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ABSTRACT
The first stage of The Swedish Healthy Building program has advanced the understanding of a number of hitherto unexplained building related health problems. Important insights have been achieved into the mechanisms and effects of biological agents indoors. New methodologies for assessing microbial emissions have been developed. The mechanisms of interaction between pollutant gases, building materials and room air are now better understood especially the mechanisms behind sorption and sink effects. In the indoor environment a large number of risk factors for adverse health effects are suspected. Some of these risk factors originate in misconduct in the design, construction and maintenance of buildings. Especially damp or humid buildings present increased risks but other factors also play a role.

INDEX TERMS
Building-related health problems, Risk factors, Chemical sorption, Inflammation, Socio-demographic confounders

INTRODUCTION
The on-going Swedish Healthy Building Research Program supports Swedish and Nordic scientists in resolving key issues of the indoor environment. The first stage of the program (1998-2000) has advanced the understanding of a number of hitherto unexplained building related health problems.

GOALS
The prime goals of the research are to
• increase the knowledge on building related adverse effects on the occupants as well as on the indoor environment itself, and
• diminish the risk of building misconduct, which may affect the occupants and/or the indoor environment.

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RESULTS AND DISCUSSION

**Microbial emissions.** By scientists within the program, new methodologies for assessing microbial emissions have been developed including methods for bacterial biomass, endotoxins, toxigenic fungi, and volatile organic compounds of microbial origin (MVOC). Such new methodologies include:

- Bacterial biomass, endotoxins: GC-tandem-MS
- Toxigenic fungi: PCR-methods
- Microbial VOCs (MVOC): Supercritical extraction in combination with GC/MS or GC/UV + GC/MS

**Inflammatory reactions.** Irritation symptoms among occupants may largely be related to inflammatory reactions in the airways membranes. So far, the research results indicate dose-response relationships between exposure and inflammation but not yet a clear relationship between inflammation and irritation symptoms. There might be a potential to reduce airways inflammation in relation to the school environment by improving cleaning and ventilation, and by avoiding building dampness. Most of these results need to be confirmed by additional studies before they can be judged as conclusive.

![Figure 1. Inflammatory response and irritation symptoms as a result of exposure to some indoor pollutants](image1)

**Sorption and sink effects.** The mechanisms of interaction between pollutant gases, building materials and room air are now better understood especially the mechanisms behind sorption and sink effects. Techniques for modeling VOC and moisture sorption effects on building materials and indoor products have been developed. An initial absorption of pollutants to materials may be followed by a period of desorption and re-emission to the indoor air. Prolonged emissions (and prolonged exposures of the occupants) may be the result. Through chemical reactions in the supply air or the room air, volatile organic compounds (VOCs) in combination with ozone ($O_3$) may result in aldehydes and short lived but reactive products. The resulting pollutants are suspected to cause irritation symptoms. Increased ventilation might be a cure.

![Figure 2. Sorption and sink effects of VOCs and moisture in building materials and indoor products](image2)
**Risk factors.** In the indoor environment a large number of risk factors for adverse health effects (asthma, increased bronchial responsiveness, irritation, SBS in general) are suspected. Some of these risk factors originate in misconduct in the design, construction and maintenance of buildings. Especially damp or humid buildings present increased risks but other factors also play a role. Increased risk seems to be associated with, i.a., “negative” demographic and socio-economic segregation in housing areas and “negative” selection and migration of occupants, inadequate ventilation, dampness in buildings, certain building designs such as concrete slab on ground and PVC-flooring, presence of moulds and/or mouldy odor, and exposure to specific chemicals.

A decreased risk seems to be associated with, i.a., “positive” demographic and socio-economic segregation in housing areas and “positive” selection and low migration rate, one-family houses, ownership and possibilities to self-control in buildings, new buildings with selected materials and careful design, buildings with low microbiological activity as indicated by some biochemical indicators, adequate air exchange rate, and a high cleaning frequency.

**Figure 3.** Risk factors for some potential building related health effects

Furthermore, misconduct in the design, construction and maintenance of buildings seems to be associated with adverse health effects. Especially damp or humid buildings present increased risks but other factors also play a role, such as floor dampness in combination with concrete slab on ground and flooring material containing PVC, inadequate ventilation and cleaning, the presence of moulds or moldy odor, and the exposure to certain chemicals or pollutant indicators.
Some of the results on risk factors are being based on a fairly small number of buildings, samples, measurements, and subjects. For example, before general judgments can be made of which ventilation to prefer, a large and representative building population should be investigated. In some questionnaire studies puzzling results have been obtained. A positive relationship has been suggested between dry air perceptions and reported vapour condensation on window panes as well as a positive relationship between beneficial health effects and the age of a building. To help in resolving these questions improved exposure and technical assessments are needed in the field investigations.

**Prevention.** The research has identified a number of preventive measures that should be taken in the conduct of buildings to avoid indoor air problems. They include good management of buildings, ventilation systems and cleaning technology, the use of control and adequate criteria for building materials and indoor products, and development and application of adequate test methods for material emissions and ventilation systems. If applied jointly, these measures are expected result in adequate ventilation rates, decrease in airborne levels of particles as well as of short-lived, reactive compounds and other air pollutants, prevention of moisture damages and microbial problems, and lower energy consumption.
The results of the research in the key action have confirmed that co-operation between disciplines should be more pronounced in all research on building related health effects. Perception studies by behavioral researchers and health studies by medical researchers should be combined with objective quantitative measurements by technical researchers of air quality and other properties of the building. Questionnaire and other field studies of exposure-response relationships should be combined with technical mapping and exposure measurements.

**Behavioral research.** A number of urban sociological issues become critical when questionnaire surveys in a municipality are combined with official statistics to demonstrate relationships between socio-economic factors, type of building and health effects. The process of pull-and-push factors defined from housing, socio-economic and health perspectives are very important. In practice, this means that care must be taken when choosing reference groups in questionnaire surveys. There still remains research to be done where such factors can be directly related to the housing conditions of individuals.

Differences between domestic buildings in perceived indoor climate and reported health effects may be due to kind of ownership, the occupants’ possibilities to self-control the home environment and most probably due to strong segregation in living based on socio-economic factors. For example, further behavioral research is needed before it is possible to state that anthroposophic buildings have better indoor qualities due to physical differences. Other aspects need to be discussed. The selection of personnel to institutions with a clearly pronounced ideology could affect the recruitment of persons in a favorable way. They may be more positive to the working methods and the workplace in general compared with traditional institutions.

**Exposure assessments.** Better exposure assessments can be done by including visual and engineering inspections (e.g. walk-through surveys, visual detection of dampness and water leaks, building physics examination, defining type of ventilation system) and/or exposure assessment of indoor air pollutants, at least in sub-samples of the study buildings. The scientific value of the results would increase and false interpretations be avoided. This is analogous with how medical findings are being strengthened by combining health questionnaires and clinical examinations of the study subjects.

**Table 1. Some of the projects participating in the first stage 1998-2000**

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Authors</th>
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<tr>
<td>Health effects of the indoor environment. New buildings, redecoration, and geriatric hospitals; Dan Norbäck</td>
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<td>Socio-economic factors, type of building and health effects in different domestic areas; Kjell Andersson</td>
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<td>Review of the entire scientific literature on damp buildings and health made by a Nordic interdisciplinary expert-group - NORDDAMP; Carl-Gustaf Bornehag</td>
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<td>Damp buildings and health; Carl-Gustaf Bornehag</td>
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<td>Indoor environment in dwellings, sick building syndrome (SBS) and discomfort among occupants; Karin Engvall</td>
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<td>Effects of short-lived and reactive compounds on indoor air quality; Mikael Sundahl/ Björn Lundgren</td>
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<td>Particles in indoor air – problem, presence, character, measuring methodology and control measures; Anders Jansson</td>
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<td>Sorption of gaseous compounds on indoor materials- consequences for air quality; Hans Stymne/ Peter Hansson</td>
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<td>Airborne moulds and mycotoxins in Swedish problem houses; Carl Johan Land/ Aime Must</td>
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ACKNOWLEDGEMENTS
The Key Action “The Healthy Building” is supported mainly by funds from the former Swedish Council for Building Research (BFR) and from its successor the new Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas).

REFERENCES