</li> <li>-residency time</li> </ul> <p><b>attitudes:</b></p> <ul style="list-style-type: none"> <li>-dwelling satisfaction</li> </ul>	<p><b>air quality:</b></p> <ul style="list-style-type: none"> <li>-air</li> <li>-diffuse odour</li> <li>-specific odour</li> <li>-moisture</li> </ul> <p><b>thermal comfort:</b></p> <ul style="list-style-type: none"> <li>-air temperature</li> <li>-warmth/cold surface</li> <li>-drought,</li> <li>-humidity</li> </ul> <p><b>sound quality:</b></p> <ul style="list-style-type: none"> <li>-diffuse noise</li> <li>-specific noise</li> </ul> <p><b>illumination:</b></p> <ul style="list-style-type: none"> <li>-daylight</li> <li>-sunlight</li> </ul>	<p><b>SBS-symptoms:</b></p> <ul style="list-style-type: none"> <li>-ocular</li> <li>-nasal</li> <li>-throat</li> <li>-cough</li> <li>-facial dermal</li> <li>-headache</li> <li>-fatigue</li> </ul>
<p>Dwelling</p> <ul style="list-style-type: none"> <li>-size</li> <li>-floor</li> <li>-population density</li> <li>-water leakage</li> <li>-condense</li> <li>-redecorating</li> </ul>			

When indoor environment and health perceptions in an particular building are evaluated, a presentation in a standardised graphic form is used. The “**indoor environment profile**” and “**health profile**” shows the prevalence of annoyance and symptoms in relation to norm values. Norm values for environmental perceptions are average prevalence data in the Stockholm area. Norm values for the health profile are expected prevalence figures calculated by a multiple logistic regression model, adjusting for ownership and demographical parameters, using the model developed in study II.

Figure 3 and 4 are adapted from paper I

**Figure 4.** Indoor environment profile shows the frequency (%) for environment questions, health profiles shows prevalence (%) of SBS-symptoms in general, as well as building related symptoms.



One question in the questionnaire gives the occupant the possibility to evaluate 16 different common indoor environmental problems that may occur in their homes. In a cross sectional study with a stratified random sample with 609 multifamily buildings and 9 809 dwellings in Stockholm (Study II) the most usual problems for all building periods concerned “low indoor temperature during winter”, “noise”, “cold floors”, “smells of cooking”, “dry air”, and “draught”. In buildings built before 1931 the number 1 problem is about “too low indoor temperature”, for buildings between 1931-1960 it is “noise” problems, for 1961-1975 it is “cold floors” and in buildings built after 1976 “dry air” is ranked as number 1. However “dry air” is not a new problem only for these new building periods, also occupants living in older buildings, evaluate this problem among the five most stated (Figure 5).

**Figure 5.** Ranking list of indoor environment problems evaluated by occupants living in multi-family buildings in Stockholm 1991/1993 (Engvall 2000). "Rate the problems that may possible occur in your home. Mark the degree to which you agree with various statements - I agree entirely, partly, not at all, have no opinion".

Building period					
Rank	- 1930	1931 – 1960	1961 – 1975	1976 – 1984	1985-1990
1	low indoor temp. winter <sup>1</sup>	noise	cold floors	dry air	dry air
2	noise <sup>2</sup>	cold floors	low indoor temp. winter	cold floors	cold floors
3	cold floors <sup>3</sup>	draught <sup>6</sup>	draught	smells of cooking	low indoor temp. winter
4	smells of cooking <sup>4</sup>	low indoor temp. winter	smells of cooking	low indoor temp. winter	low indoor temp mornings <sup>8</sup>
5	dry air <sup>5</sup>	condens <sup>7</sup>	dry air	noise	noise

1 = "it is often too cold in the apartment during the winter"

2 = "I hear sounds from neighbours far too often"

3 = "the floor of the apartment often feels too cold"

4 = " I am often annoyed by smells of cooking in the apartment"

5 = "the air in the apartment often feels too dry"

6 = "I often feel draughts from windows and/or the balcony door"

7 = "condensation often occurs on the windows when I am cooking"

8 = "the apartment often feels too cold in the mornings"

## A statistical model to identify multi-family buildings with SBS - Study II

The three-month prevalence of weekly symptoms was quite high. Cough, nasal symptoms, throat symptoms were most common. In total, 36% reported at least one weekly symptom. And 13% reported at least one weekly building-related symptom. Headache and fatigue was not analysed in this study. Personal risk factors for symptoms were female gender, a history of atopy, high age (>64 y). Moreover, symptoms were more common in newer buildings and the relationship between symptoms and age and gender was the same for all building periods. Subjects owning their own dwelling reported less SBS symptoms, but the relationship between ownership and

building age was strong. A multiple logistic regression analysis was developed including the major predictors, adjusting for ownership of the building, building age and size, age, gender, atopy. A similar pattern of risk factors was found, when comparing risk factors for total symptoms, building-related symptoms. Risk factors for total symptoms are presented in table 1.

**Table 1.** Significant predictors of total symptoms in the final models (OR= odds ratio)

Factor	Eye OR (95% CI)	Nose OR (95%CI)	Throat OR (95% CI)	Cough OR (95%CI)	Facial skin OR (95%CI)
<b>Ownership:</b>					
private	1	1	1	1	1
public	1.4(1.4-1.5)	1.4(1.4-1.5)	1.7(1.7-1.8)	1.3(1.3-1.4)	1.2(1.2-1.3)
<b>Age:</b>					
18-64y	1	1	1	1	1
>64 y	1.6(1.6-1.7)	1.2(1.2-1.3)	1.4(1.3-1.4)	1.5(1.4-1.5)	0.4(0.3-0.4)
<b>Gender:</b>					
male	1	1	1	1	1
female	1.5(1.5-1.6)	1.1(1.1-1.1)	1.6(1.6-1.7)	1.2(1.2-1.3)	2.3(2.2-2.4)
<b>Atopy:</b>					
no	1	1	1	1	1
yes	6.8 (6.6-7.1)	6.5(6.3-6.6)	4.9(4.7-5.0)	5.6(5.4-5.8)	4.6(4.5-4.8)

The statistical model was applied to calculate the proportion of multi-family building with a significant excess of at least one symptom, here defined as “risk building”, for buildings of different age in the total building stock. According to the model, 5% of all buildings built before 1961, 7% of those built in 1961-1975, 13% of those built in 1976-84, 15% of those built in 1985-90 would have significantly more SBS than expected (Figure 6).

**Figure 6.** Proportion of "risk building" in Stockholm, buildings of different building periods.

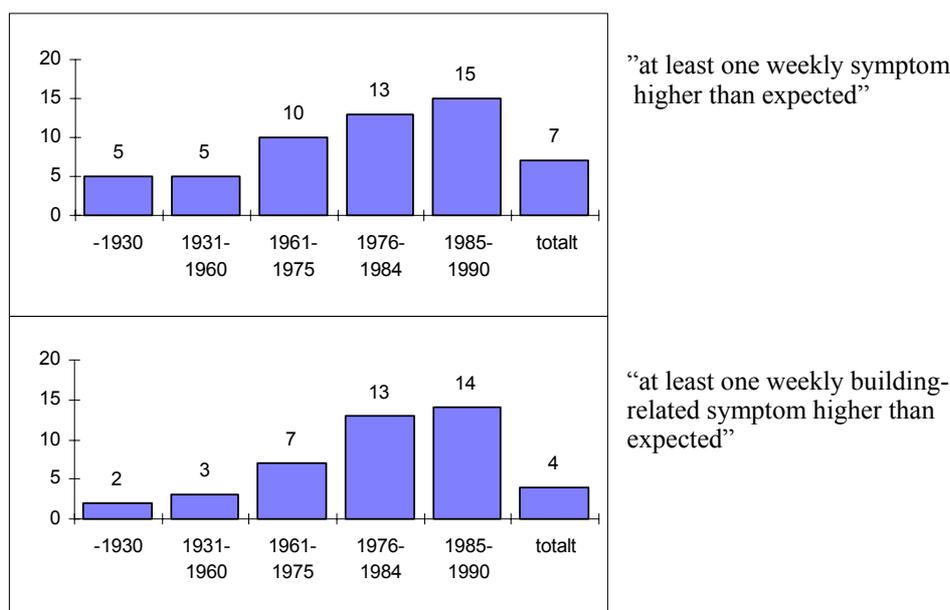


Table 1 and Figure 6 are adapted from paper II.

### Indicators of building dampness in relation to SBS - Study III

Most of the buildings (45%) had exhaust ventilation only, 21% had both supply/exhaust ventilation, 34% had no mechanical ventilation. In total, 38% of the buildings were public owned, 29% were owned by the inhabitants, 33% had a private landlord. Reports on signs of building dampness, high air humidity were common. Condensation on windows, high air humidity in the bathroom, mouldy odour, and water leakage was reported from 9%, 12%, 8%, and 13% of the apartments. In total, 29% had at least one sign of dampness. A history of water leakage was most common in the oldest buildings, built before 1931 (15%). All other types of building dampness were most common in buildings from 1961-75. Signs of condensation, high air humidity, and mouldy odour were less common in dwellings owned by

the inhabitants; water leakage was more common in dwellings owned by a private landlord. There was slightly more condensation on windows and high air humidity in dwellings without mechanical ventilation. The mean population density was 0.8 subjects per room, only 2.8% of all apartments had more than 2 subjects per room. The population density was 10-20% higher in buildings with signs of dampness, a numerically small but statistically significant difference.

All indicators of dampness were related to an increase of all types of symptoms, significant even when adjusting for age, gender, population density in the apartment, type of ventilation system, ownership of the building. A combination of mouldy odour and signs of high air humidity was related to an increased occurrence of all types of symptoms (OR=3.7-6.0). Similar findings were observed for a combination of mouldy odour and structural building dampness (water leakage) (OR=2.9-5.2) (Table 2). The relationship was similar in all age classes when stratifying different building periods (Table 3 and Table 4). A dose-response relationship between symptoms and number of signs of dampness was observed. In dwellings with all four dampness indicators, OR was 6.5, 7.1, 19.9, 5.8, 6.1, 9.4, 15.0 for ocular, nasal, throat, cough, headache and tiredness, respectively, as compared to dwellings without any signs of dampness (Table 5).

**Table 2.** Different symptoms in relation to combinations of mouldy odour and other building dampness characteristics

Type of symptom	Mouldy odour and signs of high air humidity <sup>a</sup> Adjusted OR(95%CI) <sup>c</sup>	Mouldy odour and structural building dampness <sup>b</sup> Adjusted OR (95%CI) <sup>c</sup>
Eye irritation	5.50(5.20-5.81)***	5.20(4.82-5.62)***
Nasal	4.28(4.08-4.49)***	4.31(4.03-4.61)***
Throat	5.29(5.01-5.58)***	5.08(4.72-5.48)***
Cough	3.97(3.74-4.22)***	3.78(3.46-4.12)***
Facial skin irritation	4.05(3.83-4.28)***	2.94(2.70-3.20)***
Headache	5.97(5.68-6.28)***	3.32(3.08-3.58)***
Tiredness	3.67(3.51-3.84)***	4.12(3.87-4.39)***

\*\*\*p<0,001

<sup>a</sup>A combination of mouldy odour and either condensation on windows or high air humidity in the bathroom

<sup>b</sup>A combination of mouldy odour and episodes of a major water leakage during the past five years.

<sup>c</sup> Adjusting for age, gender, each of the two combined dampness indicators, separately in the model.

**Table 3.** Different symptoms in relation to combinations of mouldy odour and signs of high air humidity for different building periods (adj.OR).

Mouldy odour and signs of high air humidity <sup>a</sup>				
Type of symptom	-1960 OR(95%CI) <sup>c</sup>	1961-1975 OR(95%CI) <sup>c</sup>	1976-1984 OR(95%CI) <sup>c</sup>	1985-1990 OR(95%CI) <sup>c</sup>
Eye irritation	3.5(3.2-3.8)	0.7(9.7-12.0)	5.0(4.0-6.5)	3.6(2.2-5.7)
Nasal	4.9(4.6-5.2)	3.0(2.8-3.3)	6.2(5.0-7.6)	4.4(3.0-6.6)
Throat	4.2(3.9-4.6)	6.2(5.7-6.8)	5.2(4.2-6.5)	4.0(2.6-6.2)
Cough	4.3(3.9-4.6)	2.5(2.3-2.8)	9.2(7.3-11.7)	6.0(3.8-9.2)
Facial skin irritation.	4.2(3.9-4.5)	3.6(3.2-4.0)	7.0(5.6-8.7)	3.0(1.8-4.7)
Headache	4.5(4.2-4.8)	8.1(7.5-8.9)	7.6(6.2-9.4)	11.6(7.7-17.2)
Tiredness	3.3(3.1-3.5)	4.7(4.4-5.1)	4.5(3.6-5.5)	4.2(2.8-6.2)

\*\*\*p<0.001 for all entries

a A combination of mouldy odour and either condensation on windows or high air humidity in the bathroom

c Adjusting for age, gender, each of the two combined dampness indicators, separately in the model.

**Table 4.** Different symptoms in relation to combinations of mouldy odour and structural building dampness for different building periods (adj.OR).

Mouldy odour and structural building dampness <sup>b</sup>				
Type of symptom	-1960 OR(95%CI) <sup>c</sup>	1961-1975 OR(95%CI) <sup>c</sup>	1976-1984 OR(95%CI) <sup>c</sup>	1985-1990 OR(95%CI) <sup>c</sup>
Eye irritation	4.2(3.8-4.6)	8.4(7.3-9.8)	12.0(8.6-16.8)	9.8(3.0-31.8)
Nasal	4.1(3.8-4.4)	5.0(4.4-5.7)	8.1(5.9-11.0)	1.5(0.4-6.4)
Throat	4.7(4.2-5.2)	6.1(5.3-7.0)	7.0(5.1-9.6)	8.5(5.4-61.5)
Cough	4.5(4.1-5.1)	1.9(1.6-2.7)	5.4(11.1-21.1)	NA
Facial skin irritation	3.6(3.2-4.0)	1.3(1.1-1.7)	6.8(4.9-9.6)	15.1(4.5-51.1)
Headache	1.7(1.5-1.9)	8.8(7.7-10.1)	8.4(6.2-11.3)	NA
Tiredness	3.7(3.5-4.0)	5.2(4.6-6.0)	9.6(6.8-13.5)	0.7(0.2-2.7)

\*\*\*p<0.001 for all entries

b A combination of mouldy odour and episodes of a major water leakage during the past five years.

c Adjusting for age, gender, each of the two combined dampness indicators, separately in the model.

**Table 5** Adjusted odd ratios and 95% confidence intervals (CIs)<sup>a</sup> for relationships between different symptoms and building dampness index

Type of symptom	Number of dampness characteristics			
	1	2	3	4
	adjOR(95%CI)	adjOR (95% CI)	adjOR (95%CI)	adjOR (95%CI)
Eye irritation	1.45(1.4-1.5)	3.17(2.93-3.22)	5.42(5.07-5.80)	6.53( 5.61-7.61)
Nasal	1.17(1.1-1.2)	1.99(1.90-2.08)	4.22(3.96-4.50)	7.12( 6.20-8.17)
Throat	1.47(1.4-1.5)	3.25(3.10-3.40)	4.11(3.83-4.40)	19.91(17.05-23.24)
Cough	1.70(1.6-1.8)	2.22(2.10-2.35)	2.79(2.56-3.03)	5.82 ( 4.95-6.85)
Facial skin	1.51(1.5-1.6)	2.61(2.49-2.74)	2.82(2.61-3.04)	6.10 ( 5.22-7.12)
Headache	1.37(1.3-1.4)	2.60(2.48-2.72)	5.31(4.98-5.66)	9.36 (8.13-10.78)
Tiredness	1.40(1.4-1.4)	1.84(1.78-1.91)	3.56(3.35-3.78)	14.95(12.44-17.98)

\*\*\*p<0.001 for all entries

<sup>a</sup>Adjustment was made for age, gender and dampness index

Coding of dampness index: 0=none of the four signs present 1=any of the four signs of dampness present (condensation on windows, high air humidity in bathroom, mouldy odour, or water leakage)

2=any two of the four dampness indicators present 3=any three of the four dampness indicators present

4=all four indicators present

Table 2 and table 5 are adapted from paper III

## Heating, ventilation, energy conservation, reconstruction in relation to SBS - Study IV

The population was relatively stable, 77% had lived more than 3 years in the same apartment. Most of the buildings (84%) had no mechanical ventilation; the district heating system heated the majority (65%). A few buildings had oil combustion in the house (27%), heating by electric radiators (3%), wood combustion (5%), and additional heat pump to extract energy from the surroundings (2%). In total, 48% lived in buildings that had gone through at least one type of reconstruction or energy saving remedies, during the latest 10 years, including exchange of heating or ventilation system, and sealing measures (exchange of windows, sealing of window frames, roof/attic insulation, and phased insulation).

Subjects in buildings with a mechanical exhaust ventilation system reported less symptoms (OR=0.75-0.92), as compared to those without mechanical ventilation, except for throat irritation and tiredness which was slightly more

common (OR=1.08-1.24). Subject in buildings with supply/exhaust ventilation had less symptoms (OR=0.28-0.73), except for cough and headache which was more common (OR=1.18-1.97). Heating by electric radiators, and wood heating was associated with an increase of most symptoms (OR=1.18-1.74). Energy saving was associated with both a decrease and increase of different symptoms (Table 6). Major reconstruction of the interior of the building was associated with an increase of most symptoms (OR=1.09-1.90), buildings with more than one sealing measure had an increase of ocular, nasal symptoms, headache and tiredness (OR=1.22-2.49)(Table 7).

**Table 6** Adjusted odd ratios (OR) with 95% confidence interval (CI) for relationship between different symptoms, energy saving remedies, major reconstruction (restriction to isolated measures).

	Eye	Nasal	Throat	Cough	Facial skin
Exchange of ventilation	0.7(0.6-0.8)	1.2(1.1-1.4)	2.0(1.8-2.3)	0.6(0.5-0.8)	0.9(0.8-1.0)
Exchanged heating system	1.3(1.1-1.4)	1.3(1.2-1.4)	1.2(1.1-1.4)	1.1(0.9-1.2)	0.8(0.7-0.9)
Additional heat pump	1.7(1.2-2.4)	1.8(2.4-3.5)	5.0(3.9-6.6)	1.7(1.2-2.4)	2.2(1.7-2.8)
Total reconstruction	1.6(1.4-1.9)	1.3(1.1-1.4)	1.0(0.9-1.1)	1.9(1.7-2.2)	1.3(1.2-1.4)

	Headache	Tiredness
Exchange of ventilation	0.7(0.6-0.8)	1.2(1.1-1.4)
Exchanged heating system	1.3(1.1-1.4)	1.3(1.2-1.4)
Additional heat pump	1.7(1.2-2.4)	1.8(2.4-3.5)
Total reconstruction	1.6(1.4-1.9)	1.3(1.1-1.4)

The multiple logistic regression models include age, gender, hay fever, current smoking, population density (subjects/room), type of ventilation (dummy), type of ownership (dummy), type of heating system (dummy) kept on the model simultaneously, each of the exposure variables (energy saving remedies) added separately in the model. The analyses were restricted to subjects with isolated measure, compared with subjects in buildings without any measurements at all.

**Table 7** Relationship between number of sealing measures and different symptoms.

Type of symptom	Number of sealing measures	
	1 adjOR(95%CI)	2 adjOR (95% CI)
Eye irritation	0.92(0.87-0.98)**	2.49(2.21-2.79)***
Nasal	0.89(0.84-0.93)***	1.32(1.19-1.46)***
Throat	0.99(0.93-1.05)	0.89(0.79-1.01)*
Cough	0.71(0.66-0.77)***	0.60(0.51-0.71)***
Facial skin irritation	0.63(0.59-0.66)***	0.81(0.71-0.93)**
Headache	1.51(1.44-1.59)***	1.22(1.10-1.35)***
Tiredness	0.98(0.95-1.02)	1.86(1.74-1.99)***

\*\*\*p<0.001

The multiple logistic regression models include age, gender, current smoking, hay fever, population density (subjects/room), type of ventilation (dummy), type of heating system (dummy), type of ownership (dummy), sealing-index in the model.

Coding of sealing index:

0=No sealing measure (reference category)

1=Any of the four sealing measures (sealing of window frames, window exchange, insulation of phased, or insulation of roof/attic)

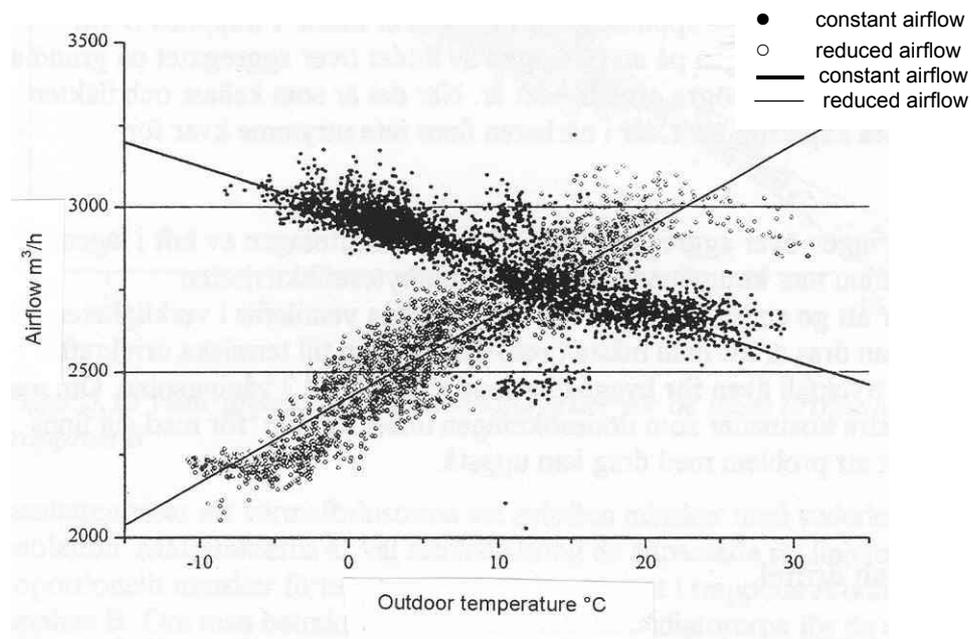
2=Two or more of the four sealing measures

Table 6 and Table 7 are adapted from paper IV.

## Seasonal adapted ventilation and air quality in relation to symptoms -Study V

How the two operational principles work at different outdoor temperatures illustrates in Figure 7. The “seasonally adapted ventilation” gives a lower airflow at lower outdoor temperature, while the constant flow operation creates an inverse relationship.

**Figure 7** Airflow rate for different outdoor temperature for dwellings with constant airflow compared to dwellings with seasonal adapted airflow (reduced airflow).



The season adapted ventilation is programmed to give a 25-30% lower outdoor air flow during the heating season, when the questionnaire evaluation was performed. This reduced ventilation increased the relative air humidity by 1-3% in the living room, 1-5% in the bathroom during heating season. The room temperature increased 0.1-0.3°C, 24-h mean CO<sub>2</sub> increased from 721 ppm to 761 ppm. Mean carbon dioxide (CO<sub>2</sub>) concentration in the bedroom during the night period (midnight to 6 a.m.) increased from 920 to 980 ppm at reduced flow (Table 8).

If nocturnal CO<sub>2</sub>-data is used to calculate personal outdoor airflow, assuming equilibrium, the mean personal outdoor airflow in the bedroom was 8.6 L/s at constant flow, 7.8 L/s at reduced flow, a 9% reduction. The measured mechanical ventilation flow was 19% lower at reduced flow operation. The consumption of electricity for the operation of ventilation fans was reduced by 17%, the energy consumption for heating of the ventilation air was reduced by 13% at reduced flow.

**Table 8** Temperature, air humidity, ventilation flow and carbon dioxide concentration in dwellings with constant airflow and with reduced airflow under the heating season (November –March)

Variable	Constant air flow arithmetic mean range	Reduced airflow arithmetic mean range	P-value
Room temperature, living room (°C)	21.1 (0.58)	21.2 (0.48)	<0.001
Room temperature, bedroom (°C)	20.6 (0.41)	20.7 (0.44)	<0.001
Outdoor temperature (°C)	0.6 (3.60)	0.6 (3.60)	NS
Exhaust air flow (m <sup>3</sup> /h)	2775 (229)	2258 (199)	<0.001
Relative air humidity living room (%)	32 ( 4.5)	34 ( 8.7)	<0.001
Relative air humidity bathroom (%)	48 (10.3)	55 (14.8)	<0.001
Carbon dioxide concentration in bedroom (CO <sub>2</sub> )	721 (235)	761 (313)	<0.001

The indoor air quality was perceived as poorer at reduced outdoor air flow, both in the bedroom and in the apartment as a whole, the perception of stuffy odour was more common (Table 9). No significant influence on any medical symptoms or perception of air dryness or thermal discomfort could be detected.

**Table 9** Perception of indoor air quality and general thermal comfort during constant ventilation flow operation, as compared to seasonal adapted ventilation (SAV), with a 20% reduced mechanical ventilation flow during the heating season (November- March)

Type of perception/discomfort	Constant flow <sup>a</sup> (N=44) (%)	SAV flow <sup>b</sup> (N=44) (%)	p-value <sup>c</sup>
Often perception of dry air	3	8	NS
Pungent odour	7	7	NS
Mouldy odour	5	15	NS
Musty odour	18	20	NS
Stuffy odour	12	30	0.05
Poor or very poor indoor air quality in general – living room	5	7	NS
– bedroom	0	5	0.04
– apartment	2	12	0.03
Poor or very poor thermal comfort in general - apartment	26	14	NS

<sup>a</sup>Group B during the first heating season and group A during the second heating season

<sup>b</sup>Group A during the first heating season and group B during the second heating season

<sup>c</sup>Statistical testing of changes of perception index in the group with constant airflow system, as compared to changes of perception index in the group with SAV flow, by Mann Whitney U-test

*Coding of perception of dry air:* 0=never; 1=sometimes; 2=often perception of dry air

*Coding of odour perception:* 0=no odour, 1= odour

*Coding of indoor air quality in general:* 0=very good; 1=good; 2=acceptable; 3=poor; 5=very poor

*Coding of thermal comfort in general:* 0=very good; 1=good; 2=acceptable; 3=poor; 5=very poor

\* Calculated as difference in perception index (0-2) with reduced airflow system and constant airflow system after the study period

†Proportion of subjects (%) with a negative value of perception change (range -2 to 2).

‡Proportion of subjects (%) with a positive value of perception change (range -2 to 2)

§Test for difference in perception change in group 1 with group 2 with control units, by Mann Whitney U-test

Figure 7 and table 8 and table 9 are adapted from paper V.

## Discussion

A sociologically validated self-administered questionnaire, developed specifically for residential indoor investigations, was developed. It can be used both in epidemiological investigations as well as in practical building investigations, to identify specific environmental factors that could be improved in the dwelling. As a next step, a statistical model was developed that could be used to identify “risk buildings”, with significant increase of SBS. In such models, it is necessary to adjust for ownership and population characteristics of the inhabitants in the building. The proportion of “risk buildings” was highest in the newest buildings, suggesting a need to further investigate if newer building technology is creating new indoor environmental problems. Signs of high relative air humidity, and building dampness were consistently associated with medical symptoms. The associations remained even when adjusting for personal factors and other building-related factors linked to ventilation, social indicators such as ownership, and population density in the apartment. The associations were strengthened by combining signs of dampness with perception of mouldy odour, an association between symptoms and number of signs of dampness was observed.

The presence of a mechanical ventilation system was associated with a decrease of many symptoms. Heating by electric radiators, wood heating, use of heat pumps for energy saving was associated with symptoms. Moreover, major reconstruction, multiple sealing measures seemed to be risk factors for symptoms. A reduction of outdoor ventilation flow in dwellings during the heating season to a level below the current Swedish ventilation standard (0.5 ACH), may cause a perception of impaired air quality even though technical measurements may only demonstrate small increase of indoor temperature, relative air humidity, and bedroom CO<sub>2</sub> concentration.

## Comments on development of an indoor questionnaire for residential use

A validated self-administered indoor environment questionnaire (SIEQ) was developed, from a sociological point of view. It means that not only medical symptoms, but also the perception of the indoor environment, the function, use and maintenance of the dwelling is in focus. The inhabitant's attitude has its focus on satisfaction with the dwelling and building. Personal relationships are more oriented to the building owner and caretaker. The main issues in developing the SIEQ questionnaire are indoor environment and health; these factors are operationalised as different indicators and questions. It is clear that dwellings have different indoor environments compared to work places and public environments, with respect to privacy, ownership, productivity, organisational and psychosocial aspects, ventilation and personal density. Previous questionnaire studies on sick building syndrome (SBS) have mainly been dealing with work-environments (e.g. offices, schools and hospitals)<sup>64,123-124,147</sup>, there is a lack of studies in dwellings<sup>68,122,125</sup>. Validation on SBS symptom questionnaires have been published<sup>140-141,148-149</sup>. To our knowledge, SIEQ is the first validated questionnaire particularly developed for residential use, covering a broad aspect of the home environment, not only SBS-symptoms.

### Validity aspects

From a sociological point of view, the validation process is essential since good validity presupposes good reliability; the reliability can be good even if the validity is poor. The validity of a questionnaire is good when it measures what is intended to be measured. The validation process was performed in four different steps, following common principles used in sociology<sup>150-153</sup>. To our knowledge, a similar validation procedure has not been previously described for currently used indoor questionnaires. Expressions in every day languages were identified, describing characteristics of the building and its function from the occupant's perspective. This was done in order to achieve a good content validity. Significant aspects of the indoor environment were selected, based on qualitative interviews, to achieve both a good content and internal validity. The interview questionnaire was transformed into a self-administered questionnaire and finally, statistical tests and technical criteria were applied to reduce the number of questions.

Construct validity is a term used in sociology to describe the agreement between a theoretically defined variable, and the empirical measurements of the variable. In research on the indoor environment, it can be defined as the

agreement between the indoor environmental experiences reported in the questionnaire, technical measurements and inspections. Some tests of the SIEQ have been performed, concerning physical variables (temperature, humidity)<sup>154</sup>. The relationship between measured air velocity and perception of draught has also been verified<sup>155</sup>. Technical measures confirmed that the dwellings in a building built with an acoustic insulation above Swedish standards, were less noisy than normally, the occupants were less disturbed by noise than in reference buildings<sup>156</sup>. Finally a conclusion from technical inspection in 140 dwellings in 11 buildings was that "the occupant's experience of the indoor environment gave a clear indication of the status of the dwelling"<sup>157</sup>.

### Responsiveness

Responsiveness is a sociological term used to describe the sensitivity of the questionnaire e.g. when environmental changes are performed in a building. In one study, SIEQ was tested in an intervention study, it was possible to measure differences in the questionnaire response before and after environmental improvements in a multi-family house<sup>158</sup>.

### Reliability

The reliability was tested and no systematic differences in response was observed, neither on area level nor on building level, when applying the questionnaire after one or two year, during the same season. From a sociological perspective, a good stability on a group level is most important. When testing reliability on individual level, asthmatic symptoms had a fair to good agreement (Cohens kappa =0.74), while the kappa value was lower (0.26-0.48) for most of the SBS-symptoms, and 0.33-0.55 for the different environmental perceptions. The reason could be a too long recall period and SIEQ may need more tests on individual level. Previous test-retest studies on other indoor questionnaires have been performed dealing mainly with occupational environments<sup>149,159-160</sup>. The commonly used MM-questionnaire was reported to yield kappa values from 0.40-0.70 for SBS-symptoms, 0.49-0.70 for environmental variables<sup>159</sup>. A new SBS-questionnaire developed for work environment in Denmark had kappa values from 0.40-0.75 for SBS symptoms<sup>160</sup>. In a German study also in work places, kappa values from 0.25-0.88 were reported for SBS symptoms and from 0.35-0.82 for complaints on indoor environment<sup>149</sup>. The kappa values between 0.40-0.70 are considered to indicate good agreement, while values greater than 0.75 are considered to indicate excellent agreement beyond chance, values below 0.40 may be taken to represent poor agreement beyond chance<sup>161</sup>.

## Burden

The response rate depends on the respondent burden, e.g. how difficult and time-consuming the questionnaire is, as well as other aspects such as the procedure when administrating the questionnaire<sup>150-153</sup>. The response rate has mostly been over 75% often 85-90% and partial loss of data due to lack of answers from specific questions was low. This suggests that the respondent burden of SEIQ is low.

## Reference values

This thesis has generated reference data for 609 multifamily buildings in Stockholm with 14.235 dwellings selected by stratified random sampling. Other indoor questionnaires have collected non-stratified data from a small number of “healthy” buildings<sup>159</sup>, or in larger stratified randomly selected data such as the ELIB study covering 1029 multifamily buildings in different parts of Sweden<sup>162</sup>.

## Comments on occupants ranking of indoor environmental problems

Using reference values one compares a separate building with representative values from cross-sectional studies and then evaluate the results as more or less normal to standards. Another way is too let the occupants evaluate different indicators them selves, as was done in the cross sectional study in a stratified random sample of 609 multifamily buildings and 9 809 dwellings in Stockholm. With a possibility to rank 16 different common indoor environmental problems that may occur in their homes three of following five problems had a top ranking these were “low indoor temperature during winter”, “noise”, “cold floors”, “smells of cooking”, “dry air”, and “draught”. In buildings built before 1931 the number 1 problem was about “too low indoor temperature”, for buildings between 1931-1960 it was “noise” problems, for 1961-1975 “cold floors” and in buildings built after 1976 “dry air” is ranked as number 1. A sensation of dryness as a risk factor for SBS has been an important indicator of the “sickness” of a building<sup>163</sup>. However “dry air” seems not to be a new problem only for these new building periods, also occupants living in older buildings, put this problem among the five most stated. Studying the mutual range among the top five problem statements for different building periods, the statement on “dry air” and “low temperature” has become higher in the ranking order in newer

buildings, “draught”, “noise” and “smells of cooking” has become lower in the ranking order in new buildings.

## Comments on internal validity of epidemiological studies

### Selection bias

Selection bias can occur as a result of both a low response rate and an incorrect study design. Studies II – IV were large cross sectional studies, selected by stratified random sampling with a higher proportion of subjects in newer buildings. The buildings were selected from the building register in the municipality of Stockholm and the subjects were identified by combining this register with the civil registration register. These registers have a high quality and the proportion of subjects not found in the registers is negligible. The main sampling was done in 1991 and an additional sampling in 1993. In Study IV, a sub-sample of buildings build before 1961 was used. Selection bias due to low response rate is not likely since the participation rate was high and similar in the two samples (77%). The proportion of participants was similar in all age classes of the buildings, similar with respect to ownership. The age distribution was similar to the general population in Stockholm. Because of the cross-sectional design, selection effects where subjects with building-related symptoms had moved to other buildings could occur. However, the available data indicated that the population was relatively stable. The proportion of females (60%) was slightly higher than in the total adult population in Stockholm (53%). In the longitudinal experimental study the participation rate was reasonably good (76%). Since the study had a cross-over design the influence of building-related confounders such as differences in cardinal points, topography, seasonal effects was eliminated.

### Information bias

Many methodological problems are inherent in epidemiological studies on medical symptoms, particularly with regard to information bias. Since health questions can be sensitive issues, the “health question” in SIEQ is surrounded by more “neutral” environmental questions. Reporting of annoyance reactions to environmental factors can be influenced by information on the purpose of the study<sup>164</sup> or the attitude towards the noise-source<sup>165</sup>, dissatisfaction with the municipality services<sup>166</sup>. In addition,

attitudes may cause a cognitive bias of reporting symptoms, as was shown in an experimental exposure chamber study<sup>167</sup>. In the SIEQ, the initial questions deal with general satisfaction or dissatisfaction with different aspects of the apartment, e. g. size, planning and standard, rent cost, management. These questions are put first in order to minimise "spill over effects" of emotional feelings on the reporting of environmental factors. When studying total symptoms or building-related symptoms, similar predictors of symptoms were identified, this makes it less likely that our results are seriously affected by attitudes to the building.

Another methodological problem is possible recall bias in relation to awareness of the exposure. Building age and ownership was obtained from the building register, information on the ventilation system, heating system, reconstruction and energy saving was obtained from the building owner. Thus, this information was gathered independently of the participants. Information on signs of building dampness was assessed by the SIEQ-questionnaire. This could result in recall bias. In previous validation studies on self-reported building dampness, a good reproducibility of self-administered questions on building humidity, visible moulds, flooding has been reported when comparing with expert observation in dwellings<sup>108,168</sup>. From Canada, the Netherlands, Sweden, there has been similar reporting of signs of dampness by subjects with and those without respiratory symptoms<sup>108,168,176</sup>.

A problem pointed out by Peat et al.<sup>98</sup>, is co-variation between building dampness and other environmental factors in the building, e.g. population density and ventilation flow. We made adjustments for other building factors, such as population density, type of ventilation system, ownership of the building, without any major change of the associations between signs of dampness or different energy saving measures and symptoms.

The intervention study (V) had a cross-over design; the ventilation principle was changed without the occupant's knowledge. Technical measurements were performed in a separate part of the building, among subjects not included in the study population. By this design, we could eliminate information bias that could occur if we had been performing technical measurements in apartments belonging to the participants.

A number of statistical tests were carried out in the cross sectional studies (II- IV), but they were all highly significant. Thus, we do not believe that our conclusions are seriously biased by selection or information bias, or due to chance findings, or selection of a particular statistical model. The true

adverse health effect of building factors could, however, been underestimated if there were a health based selection.

## External validity

The SIEQ-questionnaire was developed for Scandinavian conditions, but could probably be used in temperate climate zones in other parts of the world. Due to cultural and linguistic differences, differences in the use of the dwelling, the local user of the questionnaire must consider such limitations. Locally produced normal values, locally developed statistical models are also crucial when evaluating the results in particular buildings. Since the multi-family buildings were stratified and randomly chosen as well as the subjects in the study the results are representative for the ordinary building stock and population in the Stockholm area. The prevalence of SBS-symptoms are nearly the same as in the large ELIB study<sup>162</sup> covering the whole country, which suggests that results should have sufficient external validity.

## Comments on development of decision model

The decision model study (II) showed that symptoms compatible with sick building syndrome are common in the general population in Stockholm, related to atopy, age, female gender, building age, ownership of the building. Similar predictors were identified in this study, irrespective of studying total symptoms or building-related symptoms. In view of these findings, the subsequent studies in the thesis focused on total symptoms, irrespective of the participant's opinion about causes. Moreover, symptoms were more common in newer buildings and the relationship between symptoms and age and gender was the same for all building periods. In Scandinavia, self-administered questionnaire studies are commonly used as a first step in routine investigations in problem buildings<sup>139</sup>. The distribution of important risk factors for SBS, e.g. demographic factors or occurrence of atopy, may differ between buildings. To identify building-related problems, it is important to take such aspects into consideration. This investigation has demonstrated a new method to create such decision models and identify "risk buildings", controlling for other important risk factors.

## Comments of personal risk factors

The results concerning gender are in accordance with previous studies in the general adult population<sup>125-126</sup>, in office workers<sup>124,132</sup>. The reason for the gender difference is unclear, however, it has been proposed that it could be related to differences in life situations and social roles, a reflection of general excess of psychosomatic symptoms among women, but it could also reflect differences in exposure situations<sup>169</sup>. In a recent study, it was reported that females had a lower sense of coherence (SOC) than men, that subjects with low SOC had 2-3 times more SBS-symptoms. A person with a low sense of coherence is more likely to perceive stressful situations as threatening and anxiety provoking<sup>41</sup>.

The difference between age and SBS seems to be more complex, there is no consistent pattern reported from the literature<sup>119-120,170</sup>. We found a higher prevalence of facial dermal symptoms in younger subjects, but for all other symptoms the prevalence was higher among those above 65 years. The age relation was inversed, with more symptoms in younger subjects, if building-related symptoms were considered. A study population among younger subjects (<40 year) in Denmark reported more mucosal irritation during springtime (OR=1.5) than older subjects<sup>126</sup>. Burge<sup>130</sup> found that those between 21 and 40 years of age reported more symptoms than either younger or older subjects. Oie et al.<sup>39</sup> found that very young subjects reported more symptoms, Brasche<sup>131</sup> found that age is a significant risk factor for SBS but only in men. In five studies, no relationship between age and SBS could be demonstrated<sup>63,68,127,132,171</sup>. The large ELIB-study report varying relationship between age and SBS<sup>125</sup>.

We defined a history of atopy as having either asthmatic symptoms, hay fever or eczema, in accordance with the questions used in the MM040 questionnaire<sup>139</sup>. In the initial version of the questionnaire, there was only one question on this topic, which made it impossible to use a more strict definition of a history of atopy. This wide definition of atopy may include other types of hypersensitivity such as non-atopic asthma, non-atopic eczema. By using this definition a history of atopy was found to be one of the strongest predictors for all SBS-symptoms irrespective if studying symptoms in general, or building-related symptoms. Other studies using a more strict and narrow definition of atopy have found similar results in the general population<sup>68,127</sup>, in office workers<sup>171</sup>, in hospital workers<sup>172</sup>, in airline crew<sup>173</sup>.

Unfortunately, we did not have information on smoking habits in the initial version of the questionnaire used in the initial statistical model. We have included data on smoking habits in subsequent studies in the Stockholm area, it did not turn out to be a major predictor of SBS-symptoms (unpublished data). Some other studies have found a relationship between smoking and SBS<sup>67,127,132,174</sup>, but there are other studies that did not find such a relationship<sup>68,133-134</sup>. The Danish Town Hall study found a slight increase of general symptoms, such as headache and fatigue among current smokers, but no relationship between current smoking and mucosal symptoms<sup>132</sup>.

## Comments on building age and ownership

The relationship between building age and SBS was significant, even when controlling for personal factors and ownership of the building. I buildings built before 1961, only 5% were found to be "risk buildings", according to the statistical model. These buildings were mostly stone buildings, majority without mechanical ventilation. The generation of buildings from 1961-1975 were built during a building boom, had 10% "risk buildings". The next generation of buildings (1976-84) were influenced by energy saving demands with many changes in construction techniques and new building materials. In this age class, with 13% "risk buildings", dampness in the floor construction became more common, self-levelling mortar containing casein was sometimes used<sup>122,175</sup>. The highest occurrence of "risk buildings" (15%) was found in the newest buildings, built from 1985-90. However, in the newest buildings we found the widest dispersion between buildings with high and low occurrence of "risk buildings". It is therefore important to carry out further epidemiological research on buildings from the nineties, to identify new building with a low prevalence of SBS, to guide the direction for future building design.

In this initial analysis we did not control for signs of building dampness, but building dampness (of any type) was relatively equally distributed between houses of different age. It is not likely that the association between building age and SBS is due to building dampness, defined by our questions aiming to identify building with high relative air humidity, microbial growth (mouldy odour), and water leakage. Signs of building dampness in the floor concrete slab, a risk factor for SBS-symptoms<sup>122,175</sup> in newer houses; was not included in our definition of building dampness. Newer building may have better general ventilation because of a mechanical ventilation system, but may contain other building materials and other emission sources that could cause symptoms. The reason for the observed increase of symptoms in new

buildings remains unclear, but is in agreement with some previous SBS-studies in offices<sup>123</sup>, hospitals<sup>172</sup>, dwellings<sup>125</sup>. It has also been shown that moving from old to new dwelling resulted in an increase in SBS-symptoms<sup>67</sup>.

Ownership was found to be major predictor of SBS, irrespective if studying symptoms in general, or building-related symptoms. This is in agreement with some previous SBS-studies in dwellings. The ELIB study found that inhabitants in single-family houses were more satisfied with the indoor environment at home, as compared to multi-family houses<sup>125</sup>. In Sweden, a large proportion of multi-family apartments of all ages are rental, owned by the community, with similar living standards and rental costs as private apartments. In the United Kingdom, office workers employed in the public sector had a higher prevalence of SBS, as compared to office workers in the private sector<sup>129</sup>. The reason for associations between SBS and ownership of dwellings is unclear, but it could be due to difference in social status or economic value of the dwelling, or differences in building maintenance.

## Comments on building dampness indicators

At least one sign of building dampness was found in 29% of the dwellings, using the following indicators; “a history of water damage over the past 5 years”, “high air humidity in bathroom”, “condensation on windows”, “mouldy odour”. A similar total prevalence of building dampness in dwellings, using different definitions, has been reported from other Swedish studies on adults<sup>68,104,108</sup>. In the Netherlands dampness was reported in 25% of homes<sup>102</sup>, in Canadian in 38%<sup>103</sup> and in UK 31%<sup>100</sup>.

Signs of building dampness were related to an increase of ocular, respiratory, facial dermal symptoms, as well as headache and tiredness. Moreover, an association was observed between number of signs of building dampness and symptoms. Signs of building dampness in the floor construction, or visible mould growth, were not included in the SIEQ-questionnaire. This may have caused an underestimation of the true prevalence of building dampness. On the other hand, some questions were aimed to measure high relative air humidity rather than building dampness as such. During some circumstances, high air humidity may lead to microbial growth on surface, but high air humidity may also be an indication of low air exchange rate. The association between dampness indicators and symptoms were consistent even when adjusting for other environmental and social factors such as population density in the apartment, ownership and presence

of a mechanical ventilation system. Moreover, the effect of building dampness was observed in all age strata when studying different building periods, which talks in favour of a true relationship. To our knowledge, this is the second largest epidemiological study on adults relating signs of home dampness with symptoms, associations were stronger than in many comparable studies, but well in agreement with available information on health effects of building dampness<sup>35,97,98</sup>. The physiological mechanisms behind the health effects of exposures in damp buildings, as well as the type of exposure responsible for the health effects, remains unclear. Recent studies have shown decreased tear film stability<sup>109</sup>, increase of nasal mucosal swelling or biomarkers of inflammation in damp buildings<sup>177-180</sup>. Other studies have shown an increase of general symptoms such as headache or fatigue in damp buildings<sup>104,100,181-182</sup>.

## Comments on heating energy conservation, reconstruction

Buildings with electric heating, wood heating, use of heat pumps had an increase of most SBS symptoms, but these building factors were rare. Since the prevalence of building dampness was higher in buildings with wood heating or heat pumps, it cannot be excluded that the observed associations were due to effects of building dampness, since we did not control for building dampness in the statistical models. Use of heat pumps is increasing in north Europe<sup>77</sup>, new studies should be performed to confirm or reject this finding. It has been reported that older types of Swedish heat pumps could spread *legionella* bacteria and other micro-organisms. The hot water tank often has a low temperature (25-48 °C), the heated water is used for both heat pump system, tap water, showers<sup>183</sup>.

Electric radiators were associated with an increase of most types of symptoms; the prevalence of building dampness in these buildings was not increased. During the investigation period, electric heating was mostly by means of the old type of direct heating electric radiators. The result is in agreement with previous publications, showing an increased risk for ocular and airway symptoms in dwellings with electric radiators<sup>184-185</sup>. The mechanisms remain unclear, but it has been demonstrated that ultra-fine particles are generated by dust pyrolysis at hot electric wires in direct electric radiators<sup>186-187</sup>. Another possible effect could be the formation of reactive products from pyrolysis of plastic compounds in house dust, e.g. pyrolysis of phthalate plasticizers in poly-vinyl-chloride (PVC) materials<sup>188</sup>.

Inhabitants living in buildings that were totally reconstructed had an increase of most types of symptoms. The reconstruction included exchange of the interior, introduction of new building materials, e.g. painting and exchange of floor materials, as well as exchange of water and sewage pipes, electric wires. The reconstruction took place from the end of the 60's until the middle of the 70's. Reconstruction during this period may have included introduction of plastic materials containing plasticizers, including PVC. Recent studies have demonstrated an increase of respiratory symptoms in dwellings with larger amounts of plasticizer containing indoor materials<sup>189</sup>, plastic wall materials<sup>190</sup>. Since plasticizers have a low volatility, long-term exposure mediated by particles may occur in dwellings<sup>191</sup>.

There were some indications that sealing of buildings, in order to save energy, could be a risk factor for symptoms. Building with more than one sealing measure (window exchange, sealing of window frames, insulation of roof/attic, phased insulation) had a slight increase of at least one SBS-symptom (OR=1.31; 95% CI 1.23-1.39). This is in agreement with one previous study from former East Germany, reporting an increase of health problems after thermal insulation of dwellings<sup>72</sup>. Our study did not support the view that energy-saving measures, in general, is an important risk factor for SBS-symptoms in dwellings. There is, however, a need to ensure that there is sufficient air exchange rate in the buildings after major reconstruction or multiple sealing measures in older dwellings.

## Comment on SBS and mechanical ventilation

In the initial statistical analysis, stepwise regression was used to construct a statistical model with a few explanatory variables. In this multiple regression model, covering all types of buildings, building age and ownership were the main predictors of symptoms; type of ventilation had lower explanatory value. In the further statistical analysis, we found that those living in older buildings with a mechanical ventilation system had fewer symptoms, as compared to those with natural ventilation only, particularly ocular and nasal symptoms. In 1996, the governmental Commission of Environmental Health concluded that 50% of Swedish multi-family dwellings did not fulfil the ventilation standards (0.35 L/s and m<sup>2</sup> of floor area, corresponding to 0.5 ACH)<sup>192</sup>. Moreover, CO<sub>2</sub> levels above 1000 ppm are common in bedrooms<sup>63</sup>. Our data supports the view that there is a need for increased ventilation flow in older multi-family houses. This is in agreement with conclusions from two review articles, suggesting that symptoms are more common at a personal airflow rates below 10 L/s<sup>61,62</sup>.

## Comments on ventilation flow and energy consumption

Seasonal adapted ventilation (SAV) is a new concept of energy conservation used in some multi-family houses in Sweden. The idea is to reduce airflow during the heating season, in order to reduce energy consumption and increase the thermal comfort. During the warmer part of the year, the air flow is increase in order to achieve a cooling effect. Since this ventilation principle reduces the mechanical air flow rate by 25-30% during the heating season (November-March), impairment of indoor air quality may occur. To our knowledge, our experimental study is the first health evaluation of SAV, one of the few experimental studies on health effect and annoyance in relation to ventilation flow in dwellings. Most experimental studies on ventilation flow in relation to heath aspects have been performed among office workers<sup>48,61-62</sup>. Despite limitations as the small study population, we could demonstrate an increase of stuffy air and perception of poor indoor air quality in the bedroom and in the apartment as a whole.

Since the building had a well functioning mechanical ventilation system, the average CO<sub>2</sub> concentration was below the 1000 ppm comfort limit value<sup>33,47</sup>, even when operating with a reduced ventilation flow. There was also a smaller increase in the CO<sub>2</sub> level than would be expected from a 20% reduction of ventilation flow rate. One explanation could be that the inhabitants compensated the reduced flow by increasing the natural ventilation. The indoor temperature was only slightly influenced by the operational principle, with 0.1-0.2 °C higher temperature when using SAV, during both the heating season, and the summer period. A reduced ventilation flow could be expected to increase the indoor relative air humidity. This could increase the risk for house dust mite infestation<sup>48</sup>. We did not measure relative air humidity in the bedroom, but the humidity in the living room was below 40-45%, irrespectively of operational principle. In conclusion, it is less likely that the SAV had any major influence on the infestation of house dust mites, or mould growth due to condensation. To draw definite conclusion about these biological risk factors, hygienic measurements should be performed in future studies. In conclusion, reducing the ventilation flow in dwellings to a level below the current Swedish ventilation standard (0.5 ACH ) may increase the perception of impaired indoor air quality. Technical measurements could only demonstrate a minor increase of indoor temperature, relative air humidity, a 9% increase of CO<sub>2</sub>-concentration. This illustrates that it is important to combine technical measurements with a longitudinal evaluation of occupant reactions, when evaluating energy saving measures.

## Conclusions and implications

The home environment is an important issue. Residential buildings are important social environments, important investments both for the individual and the society, and may have great significance for public health. The home environment is not just a function of building design or technical installations, but is directly influenced by environmental perceptions and behaviour of the inhabitants. In investigations in residential buildings, there is a need for a holistic approach, covering technical, medical, perceptual, and sociological aspects. To be able to do such studies, there is a need for questionnaires designed specifically for residential conditions. In this thesis, a validated questionnaire was developed, which can be used for residential investigations in the adult population. The development and validation process was based on sociological methods. Reference data was calculated for the Stockholm area. Moreover, a statistical decision model was developed that can be used to predict expected normal occurrence of symptoms in a particular building. The questionnaire can be used both in epidemiological investigations and as a tool for decision-makers when making priorities and identifying “risk building” where measures should be taken.

The epidemiological studies found that symptoms compatible with the sick building syndrome were common in the general population in Stockholm. Important predictors of symptoms were female gender, high age, and a history of atopy or asthma. Those living in newer dwellings, built after 1975 had a higher proportion of “risk buildings”, with more symptoms than expected. Moreover, subjects in newer dwellings ranked perception of air dryness as the most common indoor problem, while those in older buildings ranked noise and thermal comfort as the greatest problem. This indicates that there is a health problem in some of the newer residential buildings, possible linked to impaired indoor air quality. There were a larger variation of symptoms within the newest buildings, suggesting that some of the new dwellings were “healthy buildings” while others had environmental problems. More detailed technical investigations are needed to identify building factors and exposures linked to symptoms in newer buildings. Since most newer buildings have a mechanical ventilation system, it is less likely

that the observed effect is due to low air exchange, but it could be linked to particular chemical emissions or other factors in new buildings. Since subjects living in public owned houses had more symptoms, and building age may be linked to social conditions, it could be suspected that social class was the explanation to observed associations between health and building-related factors. The questionnaire did not include information about education level, income, or civil status. In Sweden there is some connection between social group and buildings built in the 60's located in the suburbs of Stockholm. In order to control for possible social effects linked to building age, we made additional analysis stratifying for building age. These analyses did not change the results, suggesting that the associations between personal factors or building related factors was not simply a reflection of differences in social conditions.

Signs of dampness reported by the inhabitants were common in the Stockholm area, and strongly associated with symptoms. All types of building dampness were associated with symptoms, but the association were strengthened if perception of mouldy odour was combined with other dampness indicators. Moreover, there was an association between number of signs of dampness, and number of symptoms. The associations were significant even after adjusting for ownership of the building, type of ventilation system, population density in the home. Moreover, the association between dampness and symptoms were significant in all building age classes. The results suggest that building dampness is an important public health problem in Sweden. Measures should be taken to reduce dampness and microbial growth in dwellings. This could be achieved in different ways, e.g. by keeping sufficient air-exchange rate in relation to the production of humidity by the occupants. Preventive and adequate maintenance, quick repair of water leakage, and avoiding building constructions with increased risk for building dampness are other ways to reduce the occurrence of building dampness in residential buildings.

Energy conservation in buildings is an important issue, with large economical implications. There is a strong demand for a sustainable development in the building sector. Today there is a new European directive demanding the declaration of the energy consumption for each building and for Sweden this directive will be connected to the indoor environment. It is crucial that energy conservation and reconstruction of buildings does not lead to an impaired indoor environment, with negative consequences for public health. The thesis did not support the view that energy saving measures in general is an important risk factor for symptoms. Some types of measures may, however, create indoor environmental problems. Major

reconstruction and multiple sealing measures in older dwellings could be a risk factor for symptoms. Use of low-emitting building materials when renovating older dwellings should be encouraged. Direct heated electric radiators and wood heating can be a health problem in older buildings, and should be avoided. There were indications that use of additional heat pumps was associated with symptoms. Since installation of additional heat pumps is an important part of the energy conservation program in Sweden, the health consequences of these devices should be further investigated.

Previous investigations have shown that many residential buildings in Sweden, and in other countries, have poor ventilation flow. Increased ventilation flow has many beneficial effects. The indoor air humidity is decreased, which reduces risk for condensation and presence of house dust mites. Moreover, an increased air flow reduces the indoor concentration of different indoor pollutants. We found that mechanical ventilation systems were beneficial in older dwellings from a health point of view. Increased ventilation flow may lead to an increased energy cost during the heating season. One way to save energy is to use seasonal adapted ventilation (SAV). This operational principle maintains the annual average ventilation flow at the level proposed by the Swedish ventilation standard (0.5 turnovers per hour), but reduces the flow below the standard during the heating season. Technical measurements could only demonstrate a minor increase of indoor temperature, relative air humidity, bedroom CO<sub>2</sub> concentration, when operating the ventilation with a 20% reduced flow during the heating season. The questionnaire investigation showed that reducing the ventilation flow to a level below 0.5 turn over/hour may increase the perception of impaired indoor air quality in the dwelling. This illustrates that it is important to combine technical measurements with a longitudinal evaluation of occupant reaction, when evaluation energy saving measures and other building installations.

In conclusion, the thesis could identify environmental condition in residential buildings that could be improved. The interaction between the building, the inhabitant and the maintenance of the building is in many ways important. The tendencies of outsourcing the maintenance today change the distance and form of interaction between the caretaker and the occupants. In the future, demands for energy conservation and a sustainable development of the building sector will continue. It is important that this development, as well as economical demands, does not create new indoor environmental problems in future dwellings. One way to reduce the risk for such problems is to include an evaluation of occupant reactions at an early stage, when new constructions and building materials are introduced. Most likely, indoor

environment in the home environment will be an important public health issue in the future. On a global level, there is a great need to improve housing conditions in many parts of the world. Policies and developments in the field of the indoor environment and health will need a holistic approach, including a physical, medical, psychological and epidemiological aspects, as well as political, sociological, anthropological and economical dimensions. I would like to end my thesis by quoting the words of Professor Sir Howard Newby at the University of Southampton in Great Britain from an international Conference in Bergen, Norway 1990:

.....” it is no longer a question of the natural sciences and technique creating changes the consequences of which the social and humanistic sciences must clean up. We all have a responsibility for development!

Professor Sir Howard Newby, Bergen 1990

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