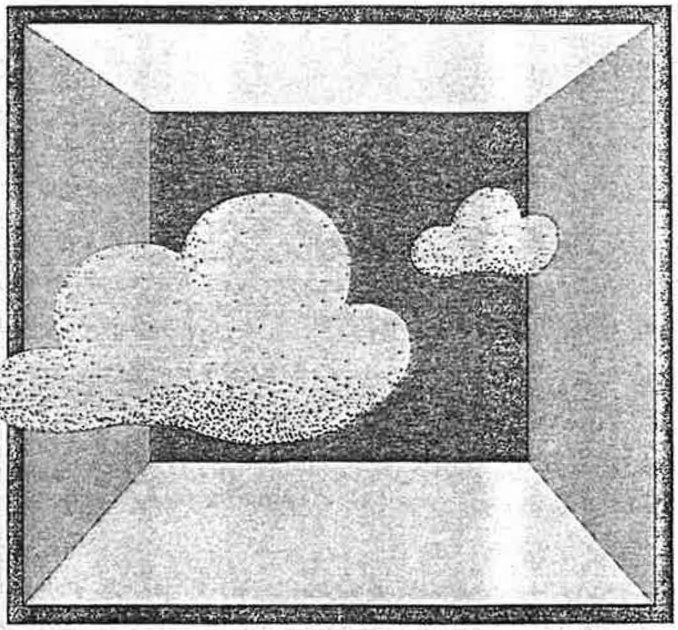
THE HEALTHY



BUILDING

Summary report from a Nordic seminar held in March 1987 and arranged by the Swedish Council for Building Research and the National Institute of Environmental Medicine

Swedish Council for Building Research,
Stockholm, 1988

THE HEALTHY BUILDING

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Edited by: Nina Dawidowicz, Thomas Lindvall, Jan Sundell

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PREFACE

Nina Dawidowicz, Thomas Lindvall and Jan Sundell
The Swedish Council for Building Research,
The Karolinska Institute and the
National Institute of Environmental Medicine, Stockholm

Over the last decade, interest in environmental hygiene in buildings has grown after many years of indifference. There are two main reasons for this: the rapid developments in building materials and in materials used for interior furnishings and fittings, and the overall interest in energy conservation. Problems such as radon, formaldehyde, mildew, asbestos, airborne ions, dry air, symptoms and complaints in child day-care centres and offices, self-copying paper, VDU terminal work and so on have been brought to the fore by the mass media and public debate. Research has been concentrated primarily on investigations, identification of sources of pollution in problem buildings and specific problems linked to individual factors such as radon, release of formaldehyde from building materials, moisture damage and mildew or the use of self-levelling liquid fillers.

Hitherto, there has not been any coherent view, or even concept, of the primary question of how a healthy building should be constructed, and of how such a building should be used and maintained in order to remain healthy. To a modest extent, efforts have been made to build healthy buildings, e.g. the Healthy Building Project linked to the 1985 Swedish Homes Exhibition, the Healthy Child Day-Care Centre project in Stockholm and a number of low-allergy building projects in the other Nordic countries, i.a. in Aarhus, Denmark.

As part of the preparations for the CIB Healthy Buildings '88 Conference, which is arranged by the Swedish Council for Building Research (BFR) and the National Institute of Environmental Medicine (SML), a Nordic seminar on the theme of The Healthy Building was held in March 1987 in Upplands Väsby, Sweden. BFR, which hosted the seminar with SML as co-arranger, has assigned priority in the current 3-year plan to the subject of "Climate and Environment in Buildings". Research and development projects within this priority area have the following goals, among others:

- to bring about interdisciplinary long-term establishment of knowledge, with contributions from medicine, chemistry, psychology, sociology, architecture, technology and so on,
- to establish how exposure to individual environmental factors and combinations of factors influences users' health and well-being, and
- to develop methods of dealing with hazardous environmental factors and their influence on buildings and their occupants.

The goal is to arrive, within the period of the programme, at designs and/or methods of constructing buildings that do not involve a health hazard for their occupants. One step towards this goal is to learn from the experience accumulated in the Nordic countries. A further step will be taken with the international Healthy Buildings '88 Conference in Stockholm, to be held on 5-8 September 1988.

The objectives of the Nordic Healthy Building seminar were:

- to summarize selected elements of knowledge and research in the Nordic countries in the fields of air quality and thermal climate:

PREFACE

- to bring about a discussion of what 'new' environmental requirements are necessary in respect of buildings in the light of research findings in this field, and
- to indicate the 'healthy' design features and methods that are already available or that can be expected within the near future.

Nordic research scientists who have been active in this problem area were invited to attend the seminar. The Nordic approach is only natural in this context, as the problems are virtually the same in all the Nordic countries, there are only a few research workers in this field in each country and there is a very healthy tradition of inter-Nordic co-operation in this area. The seminar was interdisciplinary, with participants from widely differing fields such as chemistry, physics, medicine, psychology and technology.

In order to get the seminar off to a flying start, the participants were invited to submit written replies in advance to the following questions:

- What requirements can be imposed on the indoor environment in the light of the writer's research experience?
- What technical design features should characterize healthy buildings?
- What commonly encountered technical or design features do you object to because of their effect on health?
- What research could be expected to provide results within the near future in terms of improved knowledge of how to build and maintain healthy buildings?

The written replies are presented in a report, published in Swedish (Report G20:1987). The report also presents the conclusions and recommendations reached by working groups and in plenary discussions. This publication is a summary of the seminar report. The chairman of the seminar was Thomas Lindvall, M.D., and the rapporteur was Jan Sundell, M.Sci.

The Healthy Building seminar demonstrated that the subject is very extensive, that many questions as yet remain unanswered (particularly in concrete, quantified terms) and that there is a considerable need for further R&D efforts. At the same time, it was evident from the seminar that there is actually a vast amount of knowledge among researchers and consultants in the various areas. Taken together, this pool of knowledge can provide sound and welcome guidance for those concerned in the building sector in their efforts to build and maintain healthy buildings. This is illustrated not least by the fact that the seminar participants were agreed on joint statements concerning two central problem areas; namely the use of recirculated air and air humidification. The seminar gives every promise of continued success in Nordic and interdisciplinary cooperation in this field.

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CONSENSUS STATEMENTS ON AIR RECIRCULATION AND HUMIDIFICATION

By the participants at the Nordic Healthy Building seminar in Upplands Väsby, Sweden, 1987

After thorough plenary discussions, the participants in the Nordic seminar "The Healthy Building" agreed unanimously on the following statements concerning air recirculation and air humidification.

Air recirculation

"Air recirculation is not recommended in public premises as a normal method on account of the risk of spreading gases and fumes, and in the light of practical experience of shortcomings in application and maintenance. Air from 'polluted' rooms, such as rooms used by smokers, must not be recirculated. In existing systems, air recirculation may be used, but the condition of filters and settings of fresh air supply systems must be checked at frequent intervals. For new systems, it is recommended that other means of heat recovery be employed. Air recirculation systems can be used as a method of mixing fresh air and room air when this is justified in practical terms, e.g. for thermal reasons. If air recirculation is used in new building developments, special requirements must be fulfilled in respect of adjustment, regular performance checking and cleaning of ducting systems."

Air humidification

"General air humidification is not recommended for hygienic reasons. Such humidification can result in side-effects such as the growth of dust mites, humidifier-fever and other allergies. 'Dry air' symptoms should be countered preferably by other means than air humidification. Selective humidification may be required for special individuals/environments/processes: it is then important that a 'safe' method is selected.

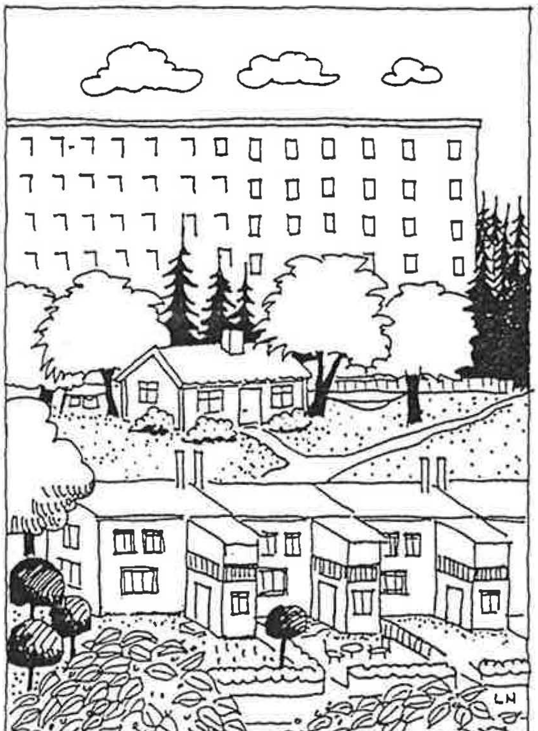
HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Thomas Lindvall and Jan Sundell
Karolinska Institute and the National Institute of Environmental Medicine

Introduction

Hitherto, there has been very little contemporary research or discussion concerning how buildings should be constructed and managed in order to promote health. As yet, only sporadic trials of ideas on this subject have been carried out on full scale, and there has not been time to evaluate their results. It is easy to get the impression that we do not know how to build healthy buildings, other than from the overall 'self-evident' respects. In particular, it seems to be difficult to agree on the design features that give rise to healthy or sick buildings. This, however, is a reflection of the construction process as such: when correctly applied in the right context and properly used, most solutions can give good end results. Nevertheless, certain solutions are more sensitive to the common faults which occur in planning, construction, operation and use. When these 'risky' systems or arrangements are used, therefore, checking and inspection at the various stages must be more comprehensive. If there is any reason to suspect that such checking or inspection may not be as thorough as necessary, such risky solutions should be avoided. Experience from the large numbers of sick buildings that have been studied in recent years also shows that the problems often depend on disregard of proven experience.

In the following, conclusions and recommendations concerning healthy buildings should considered against the above background as well as in the light of the fact that time has not been wasted on discussing matters considered to be self-evident. Consequently, factors which play an important part with regard to the overall health of a building, e.g. architectonic design, lighting or noise conditions, have therefore been dealt with only marginally. This also reflects the fact that the ongoing debate about sick and healthy buildings has been concerned primarily with the various new manifestations such as "sick building syndrome" that have largely been traced to causes such as inadequate ventilation, moisture damage and mildew, as well as the release of pollutants from building materials etc.



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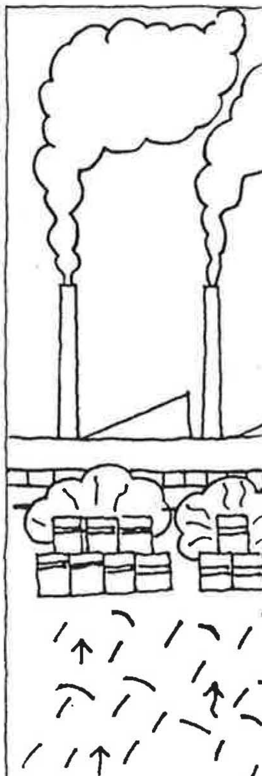

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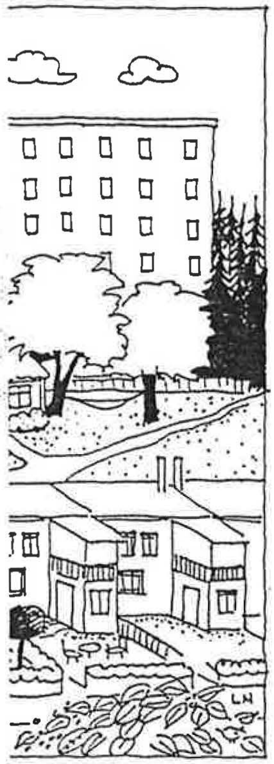


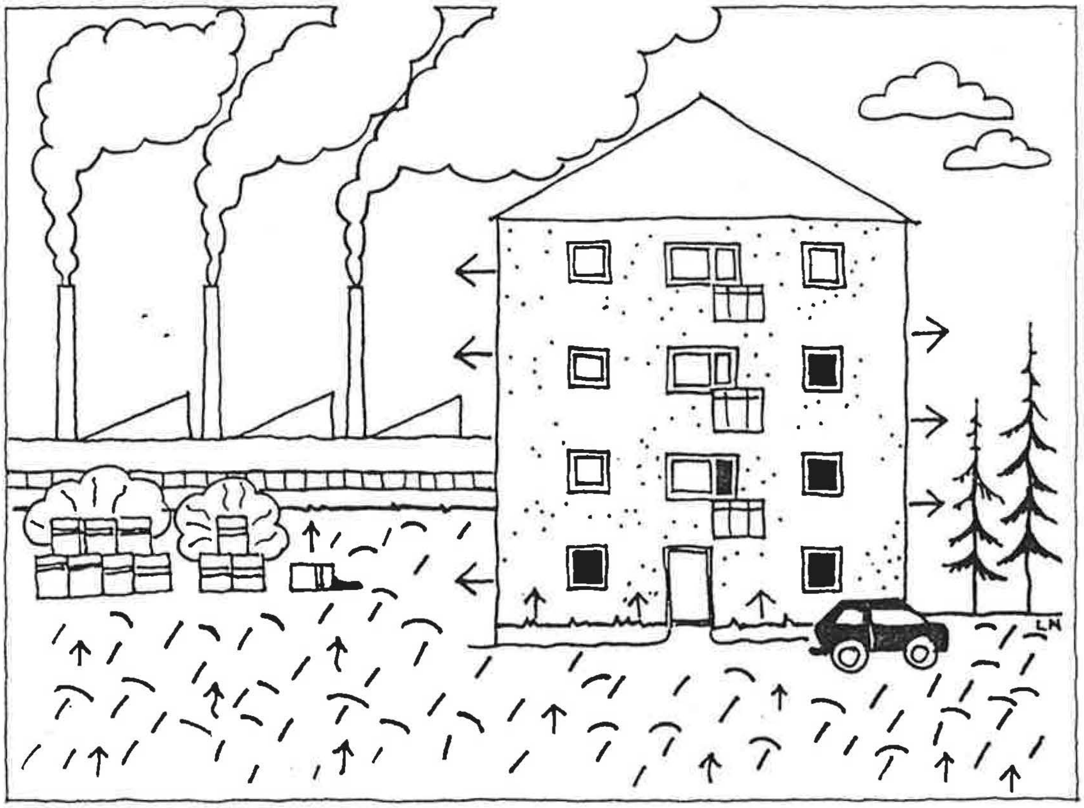
HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Building siting and local climate

Ground conditions at the prospective building site should be carefully investigated. Ground that is waterlogged, has high radon levels, that is subject to risk of slips or subsidence or where there may be sources of pollution (e.g. sites that have previously been used for industry) must be avoided.

The building and, whatever the circumstances, the fresh air inlets must be sited where outdoor air quality is good and can be expected to remain good, i.e. away from busy roads, parking lots, industrial plants, etc.

The building should be orientated with due regard to sun, wind, outdoor environment and need of contact with the surroundings. These considerations are of importance in terms of health, social welfare, energy economics and aesthetics.



HEALTHY BUILDINGS
CONCLUSIONS AND
RECOMMENDATIONS

Building physics/ Building technology

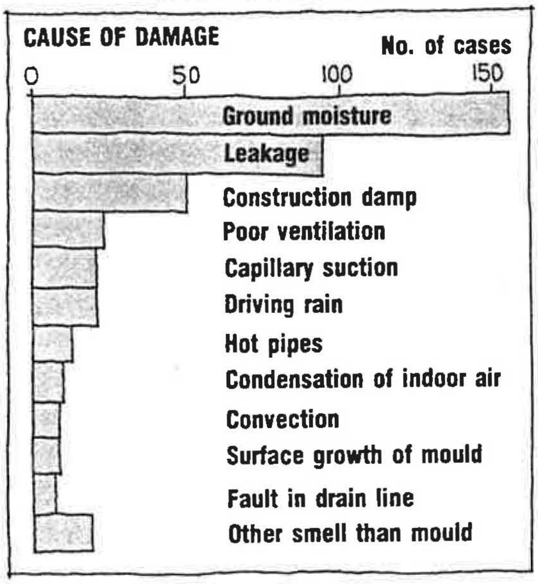
A general requirement of construction is that a building should be constructed in such a manner that it is and will remain dry. Water must be led away, wherever it may occur or be encountered: on the roof, in the foundations, in bathrooms, around windows, in exterior walls and so on. External designs or features that are sensitive to moisture must be thermally insulated on the cold side, which will result in a warmer and drier structure. Features that need to be ventilated must be ventilated. Such ventilation today is often effected by means of fans, i.a. in consequence of the high insulation standards applied. Typical examples are wide-span roofs with little slope and underfloor spaces.

Risky design features are:

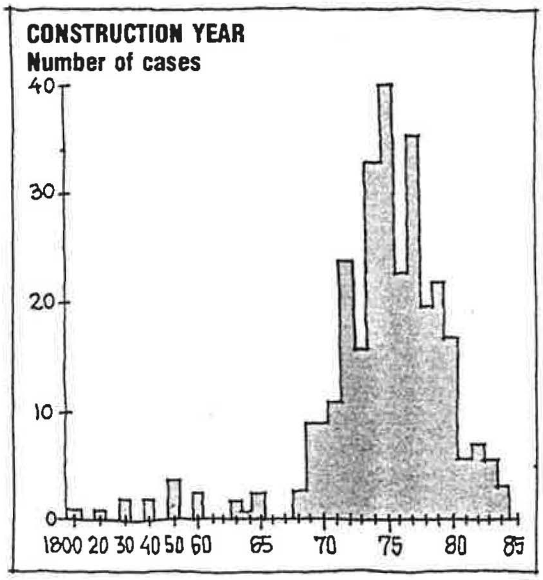
- horizontal roofs
- foundation slabs/rafts with insulation on top
- suspended floors above foundation slabs/rafts, and
- floating floors on foundation slabs/rafts.

R&D is needed for such purposes as:

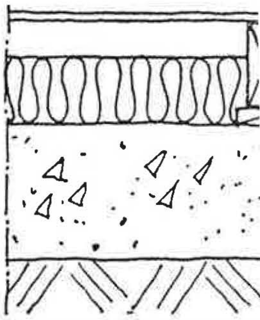
- development of design programs to predict moisture conditions and to investigate design prerequisites, and
- investigation of absorption and diffusion processes in various design arrangements.



Cause of damage according to investigations carried out by the Swedish National Testing Institute in Borås.



Construction year for houses with mould damage



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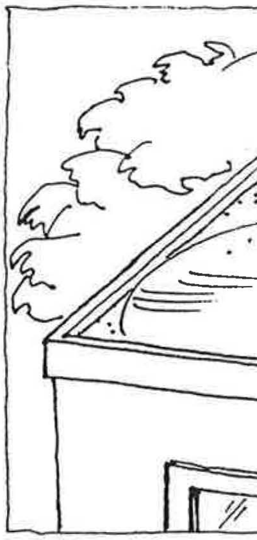

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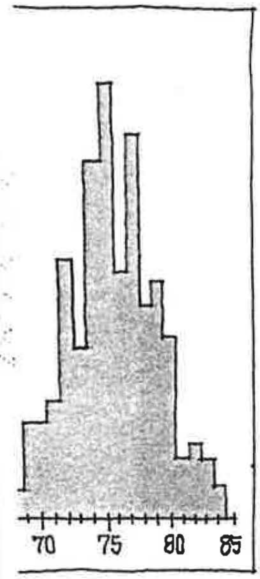
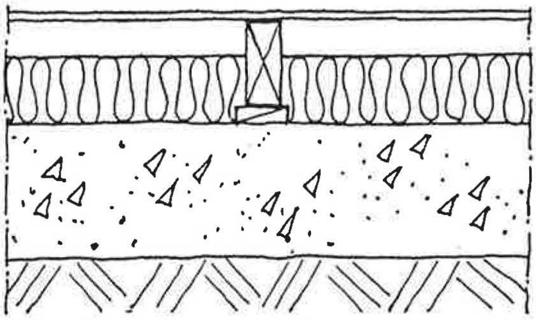
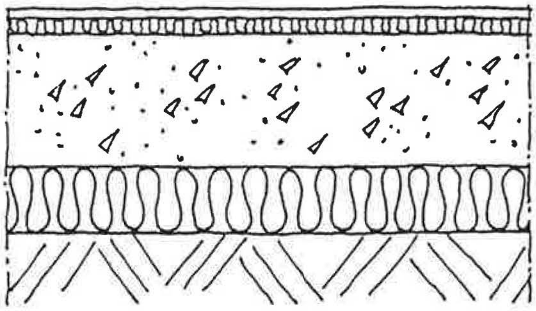


houses with mould

HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

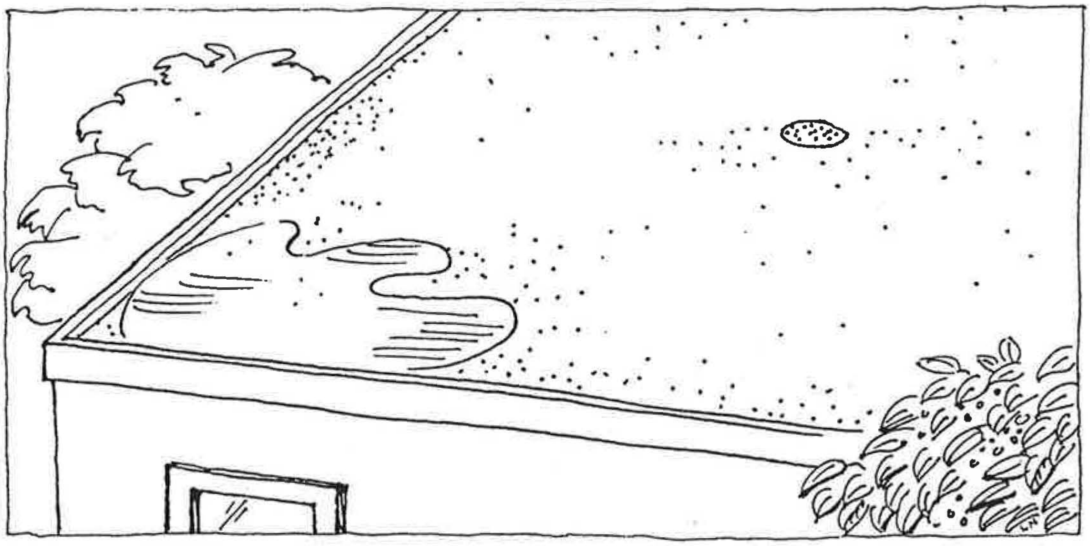


Joisted floor on concrete slab on the ground is one example of a construction which, in normal circumstances, is sufficiently moist to give rise to problems.



A concrete slab that is thermally insulated underneath will remain warm and dry. Once the construction damp has dried out there is very little risk of damage. It is best to also thermally insulate the upper side for comfort reasons. Note! This principle is applicable to small buildings and not to large industrial premises.

Horizontal roof with roof drains at high points. Residual water forms a coating of ice during the winter to the felt covering. ↓



HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Climate technology

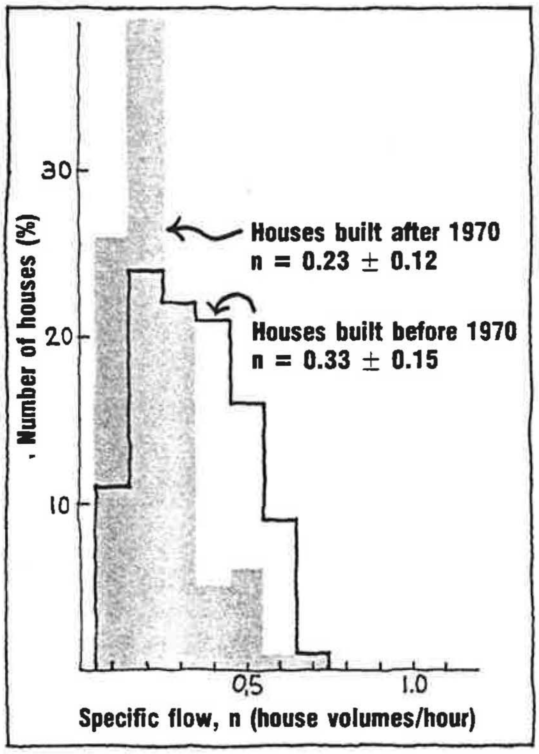
Ventilation and air quality

A basic requirement for a healthy building is that the room air must not cause illness or discomfort during normal use. The building must also be able to withstand a fair amount of misuse by its occupants without giving rise to health hazards. Ventilation, for example, must have some surplus capacity, and be "forgiving" in its operation. These basic requirements can be translated into performance requirements that can be expressed in terms of air quality or ventilation, quantified in respect of aspects such as:

- permissible limits for air pollutants,
- flow requirements for air of various qualities (outdoor air or supply air),
- requirements in respect of limitation of emissions of pollutants from various sources, and
- specific requirements in respect of design features that experience has shown to be essential for a good indoor climate.

The present situation calls for a combination of these different types of requirements. Maximum permissible values should be specified for commonly encountered and well-researched pollutants such as humidity, formaldehyde, man-made mineral fibres (MMMF), radon, asbestos, NO_x and total organic substances, as well as for indicators such as CO_2 (occupants) and CO (tobacco smoke, vehicle exhausts). However, owing to the lack of knowledge of interaction between pollutants, it is difficult to specify values for many substances (e.g. amines, phthalates etc.) that would ensure a healthy building.

Requirements for maximum permissible emission levels of selected types of pollutants must be specified. A proposal for a standard Nordic test method (Nordtest) is under development. A draft test method relating to particle emission from materials also exists in Denmark.



Outdoor air flow specified as specific flow n for one-storey and two-storey houses. The houses have been divided into groups, based on the year of construction. Ventilation system; S-system.

n-ALKANES

n-Hexane
n-Heptane
n-Octane
n-Nonane
n-Decane
n-Undecane
n-Dodecane
n-Tridecane
n-Tetradecane

BRANCHED ALKANES

2-Methylpentane
2-Methylhexane
3-Methylheptane

ALKENES AND CYCLO

Cyclohexane
Methylcyclopentan
1-Octene
1-Decene

HALOGEN DERIVATIV

Trichlorofluorome
Dibromochlorometh
1,2-Dichloroethan
Dichloromethane
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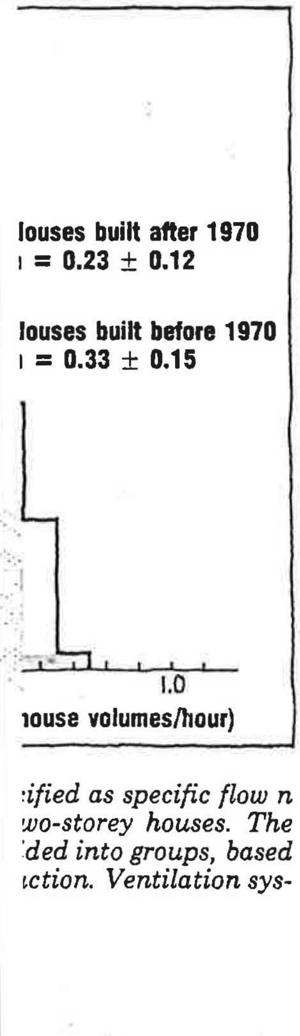

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BRANCHED ALKANES

2-Methylpentane
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ALKENES AND CYCLOALKANES

Cyclohexane
Methylcyclopentane
1-Octene
1-Decene

HALOGEN DERIVATIVES

Trichlorofluoromethane
Dibromochloromethane
1,2-Dichloroethane
Dichloromethane
Trichloromethane
Tetrachloromethane
1,1,1-Trichloroethane
Trichloroethene
1,1,2-Trichloroethane
Tetrachloroethene
Chlorobenzene
1,4-Dichlorobenzene

ALCOHOLS

Methanol
Ethanol
2-Propanol
2-Methyl-1-propanol
1-Butanol
1-Pentanol
2-Ethyl-cyclobutanol

ALDEHYDES

Formaldehyde
Acetaldehyde
Butanal
Pentanal
Hexanal
Benzaldehyde
Nonanal

KETONES

2-Propanone
2-Butanone
3-Methyl-2-butanone
3-Heptanone

ESTERS

Ethylacetate
n-Butylacetate
2-Ethoxy-ethanolacetate

AROMATIC HYDROCARBONS

Benzene
Toluene
Ethylbenzene
1,3-Dimethylbenzene
1,4-Dimethylbenzene
1,2-Dimethylbenzene
n-propylbenzene
1,3,5-Trimethylbenzene
1,2,4-Trimethylbenzene
C_3-Alkylbenzene
1-Methylethenylbenzene
1-Ethenyl-3-ethylbenzene
1-Ethenyl-4-ethylbenzene
Naphtalene
Biphenyl

TERPENES

α-Pinene
β-Pinene
Δ^3-Carene
Limonene

List of commonly encountered colatile organic substances in indoor air.

HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Ventilation design features that can be **recommended** are:

- those in which pollutants are captured directly at source by encapsulation, local extraction etc.,
- those that feature simplicity, flexibility in respect of changed use of the premises, individual controllability and ease of understandability for individual users,
- those that can withstand windows being opened,
- those of which the performance can be easily checked (fixed instrumentation/ measurement points), that can be easily adjusted and cleaned, and those which are accessible and easily replaceable,
- decentralised, symmetrically designed systems, having well-placed fresh air inlets, good filter performance (minimum F45) and high air change rates and ventilating performance,
- systems that are quiet in operation, without low-frequency noise,
- balanced ventilation systems with heat recovery that does not recirculate pollutants.

The following ventilation design features are **risky**:

- recirculatory systems,
- natural draught systems (inadequate capacity, no routing to individual rooms, draughts),
- mechanical exhaust systems (no routing to individual rooms, draughts),
- air humidification, and particularly systems that supply water in droplet form,
- warm air systems (spread of pollutants, not easily controlled),
- rotating heat exchangers (recirculation of pollutants),
- heat exchangers that cannot be bypassed during the summer, (temperate climate zones),
- insensitive or excessively sensitive control equipment,
- all systems that are inadequately maintained, badly adjusted, incapable of being cleaned or with night set-back or weekend set-back of air flow rates when the building is new,
- ventilation ducts embedded in floor/ceiling structures.

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As far as **air humidification** is concerned, the 1987 Nordic Healthy Building seminar unanimously adopted the following resolution:

"General air humidification is not recommended for hygienic reasons. Such humidification can result in side-effects such as the growth of dust mites, humidifier-fever and other allergies. 'Dry air' symptoms should be countered preferably by other means than air humidification. Selective humidification may be required for special individuals/environments/processes: it is then important that a 'safe' method is selected.

As far as **air recirculation** is concerned, the seminar adopted the following resolution:

"Air recirculation is not recommended in public premises as a normal method on account of the risk of spreading gases and fumes, and in the light of practical experience of shortcomings in application and maintenance. Air from 'polluted' rooms, such as rooms used by smokers, must not be recirculated. In existing systems, air recirculation may be used, but the condition of filters and settings of fresh air supply systems must be checked at frequent intervals. For new systems, it is recommended that other means of heat recovery be employed. Air recirculation systems can be used as a method of mixing fresh air and room air when this is justified in practical terms, e.g. for thermal reasons. If air recirculation is used in new building developments, special requirements must be fulfilled in respect of adjustment, regular performance checking and cleaning of ducting systems."

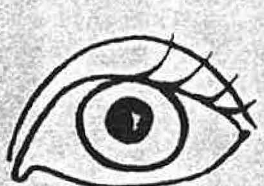
Major **R&D** effort in the field of air quality is required, including the following:

- surveys of the air pollution situation in present-day buildings,
- identification and surveying of sources of indoor pollution,
- epidemiological investigations of the link between ill-health and design features, and also between ill-health and pollutants encountered in non-industrial indoor environments,
- investigation of depot effects of pollutants in indoor environments,
- development of standardized methods of sampling and analysis, suitable for both routine measurements and research purposes,
- intercalibration of laboratories and measured data,
- investigation of ventilation requirements in different types of premises,
- investigation of the efficiency of air change in real situations,
- investigation of recirculation of pollutants caused by various types of heat exchanger under field conditions, and
- investigation of the 'dry air' symptom, including the effect of air humidification.

HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

THERE ARE OFTEN MULTIPLE CAUSES OF IRRITATION SYMPTOMS

Example 1
"Dry air"



- **low humidity**
- **formaldehyde**
- **heat radiation**
- **hovering dust**
- **heat-induced degasification**

Example 2
"Eye irritation"

- **particles**
- **gaseous irritants**
- **heat radiation**
- **vision stress**

Thermal indoor climate

Basic performance requirements are given in NKB Report No. 41 (published by the National Board of Physical Planning and Building in 1981) or in ISO Standard 7730. Heating and ventilation systems must be planned and installed so that they can be adjusted and checked regularly to ensure that the required thermal performance in the dwelling zone is maintained.

R&D is needed for the development of:

- instruments and methods that will permit the end user to check climatic conditions, and
- climate control systems and instructions that will allow the end user to control his/her own local climate conditions.

Other climatic factors

It is important that the requirements of all important climatic factors are fulfilled simultaneously. Air quality, thermal climate, noise and lighting conditions etc. must all lie within their permitted ranges at the same time.

Ion generators are considered to be a **risky** solution.

R&D is needed in respect of:

- the influence of low-frequency sound and infrasound,
- the perceived mental fatigue of ventilation noise and
- interactive effects between climatic factors.

HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Building materials

For healthy buildings it is essential to choose building materials with a minimum pollutants emission to the indoor air. According to a draft proposal for a Nordtest method, materials may emit a maximum of 0.15 mg/m³ formaldehyde and 2.00 mg/m³ TVOC (total volatile organic compounds) when tested. "The air from the test chamber must not be deemed to be unpleasant or annoying."

Materials to **be recommended** are ones that are:

- proven and found to be low-emittant,
- accompanied by a statement of contents in respect of pollutants emissions,
- stable, lasting and durable under the conditions likely to be encountered, and
- free from heavy metals, asbestos, biocides, radioactivity.

The following solutions are considered to be **risky**:

- materials with a large surface area, such as wall-to-wall carpets in public premises; if materials of this kind are essential in view of, for example, persons suffering from impaired hearing, the cleaning level must be raised,
- materials that are not accompanied by a "statement of contents" in respect of health importance or have been "tried and proven" for a long time,
- materials containing substances that may be suspected of being toxic in the concentrations concerned,
- plastic wall coverings and painted glass-fibre woven fabrics in wet spaces,
- raw materials liable to cause charges of more than 1000 volt at 22°C, 25 % RH, and
- use of protective agents against biological degradation; the building shall be constructed so that such agents are superfluous.

R&D is needed for:

- studies of sorption and diffusion processes in different materials, and
- development of methods for testing of degasification from materials for both laboratory and field conditions.

Diagnosis of malfunction

In the light of experience from investigations of "sick buildings", buildings affected by mildew, etc., an investigative and action procedure that is carried out in stages is considered to be appropriate. It is of particular importance to use uniform questionnaires and measuring procedures in order to allow comparisons and to build up a larger bank of

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R&D is needed for, among other things:

- testing and further developing the investigative and action methods used today,
- checking in adequate studies the results of completed actions in buildings with environmental problems,
- development of methods for identification and characterization of sources of pollution,
- development of methods for compilation and evaluation of sensory reaction patterns and reaction intensity, and
- development of objective clinical methods for investigation of symptoms included in "sick building syndrome" and other symptoms of ill health associated with buildings.

Operation and maintenance, the building process

Purchasers/users of buildings must learn to express quantified requirements that can be checked, and also to check that the requirements have been fulfilled. Maintenance and operational aspects must be considered throughout the building process. In this context, the working environment of the operational and maintenance personnel, as well as of their need of training, must not be forgotten. Technical descriptions and instructions for the user must be prepared towards completion of the building process.

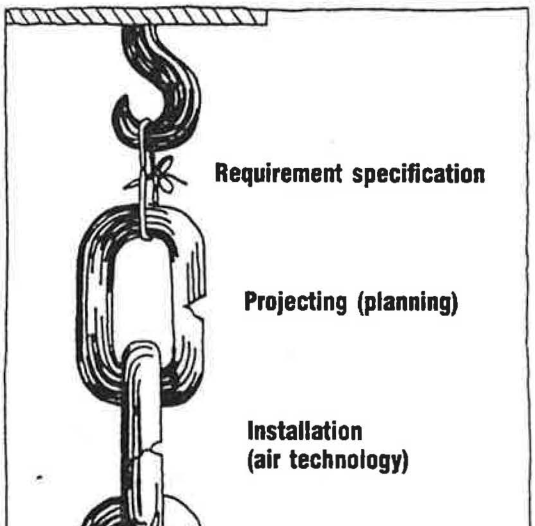
Design features/measures that are **recommended** are:

- the use of well-proven design solutions and materials,
- allowing sufficient time for thorough performance of the work of both planning and construction, including time for drying out, adjustment, performance checking and remedying of faults (quality assurance),
- ensuring smooth cooperation between the various parties involved in the building process; one person should provide the link throughout the entire process from planning to occupation and by all means also during a follow-up phase,
- not to make the building too dependent on sensitive technology that could easily fail to work properly,
- to prepare maintenance routines as early as during the planning phase,

- to provide a long guarantee period in order to ensure time in which to discover hidden faults,
- to allow the building process to compete in terms of quality instead of just in terms of price,
- to maintain a high cleanliness level without the use of hazardous cleaning agents,
- to teach operating and maintenance personnel (and also their superiors) that climatic and hygienic aspects are more important than energy aspects, and
- to carry out regular performance checks.

R&D is needed in various areas, including:

- investigation of factors that prevent, say, ventilation systems from receiving sufficient maintenance.



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HEALTHY BUILDINGS CONCLUSIONS AND RECOMMENDATIONS

Standards and other social steering means

Over the last ten years, the building debate has been concerned largely with energy aspects. This has resulted in standards and propaganda efforts ("conserve energy!") intended to direct building along the path of more airtight buildings with lower energy consumptions. This has been the direct cause of many of the problems encountered in sick buildings. Uncritical energy conservation often results in major risks of greater damage and symptoms or other problems for users. The public incentives and steering system (standards, loan conditions, information to property-owners and users etc.) must therefore be reviewed so that the primary hygienic aspects are better considered.

A checklist for healthy buildings

It is suggested that the following questions should be answered:

- Is the building suitably sited in view of external environmental factors?
- Do ceiling heights, room shapes and colours provide a good environment (generous with daylight)?
- Can the technical solution chosen lead to problems with moisture penetration into the building, or with condensation etc.?
- What is the risk of water damage? Is it possible to detect water damage in time?
- How does the technical solution/material chosen affect pollution levels in the room air?
- Has the building been designed with a holistic approach to acoustics?
- Do the various design features also make allowance for individual requirements (e.g. allergics)?
- Have designs and materials been tested on a large scale?
- Has sufficient time been allowed for careful planning and construction work, as well as for drying-out?
- Are all the parties of the building process working smoothly together?
- Is the building excessively dependent on technology that can fail? Does it have a sound default state?
- Have maintenance routines been planned during the planning phase?