Report No 17
Indoor Air Quality and the Use of Energy in Buildings

EUROPEAN COLLABORATIVE ACTION
INDOOR AIR QUALITY & ITS IMPACT ON MAN
(formerly COST project 613)

Environment and Quality of Life

Report No 17
Indoor Air Quality
and the Use of Energy in Buildings

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This report provides key elements of a strategy by which designers, engineers, manufacturers and other decision makers can achieve a good balance between energy use in buildings and indoor air quality (IAQ).

Following the recommended procedure will reduce the risk of poor IAQ and waste of energy.

In this series the following reports have already been published.

- Report No. 1: Radon in indoor air. (EUR 11917 EN) *
- Report No. 2: Formaldehyde emission from wood-based materials: guideline for the determination of steady state concentrations in test chambers. (EUR 12196 EN) *
- Report No. 3: Indoor pollution by NO_2 in European countries. (EUR 12219 EN)
- Report No. 4: Sick building syndrome - a practical guide. (EUR 12294 EN)
- Report No. 5: Project inventory. (S.P.I. 89.33) *
- Report No. 6: Strategy for sampling chemical substances in indoor air. (EUR 12617 EN)
- Report No. 7: Indoor air pollution by formaldehyde in European countries. (EUR 13216 EN) *
- Report No. 8: Guideline for the characterization of volatile organic compounds emitted from indoor materials and products using small test chambers. (EUR 13593 EN)
- Report No. 9: Project inventory - 2nd updated edition. (EUR 13838 EN) *
- Report No. 10: Effects of indoor air pollution on human health. (EUR 14086 EN)
- Report No. 11: Guidelines for ventilation requirements in buildings. (EUR 14449 EN)
- Report No. 12: Biological particles in indoor environments. (EUR 14988 EN)
- Report No. 13: Determination of VOCs emitted from indoor materials and products. Interlaboratory comparison of small chamber measurements. (EUR 15054 EN)
- Report No. 14: Sampling strategies for volatile organic compounds (VOCs) in indoor air. (EUR 1605 EN)
- Report No. 15: Radon in indoor air. (EUR 16123 EN)
- Report No. 16: Determination of VOCs emitted from indoor materials and products; second interlaboratory comparison of small chamber measurements. (EUR 16284 EN)

  * out of print

Abstract

ECA (European Collaborative Action "Indoor Air Quality and Its Impact on Man", 1996. Indoor air quality and the use of Energy in Buildings. Report No 17. EUR 16367 EN. Luxembourg: Office for Official Publications of the European Community

This report provides information and advice to policy and decision makers, researchers, architects, designers, and manufacturers on (i) strategies for achieving a satisfactory balance between good indoor air quality (IAQ) and the rational use of energy, (ii) guidelines on the use of energy in buildings and IAQ currently available, (iii) significant trends in the building sector with implications for IAQ and energy use and (iv) current research concerns.

The report discusses the relationships and potential conflicts between IAQ and the efficient use of energy in buildings and related factors such as the influence of occupancy and occupant activities, energy use and sustainability, indoor air pollution and its control, and health and comfort aspects of indoor air quality and climate. The influence of climatic conditions and their variations across Europe on IAQ and energy use, socio-economic costs of poor IAQ and its relation to the use of energy and trends for the future in the building sector are also briefly addressed. Current research concerns in the field of IAQ and energy use in buildings are highlighted and gaps in knowledge and research needs are identified.

Key elements of a strategy by which designers, engineers, manufacturers and other decision makers can achieve a good balance between energy use in buildings and indoor air quality (IAQ) are proposed. Following the recommended procedure will reduce the risk of poor IAQ and waste of energy.

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SUMMARY

The aim of this report is to provide information and advice to policy and decision makers, researchers, architects, designers, and manufacturers on:

- strategies for achieving a satisfactory balance between good indoor air quality (IAQ) and the rational use of energy

- guidelines on energy and IAQ currently available

- significant trends for the future with implications for IAQ and the use of energy in buildings

- current research concerns

The report discusses the main strategies for achieving an appropriate balance between good indoor air quality and an efficient use of energy in buildings and identifies gaps in knowledge and requirements of research.

The conclusions of the report are:

1. Both the rational use of energy and the provision of good IAQ are important aspects of building design and refurbishment. There are potential conflicts between these requirements. The impact of possible energy saving measures on IAQ should always be discussed before their eventual adoption and if unacceptable, these measures should be avoided.

2. Source control should be the first priority.

3. Environmental tobacco smoke is a key pollutant, with serious energy penalties because of substantial increases in ventilation requirements. Separate smoking areas and non-smoking policies should be considered.

4. The importance of occupants should be recognized, particularly their needs for individual control, their role in ensuring that energy and IAQ systems operate correctly and the possibility that they may not act appropriately in response to errors and failures.

5. Reducing air exchange rates to save energy may result in poor IAQ.

6. Increasing air exchange rate to improve IAQ may increase energy consumption, but this may be compensated for by heat recovery.

7. Ventilation requirements should be determined considering the total pollutant load present in a building as the result of building constituents, occupants and their activities. The goal of ventilation should be to provide good IAQ and satisfaction for occupants. A secondary goal is to protect the building, installations and furnishings.

8. The recommended strategy for designing new buildings and refurbishing existing buildings taking both IAQ and energy into account (there may be some restriction of choice in existing buildings) is:

- control sources of pollution and of energy loss by using suitable materials, sealing, local extraction, etc.

- determine ventilation strategy and design ventilation systems using energy-efficient and passive technologies where appropriate

- base the design of energy systems on the required ventilation rate

- design systems for IAQ and energy control to match the abilities of the occupants and users

- design systems for easy commissioning, maintenance and control

9. The potential cost to society of poor indoor air quality is high. Remedial action to obtain good indoor air quality is likely to be cost effective even if an expensive retrofit is required. Much knowledge is already available and this needs to be put to better use by more effort on information transfer and co-ordination by those involved in the design process.

10. Control, maintenance and management procedures are essential and good strategies should be developed.

11. Research is needed in order to achieve good tools and methods for simultaneous analysis of both the energy efficiency and the IAQ.

12. Within the ECA, a standing group should be established which addresses the issue of Energy Efficiency/Indoor Environment and proposes research themes and other activities for cost-shared action programs.

1   INTRODUCTION

1.1   Aim

The aim of this report is to provide information and advice to policy and decision makers, researchers, architects, designers, and manufacturers on:

(a)   strategies for achieving a good balance between good indoor air quality (IAQ) and the rational use of energy in buildings

(b)   available guidelines and assessment techniques on energy and IAQ

(c)   significant trends for the future with implications for IAQ and the use of energy in buildings; and

(d)   current research issues

1.2   Scope, Limits and Definitions

The report deals with two objectives: good indoor air quality and energy efficiency in both new and existing non-industrial buildings. It focuses on how to achieve both of these objectives simultaneously.

The need and strategies to find the best possible balance between an efficient use of energy in buildings and a comfortable and healthy indoor environment are addressed in general terms. It is beyond the scope of this report to provide detailed guidance on how to achieve this balance in specific situations. In addition to the information provided in this report, local and regional, climatic and cultural conditions need to be taken into consideration to identify which strategy and means will be best suited in a specific case.

The report does not address life cycle considerations. It deals with energy use and environmental quality during normal use of a building and not during its production or demolition.

Throughout this report, the term 'indoor environment' refers to the combination of the thermal-, atmospheric, acoustic, actinic (lighting/radiation), mechanical, psychological and aesthetic environments. The main concern of the report is about IAQ which is defined as all features of indoor air having an impact on man and is mainly determined by the atmospheric environment, in particular by the presence of indoor air pollutants. However, other components of the indoor environment may interact with the perception of IAQ, e.g. the thermal environment.

The use of energy in buildings, the second concern in this report, is linked to several of the above mentioned components of the indoor environment, including the atmospheric, thermal and actinic environments.

For the discussion of IAQ and the use of energy in buildings, the present report will mostly consider the atmospheric and thermal environments but briefly address other components of the indoor environment where appropriate.

1.3   Background

Buildings exist primarily to provide a healthy and comfortable environment in which people can work and live. The indoor environment must be maintained at a comfortable and healthy temperature, have an adequate supply of fresh air, be free from damp, draughts and pollutants and be quiet and well lit. A comfortable indoor environment has to rely on the use of energy for lighting, ventilation, heating and/or cooling. While heating has traditionally been the major cause for energy consumption in most European countries, HVAC systems for cooling have been installed in recent years at increasing rates in Southern European countries. Also, cooling is often needed in office buildings all year round because of high internal gains due to computers and artificial lighting. This suggests that natural lighting strategies have an important bearing on the balance between heating and cooling needs of a building in most latitudes.

Most energy used in buildings is provided by fossil fuels. However, depending on climatic conditions, "natural" means such as daylighting, passive heating and cooling and natural ventilation may make important contributions.

Since the first oil crisis in 1974, energy saving has been a priority in most industrialised countries for economic reasons. More recently, environmental concerns have increased the urgency of a rational use of energy because of a possible global climate change due to high emissions of greenhouse gases into the atmosphere and in particular CO_2 emissions from the burning of fossil fuel. There is concern too, about regional and local air pollution problems due to burning of fossil fuel, and the depletion of fossil fuel resources.

This has led to international action at the highest political level culminating in the United Nations Conference on Environment in Rio de Janeiro, in June 1992. The Conference called on all governments to take action at a national level, and in particular to adopt strategies for 'sustainable development'. Sustainable development has been defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. There is therefore increasing emphasis on better use of energy resources: the rational use of energy to provide good services at minimum energy/environment cost. Since, in many European countries, buildings and their services use up to about half the total energy consumption, there is increasing pressure to aim for lower energy use, though not at the expense of the services provided in buildings. The aim is to combine healthy, comfortable indoor environments with the least amount of energy required to achieve this, taking the rational use of resources into account.

There is concern that in spite of this aim, the drive for energy saving may have an adverse effect on the indoor environment. The main concern is that some strategies for reduction in thermal loads may lead to reduced indoor air quality. There are also some other concerns for example, that thermal comfort and lighting levels will suffer, but these problems are reasonably well understood and documented. The aim of the present report is therefore mainly (i) to focus on how to reduce the use of energy in buildings and at the same time ensure good indoor air quality and (ii) to draw attention to the need to assess the impact of energy strategies on the indoor environment at an early stage of design. The report focusses on strategies and technological options. Economic conditions for their implementation and economic aspects in general, are not discussed.

1.3.1 Relationships and potential conflicts between IAQ and efficient use of energy

Air exchange between indoors and outdoors is crucial for both IAQ and the rational use of energy. The exchange rate can result from adventitious infiltrations/exfiltrations of air through the envelope, natural ventilation through doors, windows and purpose-designed openings, or be provided by a mechanical ventilation system.

Infiltration and natural ventilation depend on the air-tightness of the envelope, the strength of the forces driving infiltration (i.e. indoor-outdoor air temperature differences, wind speed) and the occupant's behaviour.

Ventilation by a mechanical system relies mainly on technical means (fans, blowers, etc.). It permits the control of air exchange and provides other facilities such as heat recovery, air cleaning, humidity/temperature control (HVAC systems), etc.

If air quality is better outdoors than indoors, any reduction in the outdoor air supply will inevitably raise the concentration of pollutants in the room air and thus decrease the indoor air quality. This may lead to adverse effects on occupants' health, comfort and productivity and, in cases of moisture, produce structural damage to the building.

In practice, fully mixed, steady-state conditions will not prevail. However, the general concept of indoor air quality being a balance between pollutant production, sinks, and the supply of outdoor air is still valid. The obvious way of reducing ventilation requirements (and thus energy consumption) is source control, i.e. eliminating or decreasing unnecessary pollution sources.

In leaky buildings, ventilation can often be reduced by improving air-tightness without compromising IAQ. Care must be taken, however, to ensure that the minimum ventilation requirements are always provided. Increasing the levels of thermal insulation must be carried out with care because of the resulting changes in distribution of temperature and humidity in the building evelope. In some circumstances this can lead to interstitial condensation and thermal bridges (BRE, 1994).

1.3.2 Energy use in the building sector

The energy used to heat and cool buildings and provide other building services such as lighting is a significant proportion of national economies and the world's energy balance. The percentage used for heating and cooling in European countries ranges from 20 - 50% of the total energy consumption (e.g. Santamouris et al., 1994), depending on the climate, the socio-economic situation and the structure of the energy use in a country.

Thermal loads connected with the heating/cooling of the air exchanged between outdoors and indoors form a high proportion of thermal loads in buildings. A significant reduction in energy consumption could be achieved if heat losses through the building envelope were decreased (e.g. by thermal insulation, multiple glazing). Energy losses due to ventilation can be reduced by using efficient ventilation technologies (e.g. heat recovery, demand control, etc.).

Energy losses by uncontrolled infiltration may also be reduced by tightening the building envelope. However, adequate ventilation to satisfy occupants requirements for health and comfort must be provided in a controlled manner. No commonly agreed values exist yet for this minimum adequate ventilation. As an example, the level of the ventilation requirements in the ASHRAE 62 standard has tripled between 1981 and 1989 (from 2.5 to 7.5 liters per second and person), partly because moderate smoking was allowed in the 1989 standard but not in the 1981 standard. The present revision not only considers occupants as a pollution source, as in the previous revisions, but also the building itself and it also considers smoking as not compatible with acceptable indoor air quality.

As another example, an overview of existing standards, requirements and guidelines for non-residential indoor environments is given in Appendix 1.

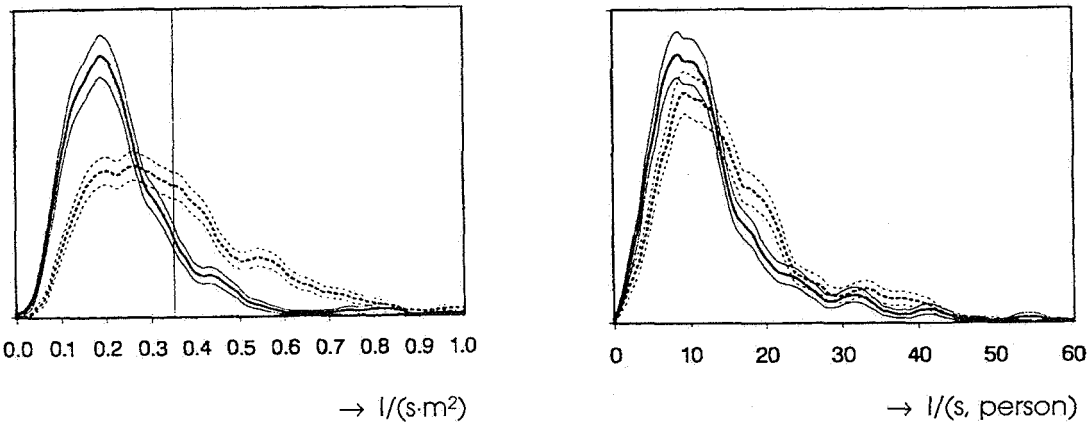$\rightarrow$ l/(s·m²) $\rightarrow$ l/(s, person)

Figure 1. Estimated frequency functions of the ventilation rate in a representative sample of single-family houses (full lines) and multi-family houses (dotted lines) in Sweden. Thin lines indicate the ranges of uncertainty.

In Sweden, a nation-wide survey on ventilation rates in occupied dwellings was conducted (see Fig. 1). It clearly demonstrates that a majority of the dwellings are below the prescribed minimum ventilation rate of 0.35 $l/(s \cdot m^2)$ as indicated by the vertical line on the left hand side of Fig. 1.

Similar results have been obtained in a Danish study of 150 naturally ventilated detached houses constructed since 1982: in about 85 % of the houses the average ventilation rate was below the Danish standard of 0.35 $l/(s \cdot m^2)$ and the mean value was 0.22 $l/(s \cdot m^2)$ (SBI, 1993). Apparently, standard setting is necessary but not a sufficient condition for guaranteeing a specific ventilation rate.

1.3.3 Influence of occupancy and occupant activities on energy consumption and indoor environment

In buildings such as dwellings or office

buildings, ventilation and heating or cooling is necessary to provide comfort and health for the occupants. When there is no occupant, the requirements are very low.

When there are occupants present, the requirements depend on different factors: physiological, psychological, sociological and cultural. There are large differences from one person to another. It is important to design buildings in order to meet the requirements of the majority of people and not just of the average occupant. The more an individual can regulate the indoor environment (e.g. by using a control device or opening a window etc.), the more satisfactory it will be. Ideally, each occupant should be able to adjust his environment to his own requirements. Clothing and activity level are important personal factors for thermal comfort.

The occupants' behaviour with respect to the opening of windows can greatly affect the ventilation system, energy consumption and indoor air quality. Occupant behaviour with respect to ventilation has been studied in Annex 8 of the Energy Conservation in Buildings and Community Systems Programme (IEA,1988). It appears that the ventilation rate due to window use is from 0.0 to 0.1 ach (air change per hour) for "low window use", 0.1 to 0.5 ach for "average window use" and 0.5 to 0.8 ach for "high window use". Window use provides the occupant with the opportunity for individual control of his environment and is welcome by most occupants.

Demand controlled ventilating systems can provide a solution which takes actual needs (occupation and activity) into account. If ventilation is demand controlled, the need to open windows will be significantly reduced and the energy consumption can be further reduced using energy efficient systems (heat recovery, etc.).

1.3.4 Energy use and sustainability

The United Nations, conscious of the complexity and gravity of the problems regarding the environment of the planet earth and also of the socio-economic situation in a large number of developing countries and regions in the world, organized the United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, in June 1992. The document issued by UNCED most relevant to the present report is the so called Agenda 21. One of the outcomes of the conference was a commitment made by governments to take action at national level to adopt strategies for sustainable development.

One of the ways this can be encouraged is through the rational use of energy resources. The issue is not to simply save energy: it is to supply the services people need from energy but with the lowest possible consumption of non-renewable energy resources.

This has a direct implication for energy use in buildings: if part of the energy services that are required in buildings can be provided by natural means (daylighting, natural ventilation and passive heating and cooling) their use should be encouraged. This must not adversely affect the comfort or health of the occupants. Some relevant paragraphs of Agenda 21 are given in Appendix 2.

1.3.5   Indoor air pollution and its control

The quality of indoor air is determined by the level of pollutants present. Some pollutants may adversely affect the health of the occupants, such as carbon monoxide and radon, others may have no health effects, but may influence comfort and perceived air quality, such as body odours. Pollutants may arise from a number of sources, e.g.

- human activities
- various materials and products including HVAC systems
- combustion processes
- microbiological organisms such as mould and dust mites
- outdoor air pollution
- the ground under the building

Information about pollution sources and pollutant loads is still scarce. Some information may be found in ECA (1992), and in Maroni et al. (1995). The effects of pollutants are generally related to their concentration in the indoor air and the exposure and susceptibility of the occupants. Information on the influence of source and environmental parameters (temperature, air velocity, etc.) on emissions and on acceptable levels of most pollutants or combinations of pollutants is generally not available.

The pollutants of main concern may vary for different types of buildings. An example of this is water vapour. Water vapour is considered important in residential buildings due to high production rates from washing, cooking, etc. In office buildings, the production rate of water vapour to the air is lower and thus of less importance.

The level of indoor pollutants can be controlled by:

- Source control, e.g. removal, replacement by an alternative material, sealing.
- Removal by local exhaust ventilation at the point at which the pollutant (e.g., moisture) is generated or by displacement ventilation.
- Dilution by ventilation.
- Air cleaning.

It is important from the point of view of energy conservation that ventilation rates should not be excessive, but at the same time an adequate supply is needed to ensure good indoor air quality (see also section 1.3.2).

The preferred method for controlling the level of pollution depends on the pollutant(s) of concern. If the main pollutants are bioeffluents from human beings, dilution by ventilation is the only realistic method of improving the air quality. In contrast, combustion products are most efficiently removed by local ventilation at the point of generation. The preferred methods may also vary for different building types. Smoking areas with increased ventilation may be an option, e.g. in offices, but may be difficult to implement in meeting rooms. The relevance of different pollutants for IAQ and preferred methods of pollution control in different indoor environments are summarized in Appendix 3.

1.3.6   Health and comfort aspects of indoor air pollution and the thermal climate

The indoor environment has to fulfil two requirements in order to satisfy the occupants. Firstly, the health risk should be negligible. Secondly, the indoor environment should be comfortable and pleasant. The degree of variation in human requirements can be quite large. This is because people have different sensitivities to the indoor environment and spend different proportions of their time there.

Health aspects. Exposure to pollutants in indoor air may cause acute or long-term health effects. For some effects, clear relationships with exposure to indoor air pollution have been reported in world literature. Among these are respiratory diseases (particularly amongst children), allergy (particularly to house dust mites) and mucous membrane irritation (particularly due to formaldehyde). Large numbers of people have been, and are still affected. For further details, see ECA report no. 10 (ECA, 1991).

Many chemicals encountered in indoor air are known or suspected to cause sensory irritation or stimulation at least at high concentrations. Some may give rise to a sense of discomfort and other symptoms commonly reported in so-called "sick" buildings. High humidity indoors increases the risk for allergy. It is also associated with an increased growth of micro-organisms such as mould and bacteria. Some asthmatic children react on exposure to mould. Some micro-organisms can grow in air humidifiers and may result in pneumonia (Legionella) and "humidifier fever".

An increased risk of developing lung cancer has been linked to exposure to environmental tobacco smoke (ETS) and to radon decay products. The effects of indoor air pollution on reproduction, cardiovascular disease and on other systems and organs have not been well documented to date. To a certain extent, this may mean that no serious effects occur, but there has been little by way of research to clearly document the absence of these types of effects.

Comfort aspects. Humans perceive the indoor climate by several senses, i.e. olfaction, the general chemical sense, thermal senses, hearing and vision. The combined response of the olfactory and the general chemical sense determines whether the air is perceived as fresh and pleasant or as stale, stuffy and irritating. It is important to realise that the sensory effects of pollutants are not necessarily linked to their toxicity. Indeed some harmful air pollutants are not sensed at all. Therefore perceived air quality is not a universal measure of adverse effects.

Man is in thermal balance when the heat generation of the body equals the loss of heat to the environment. This balance may be established by behavioural action, e.g. adjustment of clothing or activity, or it may be influenced by environmental parameters: air temperature, mean radiant temperature, air velocity and partial water vapour pressure. In addition, in a moderate environment, man's thermoregulatory system will automatically try to modify the skin temperature and the sweat secretion to maintain the heat balance. Other causes of local discomfort are (i) draughts; (ii) a too hogh vertical temperature difference between head and ankles; (iii) a too warm or cold floor; (iv) a too high radiant temperature asymmetry. Recommendations on thermal comfort are given by ISO Standard 7730 (ISO, 1993; see also Appendix 4).

High temperatures may enhance sensory and physiological effects of volatile organic compounds (VOCs) (Mølhave et al., 1993) and influence the perception of indoor air quality (Clausen et al., 1993).

Achieving good thermal comfort as well as good indoor air quality are basic requirements for an acceptable indoor environment. In the case of thermal comfort, the required thermal conditions are quite well known and defined and energy efficiency can be mainly achieved by good building design and location, thermal insulation, heating and cooling. However, in the case of indoor air quality, the required air quality and related air flow rates are not precisely identified as indicated in Table 1. This is reflected in the large variation in recommended air flow rates (see Appendix 1 and section 1.3.2 above).

A better understanding of the required air flow rates for achieving good IAQ is crucial for achieving reasonable energy efficiency. For example, the ECA recommendations in Appendix 1 give for single offices requirements ranging from 0.8 l/s,m² to 7.2 l/s,m² which is a variation of up to tenfold. The energy required to counteract ventilation thermal losses can vary by a factor up to the same magnitude.

Table 1:   Differences between some features of thermal comfort and indoor air quality with important relevance for standard setting

Features	Thermal comfort	Indoor Air Quality
comfort range	Relatively small range and identified optimum	Wide range and no identified optimum
Sensory warning to occupants	Very pronounced	Less pronounced and complex
Adaptation possibilities by users	Quite large by changing clothing and activities	Efficient odour adaptation but otherwise few possibilities

Other health and comfort aspects of the indoor environment. The main emphasis of this report is on indoor air quality and environment. However, health and comfort may also be affected by other aspects of the indoor environment, for example, by lighting and noise. These also depend on energy for their delivery. Moreover, some measures for improving energy efficiency (e.g. tight, multiple-glazed windows) can reduce noise exposure.

1.4   The Influence of Climatic Conditions and their Variations across Europe on IAQ and Energy Use

Differences in climatic conditions, as well as in available materials and socio-economic aspects are responsible for the diversity of architecture found throughout Europe. These differences, present in vernacular architecture and in construction practices, express the wisdom acquired from the experience of centuries. Recently, however, as a consequence of technological development and low energy prices, the lessons learned from the past have been neglected in favour of a more international style in architecture and a more uniform way of constructing and using buildings irrespective of climatic conditions.

Traditional building styles reflect the climates of their regions. In Northern Europe, where heating seasons are long, the multiple-glazed windows, heavy curtains, and entrance lobbies found in peoples' homes reflect their desire to keep cold draughts out. Here, mechanical ventilation may be the most effective way of reconciling good IAQ and rational use of energy. In Southern Europe, on the other hand, the barrier between the indoor and outdoor environment needs to be much more permeable with priority given to encouraging the exchange of air between indoors and outdoors in hot weather. These differences help to explain the actual discrepancies in the levels of energy used in housing in EU Member States as well as the importance given to IAQ issues.

By contrast, buildings constructed recently, tend to look alike, irrespective of their locations. In particular, office buildings because of their high internal heat gains from lighting and appliances and the building design with high solar loads tend to be air conditioned. Meanwhile, there is a trend towards the design of non-air-conditioned buildings. It is important to acknowledge that buildings do not have to be either air-conditioned or non-air-conditioned. There is actually a continuity of solutions between the two extremes from which the best compromise between low energy use and good indoor air quality and climate can be chosen for any building.

In order to favour energy efficient building designs which reflect and make the best use of local climatic conditions, more and more refined data on regional climates and urban micro-climates, in particular on solar irradiation and wind velocities, are needed.

The diversity which makes Europe - as a community of people - so rich, cannot but be strongly evident in two of the most important ways of expressing the influence of local conditions: architecture and building construction. The environment and the rational use of natural resources are common concerns. Building physics is common knowledge between professionals. Diversity on one hand and common concerns and knowledge on the other should open the way to solutions adapted to specific conditions. Therefore, this report concentrates on strategies, and the ways and means available of reaching a compromise between good IAQ and the efficient use of energy, without going into technically or numerically detailed information that could be misleading if not put into the appropriate regional and climatic context.

1.5   Socio-Economic Costs of Poor IAQ and its Relation to the Use of Energy

The potential economic impact of poor indoor air quality is quite high, and has been estimated to be in the order of tens of billions of ECU per year in western Europe. This includes costs of medical care, loss of income during illness, days lost due to illness, poor working performance and lower productivity. Labour costs are significantly greater per square metre of office space than energy and other environmental control costs (EPA, 1989). In the US, the loss in productivity for each employee which is attributable to IAQ problems is currently estimated to be 3% (14 minutes/day) and 0.6 added sick days annually (Brooks and Davis, 1992).

Other estimates have been made by calculating the impact of IAQ on productivity. For instance, in Norway, the authorities estimate that the costs to society related to poor IAQ are in the order of 1 to 1.5 billion ECU per year, or about 250 - 350 ECU per inhabitant. This estimate only includes costs related to adverse health effects requiring medical attention and does not include reduced working efficiency or job-related productivity losses (Pillgram Larsen, 1991).

Thus, from an economic consideration, remedial action to improve indoor air quality is likely to be cost effective even if an expensive retrofit is required.

1.6   Trends for the Future in the Building Sector

We can foresee the following trends over the next 20 years.

Sustainable development:

- The general public is becoming more aware of all aspects of the environment, including the immediate living environment.

- Many energy sources will be increasingly viewed as limited and nonsustainable resources.

- A change will occur from a consumer orientated society to a maintenance and recycling orientated society with respect to building products.

Health and safety:

- A further increase may be observed in cases of asthma, allergy and other hyper-reactivities which may partly be related to indoor environmental conditions and in any case, are aggravated by many indoor products.

- It will increasingly be realized that safety in buildings and the environment does not imply   absence of risk but that safety constitutes the acceptable level of risk which might be guided by comparative risk assessments.

<u>Building performance:</u>

- Increased use of new materials, building forms and components will be observed together with an increased demand for product information.

- There will be a move from centralized management control of indoor environments to individual occupant control.

- An increasing demand for fail-safe systems and low (essentially zero) emission building materials will be observed.

- There will be a continuing decrease in heat demand in the building stock but an increase in cooling demand may appear if not counteracted.

- The increase in electricity demands in buildings will in many instances be counteracted by the development of more energy efficient appliances.

- Programs for third-party financing of energy efficiency investments and of improving IAQ in various types of buildings will be established.

- There will be an increasing emphasis on the provision of energy efficient, healthy buildings, to a large extent supported by codes and standards.

2. STRATEGIES FOR ACHIEVING A GOOD BALANCE BETWEEN INDOOR AIR QUALITY AND EFFICIENT USE OF ENERGY IN BUILDINGS

The urgent need to reduce the energy used in the heating, cooling and lighting of buildings has brought about significant changes in the way buildings are designed and built. Because buildings encompass complex interactions between different requirements and subsystems, care must be taken when changes are made to any one aspect of building performance to ensure that this does not have a detrimental effect on other building functions.

This is particularly true when measures are introduced to reduce energy consumption in buildings. It is important to ensure that when energy saving measures are taken, their effects on the indoor environment are identified and quantified, and that action is taken to eliminate or reduce any detrimental effects.

The main strategies for improving the use of energy in buildings and/or the indoor environment concern:

- building location and orientation
- building design and construction
- building services systems
- control of pollution sources
- building operation and maintenance

Appendix 5 collates the principal ways of implementing strategies to improve energy performance and how they can affect the indoor environment. These effects may be beneficial or detrimental. Similarly, action taken to improve the indoor environment may have implications for energy use.

The most important features of a strategy aimed at a balanced improvement of energy use and the indoor environment are illustrated in Figure 2.

BASIC REQUIREMENTS

Define requirements on thermal climate, IAQ, humidity, noise and lighting
(based on building regulations, guidelines,.....)

Reduce external thermal and moisture loads by proper building location and design

Optimize thermal insulation, window type and window location/area.

Be cautious with unproven materials and technologies

Yes

Select zero/low emission materials and processes.
Apply ALARA (As Low As Reasonably Achievable)

No

Yes

Reduce internal heat loads

No

Yes

Reduce internal moisture loads

No

Concentrate sources
and apply
local exhaust

Yes

Use passive means of lighting, cooling, heating,
ventilation but

— ensure supply of good quality outdoor air

— ensure year around benefits

— consider potential for heat recovery

No

Use active means of lighting,
cooling, heating, ventilation
but often with a higher
energy cost.
Make maximum use of
existing knowledge and
efficient technologies and
ensure occupant acceptance

Yes

Yes

Ensure acceptable IAQ and moisture control by
appropriate ventilation strategy/system and sufficient
ventilation

No

Expect problems

Yes

Allow individual control of indoor climate as
supplement to general/automatic control

No

Risk of lower occupant
satisfaction

Yes

Provide self-explanatory or fail-safe technical systems

No

Provide adequate user/operator training

Yes

Provide appropriate commissioning, maintenance, inspection programmes, and user/operator training
Give complete and understandable information to operators and users

Yes

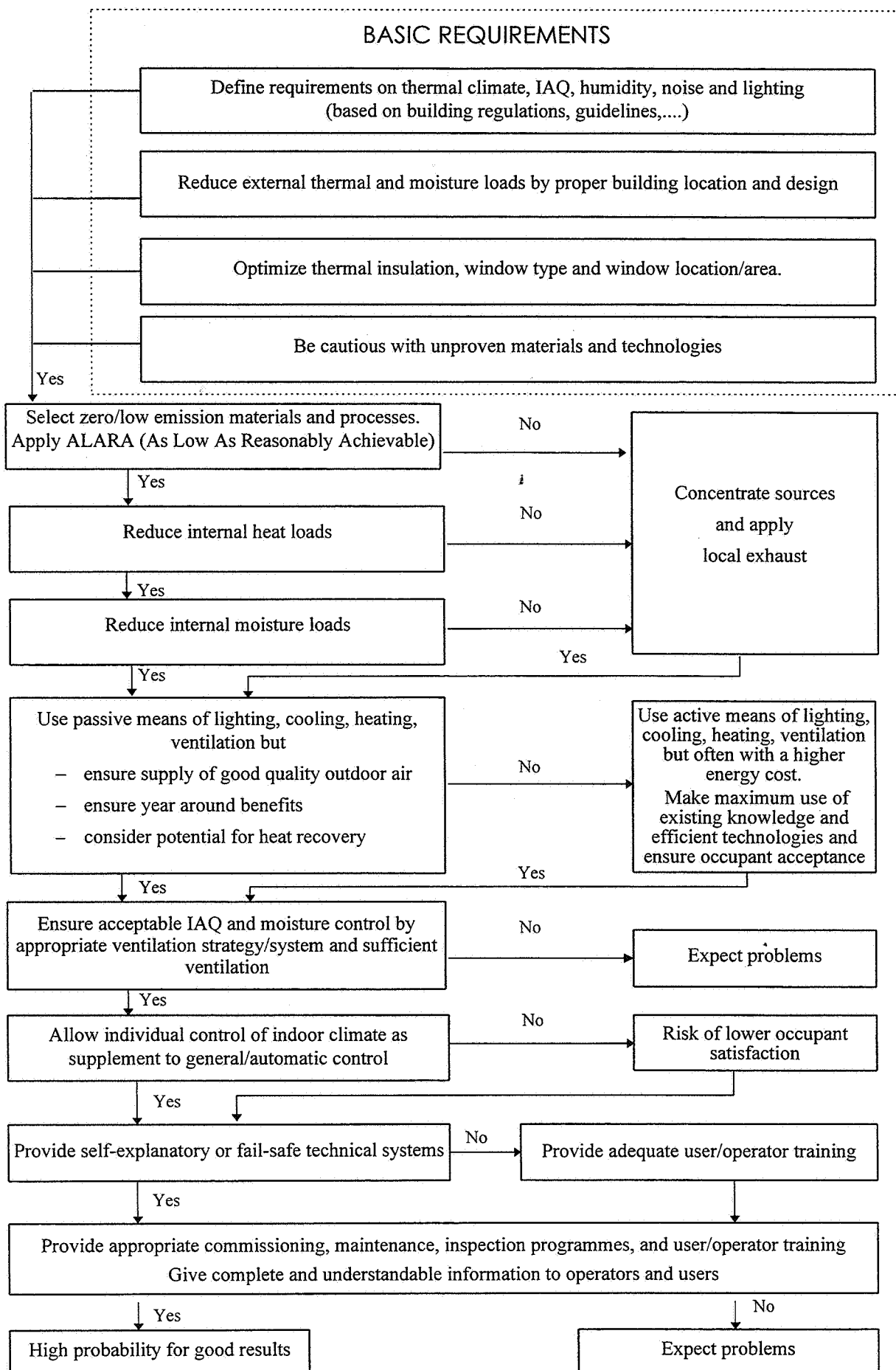High probability for good results

No

Expect problems

Figure 2. Strategy for achieving good IAQ and Efficient use of Energy

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3. ENERGY USE IN BUILDINGS AND INDOOR AIR QUALITY - POLICIES AND TOOLS

In the last decade, a number of actions have been taken to advance the general knowledge of efficient energy use in buildings as well as of indoor air quality issues. Growing environmental concerns have enforced the engagement of all parties involved. However, the issues of energy efficiency and indoor air quality have rarely been approached in a co-ordinated manner. This is evident when reviewing pertinent documents, whether appearing as policies, standards and guidelines or scientific reports.

In Appendix 6, we present a number of documents which have been reviewed regarding the energy efficiency/indoor air quality issue. The documents have been chosen for examination without attempting full national or international coverage, but may be seen as typical examples.

The documents often reflect differing views on the energy efficiency/indoor air quality issues but we have also observed a tendency towards increased understanding of the inter-relationships between the issues and the need for further support of this coordinated approach in different areas: policies, standards, R&D models, audits and monitoring practices.

The Directive 89/106/EEC on construction products defines energy efficiency and indoor air quality as part of the "Essential requirements". In Interpretative Documents (IDs), the links between these two requirements are specified, thereby constituting a framework for further regulations and standards while taking a coordinated view on energy efficiency and indoor air quality into account. Also the Directive 93/76/EEC on limiting CO_2 emissions by improving energy efficiency is of clear relevance for furthering this coordinated view, taking the variety of conditions prevailing in different parts of Europe into account.

Documents of relevance for the energy efficiency/indoor air quality issue have been produced by international organizations such as WHO, IEA, ASHRAE, ISO, CEN, etc.

A number of nation-specific regulations and guidelines have been identified. They include examples of a response to specific climatic and culturalfeatures, relevant to aspects of the energy efficiency/ indoor air quality issue at local (national) level.

Research-related activities focussing on the energy efficiency/indoor air quality - issue are being advanced by international as well as national agencies, by the EC JOULE/THERMIE programme, the European Collaborative Action (ECA), and the NATO Committee on the Challenge of the Modern Society (NATO/CCMS, 1990).

Research has resulted in the development of a wide range of various models suitable for studies of energy use, indoor climate and occupant behaviour. A short survey is given in Appendix 6.4. Although these models are based upon the same basic equations, different approaches and assumptions have led to models of different accuracies and applications. It will be important to develop further more flexible and practical methods and models for a coordinated analysis of the energy efficiency and indoor air quality issues.

4 RECOMMENDATIONS

4.1 General Considerations

The following are basic requirements for achieving good indoor air quality at a reasonable energy cost:

- <u>minimization of indoor air pollution and thermal loads</u>, e.g. by appropriate architectural and systems designs and by the choice of low or non emitting materials
- <u>use (and further development) of energy efficient technologies</u> wherever appropriate, e.g. demand controlled ventilation, heat recovery systems
- appropriate quality objectives and assurance with respect to <u>commissioning, inspection and maintenance</u> programmes

4.2 Recommendations to Specific Audiences

4.2.1 Recommendations to policy makers

In making policies for indoor air quality, it is important that the energy implications are taken into account and vice versa.

Achieving good indoor air quality requires sufficient ventilation. Therefore, good ventilation standards are very important. In order to satisfy energy conservation requirements, these standards should require elimination (e.g. no smoking) or control (e.g. no emission or low emission materials) of indoor pollution sources wherever possible.

Labelling of products and buildings and their ranking with respect to safety and emissions should be encouraged in order to facilitate informed selection and use by the consumer.

There is a continuing need to ensure that those involved in designing, building and operating buildings and their services are aware of the best practice in providing energy efficient buildings with good indoor air quality. Good informative and up-to-date texts are required covering not only energy aspects but also indoor air quality.

Information campaigns have to be repeated at regular intervals in order to ensure a lasting effect. Those responsible for designing campaigns should continually review the measures recommended, and also the need to provide advice not only on energy, but also on maintaining good indoor air quality.

4.2.2 Recommendations to building developers, designers and builders

The basic methods of achieving good IAQ are: selection of low emitting materials; local extract ventilation; dilution of pollutants by ventilation; pollutant removal from the air by filtration or by other means, source control by sealing, and source control by restrictions of the use of the source.

It is important from the point of view of energy conservation, that air exchange rates are not excessive but that, at the same time, an adequate supply is provided to maintain indoor air quality. Generally, source control should be the first priority, since dilution and air cleaning are likely to be more expensive in energy use and less effective.

Buildings and HVAC systems should be commissioned before handover to the building operators and the occupants to ensure that the building can provide adequate energy and IAQ performance.

Manuals describing the design criteria and technology as well as needs for operation and maintenance of the building without adverse impact on IAQ, should be made available to the occupants.

4.2.3   Recommendations to building operators and occupants

There is a need to ensure that there are adequate policies and procedures for operating and maintaining systems and that there is adequate information for users and operators of buildings. In a small building or dwelling, there is no building operator but at the very least, the following material should be available:

- documentation of equipment/building systems
- information for users

In large buildings, the operator or manager of the building has a key role in ensuring the building operates as was originally intended, that energy demands are kept to a minimum, that a satisfactory indoor climate is provided and that the users are satisfied.

This requires that:

- the latest guidance about pollutant sources and technical facilities is available
- the siting and sizing of activities and equipment which generate pollution is carefully considered
- a non-smoking policy is implemented or separate smoking areas are designated
- energy and ventilation systems are operated as intended and demand-controlled
- condensation of moisture is controlled by a correct balance between thermal insulation, ventilation and heating/cooling
- the operator checks if there are any problems with comfort or health of building occupants attributed to indoor air quality, checks the use or misuse of individual equipment, and, if necessary, asks for an audit considering both energy and IAQ
- persons at high risk are given special consideration (e.g. asthmatics or other particularly sensitive people)

Good building maintenance requires that:

- there is regular maintenance of the energy and air quality systems
- floors, furniture, etc. are cleaned to remove pollutants, ventilation systems are operated during the cleaning processes and the cleaning products are chosen carefully
- while renovation work is taking place (such as painting, or substitution of floor coverings) or new equipment is introduced (such as furniture or office machines), ventilation is temporarily increased and non-occupancy is considered
- HVAC systems are regularly maintained and cleaned with particular attention given to filters and drain pans
- the use of HVAC system components such as fan coil units, induction units and unit ventilators are discouraged if adequate maintenance cannot be guaranteed

4.2.4   Recommendations to manufacturers of building materials and ventilation / air conditioning systems

Recommendations to manufacturers of building materials (and consumer products for indoor use) include:
–   the development of products which have low emission characteristics when installed and when in use
–   quality (emission) control of products
–   information on the impact of products on IAQ through a labelling system
–   maintenance instructions and procedures

Recommendations to manufacturers of ventilation/air conditioning systems include:
–   products which easily allow for inspection and maintenance
–   heat exchangers which exclude transfer of pollutants between incoming and outgoing air
–   humidification systems which exclude the growth of micro-organisms
–   heating and cooling systems which minimise potential adverse effects on indoor climate and energy
–   components for demand controlled air handling systems which allow individual interaction
–   automatic control of filter performance
–   instructions for the installation and use to minimise misuse

4.3   Major Research Themes

Examples are given below of gaps in knowledge and research needs (for details, see Appendix 7):

•   Pollutants and sources. Identification of pollutants and occupant exposure, safe and acceptable emissions, safe and acceptable levels in buildings, sources and source control. Reliable criteria and procedures for the labelling of products and materials.

•   Indoor air quality & climate. Acceptable levels of both comfort and health.

•   Assessments of the built environment from both energy and indoor air quality & climate aspects. Description of technical status, energy use and indoor air quality and climate in the built environment.

•   Building services. Cost-effective low energy equipment for providing acceptable indoor air quality and climate.

•   Prediction methods. Simple methods for predicting the performance of buildings both at the design stage and when changes are made to existing buildings. The methods should include both energy and indoor climate and take occupant behaviour into account.

•   Commissioning, operation and maintenance of buildings. The effectiveness of procedures, methods of auditing or assessing and controlling existing buildings, including measurement techniques such as IAQ sensors and methods of eliminating problems with indoor climate.

•   Changes to building design and operation. Identification of problems with IAQ caused by the drive to reduce energy consumption, and development of robust solutions.

•   Information transfer. Identification of the best means to provide information to the building community to ensure application of research results, e.g. labelling systems.

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5   CONCLUSIONS

1. Both the rational use of energy and the provision of good IAQ are important aspects of building design and refurbishment. There are potential conflicts between these requirements. The impact of possible energy saving measures on IAQ should always be assessed before their eventual adoption, and where unacceptable, the measure should be avoided.

2. Source control should be the first priority.

3. Environmental tobacco smoke is a key pollutant, with serious energy penalties because of substantial increases in ventilation requirements. Separate smoking areas and non-smoking policies should be considered.

4. The importance of occupants should be recognised, particularly their role in ensuring that energy and IAQ systems operate correctly, their ability to act appropriately in the event of failure, and their needs for individual control.

5. Reducing air exchange rates to save energy may result in poor IAQ.

6. Increasing air exchange rates to improve IAQ will increase energy consumption, unless this is partly compensated for by heat recovery.

7. Ventilation requirements should be determined from the total pollutant load in a building resulting from constituents and systems and of occupants and their activities. The goal of ventilation should be to provide good IAQ. A secondary goal is to protect the building, the installations and furnishings.

8. The recommended strategy for designing new buildings and refurbishing existing buildings taking both IAQ and energy into account (there may be some restriction of choice in existing buildings) is

    *   control sources of pollution and of energy loss by using suitable materials, sealing, local extraction, etc.

    *   determine ventilation strategy and design ventilation systems using energy-efficient   and passive technologies where appropriate

    *   base the design of energy systems on the required ventilation rate

    *   design systems for IAQ (including controls) to match the abilities of the occupants and   users

    *   design systems for easy commissioning, maintenance and control

9. Improvement of IAQ is believed to be generally cost-effective. Much knowledge is already available and this needs to be put to better use by improved information transfer and co-ordination of those involved in the design process.

10. Control, maintenance and management procedures are essential and good strategies should be developed.

11. Research is needed in order to achieve good tools and methods for simultaneous analysis of both the energy efficiency and the IAQ.

12. Within the ECA, a standing group should be established which addresses the issue of Energy Efficiency/Indoor Environment and proposes research themes and other activities for cost-shared action programs.

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APPENDICES

Appendix 1: Comparison of ventilation requirements or minimum ventilation rates defined in various documents, guidelines or standards [1]

Type of building or space	Ventilation rates calculated according to ECA (1992) [2]		DIN 1946 [3] 1994	CIBSE guide 1978	French values [6]	SCANVAC Guidelines and specifications 1994	NKB No.81E Indoor climate air qualiuty 1991	Finnish national building code D@ 1987	ASHREA 62 1989
	achievable in low pollution buildings [4]	needed in average pollution buildings [5]							
	required ventilation rate [l/(s m² floor area)]	required ventilation rate [l/(s m² floor area)]	minimum ventilation rate l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]	minimum ventilation rate [l/(s m² floor area)]
Single office	3.3 1.4 0.8	7.2 4.6 2.3	1.1	---	0.7	3.2 1.4 ---	1.1	1	1.0
Landscaped office	2.8 1.2 0.7	6.7 4.2 2.1	1.6	1.3	0.5	2.7 1.2 ---	1.0	1.5	0.7
Conference room	10.0 4.3 2.4	14.3 9.1 4.6	2.8-5.6	6.0	2.5	9.6 4.2 ---	3.5	4	5.0
Class room	12.5 5.4 3.0	17.0 10.8 5.4	4.2	---	2.1	9.6 4.2 ---	4.9	4	4.0
Kindergarten	11.7 5.0 2.8	17.9 11.4 5.7	---	---	2.1	9.6 4.2 ---	4.9	2	---
Department store	5.8 2.5 1.4	13.4 8.5 4.3	0.8-3.3	3.0	1.2	5.6 2.5 ---	1.2	2	1.0

[1]   adapted from CEN/TC 156/WG6 Doc N 66;

[2]   required ventilation rates depend on outdoor air quality, occupancy, material pollution load, tobacco smoking and ventilation efficiency; the values reported below are based on no smoking and refer to three comfort categories - A, B and C - which correspond to 10, 20 and 30% dissatisfied respectively;

[3]   DIN 1946 allows as an alternative a calculation similar to the one described in draft document N 66 of CEN./TC156/WG6.

[6]   values based on French standards and particular assumptions.

[4]   values based on clean outdoor air, mean occupancy in spaces, a recommended target value of the pollution load for low polluting buildings (from ECA,1992) and a ventilation efficiency of one;

[5]   values based on mean outdoor air qualtiy and material pollution load (from ECA,1992) and a ventialtion efficiency of 0.8 (see also Joppolo and Sanvito, 1994);

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The integration of environmental and development concerns will lead to the fulfilment of basic needs, improved living standards for all, more protected and better managed ecosystems and a safer, more prosperous future.

Measures to be undertaken at an international level for the protection and enhancement of the environment must fully take the current imbalances in the global patterns of consumption and production into account.

Special attention should be paid to the demand for natural resources generated by unsustainable consumption and to the efficiency use of those resources consistent with the goal of minimising depletion and reducing pollution.

Although consumption patterns are very high in certain parts of the world, the basic consumer needs of a large section of humanity are not being met. This results in excessive demands and unsustainable lifestyles amongst the richer segments, and these place immense stress on the environment.

Access to safe and healthy shelter is essential to a person's physical, psychological, social and economic wellbeing and should be a fundamental part of national and international action.

The right to adequate housing as a basic human right is enshrined in the universal declaration of human rights and the international covenant on economic, social and cultural rights.

Despite this, it is estimated that at the present time, at least 1 billion people do not have access to safe and healthy shelter and that if appropriate action is not taken, this number will dramatically increase by the end of the century and beyond.

The objectives are to extend the provision of more energy-efficient technology and alternative/renewable energy for human settlements and to reduce negative impacts of energy production and use on human health and on the environment.

It is recommended to incorporate environmental costs in the decisions of producers and consumers, to reverse the tendency of treating the environment as 'free of charge' and to pass environmental costs on to other parts of society, other countries, or to future generations.

 Relevance of different pollutants and preferred methods of control in different indoor environments.

Table A. Relevance of Different Pollutants for Buildings and Rooms of Different Types (example based on UK experience, may differ from other countries) (cited from IEA,1987).

Key to symbols: (++)-very important; (+)-important; (o)-important in specific situations; (oo)-very important in specific situations; (p)-possibly important but current knowledge limited.

	Tobacco smoking	Body odour (carbon dioxide)	Water vapour	Comb. product	Formal-dehyde	Organics	Partic-ulates*)	Micro-organisms	Radon	Other
Dwellings								*)		
Living rooms	++	++	o	++	o	p	p	o	o	
Bedrooms	++	++	oo	oo	o	p	p	o	o	
Kitchens	+		oo	++	o	p	p	oo	o	
Bathrooms			oo	oo				oo		odour
Toilets								p		odour
Office Buildings										
Small Offices	++	++			o	o	o	o	p	
Open plan offices	++	++			o	o	o	o	p	
Schools										
Class rooms		++	oo		o	p	oo	oo	p	
Gymnasia		++	oo							
Laboratories			o		o			o		toxic chemicals
Auditoria										
Theatres,cinemas	++	++		o		o		+		
Lecture halls	++	++		+		o	p	+		
Hotels										
Bedrooms	+	++	+		o	p	p	+		
Bathrooms		++	++		o			+		odour
Public rooms	++	++						+		
Shops	++	++		o	o	o	o	+		
Hospitals	++	++			o	o	o	++		
Restaurants	++	++		o		p		+		food odours
Sports Halls		++	o					+		

*)   very important in the case of sensitivity against allergic reactions
**)   tobacco smoke excluded

Table B. Preferred Possible Methods of Pollution Control (cited from IEA, 1987)

Key to symbols: (V/v)-Dilution ventilation; (E/e)-local extract ventilation; (F/f)-Removal fron air (by filtration or other means); (S/s)-Source control (by sealing or similar means); (B/b)-Source control (by restriction on presence or use of source).

Building Type	Tobacco smoking	Body odour (carbon dioxide)	Water vapour	Comb. product	Formal-dehyde	Organics	Partic-ulates*)	Micro-organisms	Radon	Other
Dwellings										
Living rooms	V,b	V	V	E,v,b	B,s	B,s			S,B	
Bedrooms	V,b	V	V							
Kitchens	V,b		E,v	E,v						
Bathrooms			E,v							
Toilets								E		E,v
Office Buildings										
Small Offices	B,v,f	V			B,s,f,v	B,s,f,v	B,s,f,v	b		
Open plan offices	B,v,f	V			B,s,f,v	B,s,f,v	B,s,f,v	b		
Schools										
Class rooms		V			B,s	B,s	B,s	b		
Gymnasia		V								
Laboratories			E,v	E,v				b		
Auditoria										
Theatres,cinemas	B,v	V			B,s	B,s	B,s,f	b		
Lecture halls	B,v	V			B,s	B,s	B,s,f	b		E,v
Hotels										
Bedrooms	V	V	V		B,s	B,s	B,s	b		
Bathrooms			E,v		B,s,f,v	B,s,f,v	B,s,f	b		E,v
Public rooms	V	V,b						b		
Shops	V,b	V			B,s,f,v	B,s,f,v	B,s,f	b		
Hospitals	B,v	V	E,v		B,s,f,v	B,s,f,v	B,s,f	B,e,v		
Restaurants	V,b	V			B,s,f,v	B,s,f,v	B,s,f	b		
Sports Halls		V			B,s,f,v			b		

Note: Preferred method - Upper case (i.e. V, E etc.);
Preferred method - Lower case (i.e. v,e, etc.).

<u>Appendix 4</u>

Recommendations on thermal comfort given by ISO 7730 (ISO, 1993)

At light, mainly sedentary activity during winter conditions (heating period):

- The operative temperature should be between 20 and 24°C (i.e. 22 +/- 2°C).

- The vertical air temperature difference between 1.1 m and 0.1 m above floor (head and ankle level) should be less than 3°C.

- The surface temperature of the floor is normally between 19 and 25°C, but floor heating systems may be designed for 29°C.

- The radiant temperature asymmetry from windows or other cold vertical surfaces should be less than 10°C (in relation to a small vertical plane 0.6 m above the floor).

- The radiant temperature asymmetry from a warm (heated) ceiling should be less than 5°C (in relation to a small horizontal plane 0.6 m above the floor).

At light, mainly sedentary activity during summer conditions (cooling period):

- Operative temperature between 23 and 26°C (i.e. 24.5 +/- 1.5°C).

- Vertical air temperature difference between 1.1 m and 0.1 m above floor (head and ankle level) less than 3°C.

Appendix 5

Influence of important elements of building/systems planning, design, construction, operation and maintenance on energy consumption and the indoor environment.

Building/system features	Effects on energy consumption	Effects on the indoor environment	Comments
Building location and orientation			
Location • exposure to wind • shading from other buildings	Appropriate choice may reduce the energy consumption for heating, cooling and artificial lighting	Exposure to wind may influence infiltration rates	In urban areas appropriate sun rights should be granted
Building Orientation with respect to • sun • prevailing wind direction		Buildings facing south cause less overheating problems and glare than those facing east or west or having skylights Exposure of openings to prevailing wind directions may increase variations of infiltration rates	Amount of benefit from south orientation depends on latitude Care must be taken to avoid unwanted shading from urban obstacles
Building design and construction			
Rational Building Design including (in order of priority) • sizing of spaces • level(s) of comfort • location of spaces	Energy use for heating, cooling and other uses of energy such as artificial lighting can be reduced	Too small spaces may have a negative influence on comfort	It is important to consider energy uses and indoor environment all year round
Building Envelope providing: • good thermal insulation • good control of infiltration • openings appropriate for daylighting, solar gains and shading	The use of passive and natural means wherever possible will minimize the need for (all types of) commercial energy supply	A well designed envelope will improve thermal comfort, avoid draught and glare and allow for IAQ control	Good envelope design is top priority in building construction
Thermal capacity (mass)	A large thermal capacity may reduce peak loads and/or energy needs Suitable for night cooling and storage of solar energy but not suitable for (rapid) intermittent heating or cooling	Large thermal capacity improves thermal comfort in buildings for continous use by attenuating thermal swings	

Building/system features	Effects on energy consumption	Effects on the indoor environment	Comments
Building design and construction (cont.d)			
Windows	Large windows favour daylighting. When oriented south they will allow greater solar gains in winter and easier sun control (by means of shading) in summer. Large windows tend to increase heat losses	Large windows have a potential negative influence on thermal comfort because of radiant heat asymmetry and thermal convection and risk the possibility of glare and overheating If operable, windows offer a possibilty of individual control and may allow for additional ventilation	Innovative windows (e.g. incorporating control of infiltration and heat exchange) may improve both the energy conservation potential and indoor air quality control The risk of indoor air quality complaints is higher in spaces where windows cannot be opened
Design of heating systems including (1) correct sizing (2) choice of water and/or air systems; (3) heat recover where appropriate	(1) oversizing leads to waste of energy (2) air heating more suitable for rapid intermittent heating, water heating systems may be more easily insulated and require less energy for circulation (3) air heating can be combined with heat recovery (see below)	(1) undersizing may affect thermal comfort (2) air heating may be favourable for IAQ because of enforced fresh air supply but IAQ may deteriorate if ventilation ducts are not well designed and maintained	For air heating systems, air inlets and outlets have to be carefully located in order to obtain good ventilation efficiency without draughts
Building services systems			
Controlled* natural ventilation	Energy will be saved if excessive adventitious ventilation and infiltration are replaced with purpose designed controllable ventilation, e.g. trickle ventilators	Well designed systems will improve IAQ and thermal comfort. In some climates individual control is preferable. Avoid draughts. Can be used for cooling in some climates	May not be appropriate in areas with high outdoor air pollution and noise levels and in cold climates. Provide openable windows for rapid manual ventilation. Air conditioning may be required in warmer climates
Mechanical ventilation	In principle better controlled air flow rates; heat recovery possible if combined with heat pump a/o balanced ventilation system	May improve IAQ by increasing ventilation locally where strong sources of pollution a/o humidity exist (e.g. kitchen and bathrooms)	
Demand controlled ventilation • automatic • manual	By matching ventilation to actual demands, energy losses are reduced	Neutral to IAQ if properly designed, commissioned and maintained	
High efficiency ventilation	Reduces need for fresh air input	Improved IAQ because of improved uniformity	

*as opposed to infiltration (uncontrolled natural ventilation)

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Building/system features	Effects on energy consumption	Effects on the indoor environment	Comments
Building services systems (cont.d)			
Heat recovery with mechanical ventilation	Reduces energy requirements because of heat recovered from exhaust air. Not suitable in leaky buildings and not cost-effective in mild climates	May improve fresh air supply. Preheating of supply air by extraction air improves thermal comfort	Can be used for heating and cooling Transfer of pollutants from exhaust to incoming air must be avoided
Free cooling (use of outdoor air instead of cooled air for balancing thermal loads in a building)	Saves energy	May improve IAQ allowing for higher fresh air supply	
Design for natural cooling	Relies on passive systems and has few energy demands. Night cooling is one example	Proper design can reduce risk of summer overheating problems in some climates	
Air conditioning	Often uses more energy than natural ventilation and needs careful design	Properly designed and commissioned systems can provide improved thermal comfort and IAQ	Cooling towers and humidifiers can cause problems with micro-organisms (e.g. Legionella) In some climates many people prefer natural ventilation
Control of HVAC systems	Excessive temperatures are avoided if heating and hot water services are regulated using reliable automatic systems	Improves thermal comfort and possibly IAQ	Individual control of temperature is preferable
Air supply and exhaust location in rooms	Poor location may reduce ventilation efficiency and increase ventilation requirement	Poor location may increase idoor pollution levels, and cause discomfort to occupants	
Air supply and exhaust for HVAC systems	Exhaust can be used for heat recovery	Inlets located near sources of pollution, such as exhaust outlets will cause indoor pollution	
Control of pollution sources			
Selection of low (no) emission materials, processes and equipment	Saves energy by lower ventilation demands	Improves IAQ	
Separation confinement or encapsulation of sources	Limits energy losses resulting from high ventilation requirements	Allows for the reduction of air pollution, polluted areas and human exposure	Particularly important to control tobacco smoke, (preferably by a non-smoking policy)

Building/system features	Effects on energy consumption	Effects on the indoor environment	Comments
Building operation and maintenance			
Testing, adjusting and balancing of : (1) air heating/cooling systems (2) water heating/cooling systems	Avoids thermal energy losses	(1) Provides adequate IAQ if design ventilation rate is assured to all areas/spaces, and adequate comfort if draughts are avoided (2) Provides adequate thermal comfort; individual control is facilitated by water heating systems	Testing, adjusting and balancing cannot compensate for significant/major design errors
Adjustment of temperature set point in unoccupied spaces/periods	Lowering the temperature during the heating season and increasing it when cooling is required may save energy	Risk of thermal discomfort in case of inappropriate choice of start and end time of set point adjustment. In some cases increased risk of condensation and mould growth	
Selection of different target values • temperature • humidity (if controlled) during heating and cooling periods	Lowering temperature and humidity set points during the heating period and increasing them during the cooling period may save energy	Thermal comfort will be maintained if the combination of temperature and humidity falls within accepted ranges. Perceived air quality may benefit from lower temperatures	Considering different clothing habits in winter and summer, the described adjustment may even increase comfort
Use of air recirculation	May save energy	May strongly deteriorate IAQ	Used for economic reasons but often causing important comfort/health problems and productivity losses
Regular maintenance and cleaning	Essential for maintaining energy and functional efficiency of HVAC systems. Avoids important energy losses	Avoids HVAC systems becoming a source of indoor pollution. Essential for maintaining design ventilation rates and for avoiding pollution breakthrough of filters	Low emission cleaning products should be used in order to avoid IAQ problems. The use of biocides and water softeners for the maintenance of humidification/dehumidification systems may cause IAQ problems. Efficient maintenance requires clear maintenance schedules and instructions

Appendix 6 :   A review of existing energy and IAQ regulations, guidelines and
prediction methods

1.   General Overview

Table I reviews the ways in which the most relevant international documents cover the various aspects
of IAQ and the rational use of energy in buildings. Sections 2 and 3 contain a short description of the
contents of these and some further international documents.

2.   EC Legislation, Standards and Guidelines

The EC addresses the energy efficiency of buildings in two Council Directives:

2.1   Directive 89/106/EEC on construction products

The objective of Directive 89/106/EEC is to remove technical barriers to competition within the
internal EC market that may arise from regulations set by individual Member States relating to the
construction sector.   In order to achieve this objective, the Directive limits the scope of these
regulations to six defined "essential requirements" (ERs).

Directive 89/106/EEC is not primarily aimed at promoting either good indoor air quality or a rational
use of energy or a balance of both. However, the directive does allow Member States the opportunity to
set regulations for both construction works and products targeted at these two issues. This is because
two of the six essential requirements relate to "Hygiene, health and the environment" and "Energy
economy and heat retention" respectively. They are described in more detail in two "Interpretative
Documents" (IDs) established as part of a complex implementation procedure defined in the directive.
The IDs create the necessary links between the two ERs and the technical specifications to which
construction products have to conform in order to fulfil the requirements.

The ID "Hygiene, health and the environment" includes within its scope good indoor air quality by the
elimination or control of pollutants in the indoor environment. It lists options of how exposure to
indoor pollution may be controlled by legislation within the Member States, including elimination and
modification of all relevant sources, ventilation and control of exposure of people by procedural rules.

Similarly the ID "Energy economy and heat retention" provides a wide range of options describing how
this issue can be expressed in Member States' regulations.

These options include, amongst others, the following factors; thermal loads, transmission heat losses,
thermal insulation levels, air permeability, use of passive energy gains, and models for calculation of
these quantities. Also the needs of occupants in terms of thermal comfort and indoor air quality or
ventilation may be used to express this requirement, ventilation rates being mainly derived from indoor
air quality requirements.

In summary, Directive 89/106/EEC provides a frame-work for regulations by individual Member States
in relation to construction works and products. It provides a number of options that can be used to
achieve either good indoor air quality or a rational use of energy. However, the Directive does not
discuss the relative merits of these options, establish priorities or discuss the potential conflict between
indoor air quality and energy efficiency.

Table I. Summary of International Energy and IAQ Regulations/Guidlines/Standards

Aspects of IAQ and RUE*	Directive 89/106/EEC	Directive 93/76/EEC	WHO 1982 Indoor Environ.	WHO 1988 Healthy Housing	IEA - TC39 Ventil. Efficiency	IEA -TC35: Advanced Ventilation Systems
1. Does the document cover IAQ, RUE or both ?**	IAQ and RUE	RUE	IAQ and RUE	IAQ	IAQ	IAQ and RUE
2. Does the document consider energy efficiency (design standards, etc.) ? — Thermal insulation — Boiler efficiency — Air tightness — Ventilation rate — Lighting — Passive solar — Shading — Cooling	Yes Yes No Yes Yes No Only mentioned Only mentioned Yes	Yes (Energy labelling) Yes Not expressly Not expressly Not expressly Not expressly Not expressly Not expressly Not expressly	No	No	 No No No Yes (ventilation) No No No No	No No No Yes No No No No
3. Does the document include prediction models ?	No	No	No	No	No	No
4. If "yes" to question 3, does the document display or reference the underlying assumptions or data ?	---	---	---	---	---	---
5. Have the heating loads been identified and guidance given on the reduction ?	No	No	No	No		No
6. (a) Has consideration been given to pollutant source control ? (b) Are the major source categories identified and considered ?	Yes Only construction products	No No	Yes Yes	Yes Yes	Yes Yes	Yes Yes
7. Does the document support a good maintenance strategy for buildings and systems?	Only indirectly	Only for boilers	No	Yes		
8. Does the document include design of ventilation systems ? — Mechanical — Natural	 No No	 No No	Yes	 marginally marginally		
9. Does it take into account variabilities of : — Climate — Occupancy — Building types	Yes, by diff. classes Yes Yes Yes	 Yes No No	 No Yes No			
10. Does the document include building design ?	No	No	No	Yes	No	No
11. Does the document include lighting ?	No	No	Yes	Yes	No	No
12. Does the dcoument include noise ?	Yes	No	No	No	No	No
13. Is the balancing between costs and benefits discussed ?	No	marginally	No	No	No	Yes
14. References	EEC, 1989	EEC, 1993	WHO, 1982	WHO, 1988	IEA, 1993c	IEA, 1992a

* RUE = rational use of energy

** the highlighted initials are those emphasised in the document

Table I. Summary of International Energy and IAQ Regulations/Guidlines/Standards (cont.d)

Aspects of IAQ and RUE*	IEA: Annex 9 [1]	IEA: Annex 18 [2]	ASHREA Standard 62-1989.	ECA Report No. 11	Euro Passive Handbook
1. Does the document cover IAQ, RUE or both ?**	IAQ and RUE	IAQ and RUE	IAQ and RUE	IAQ	RUE
2. Does the document consider energy efficiency (design standards, etc.) ? — Thermal insulation — Boiler efficiency — Air tightness — Ventilation rate — Lighting — Passive solar — Shading — Cooling	 No No No Yes No No No No	 No No No Yes No No No No	 No No Yes Yes No No No No	No	 Yes No Yes Yes Yes Yes Yes Yes
3. Does the document include prediction models ?	Yes (simple)		No	No	Yes
4. If "yes" to question 3, does the document display or reference the underlying assumptions or data ?	Yes		---	---	Yes
5. Have the heating loads been identified and guidance given on the reduction ?	No		No	No	Yes
6. (a) Has consideration been given to pollutant source control ? (b) Are the major source categories identified and considered ?	Yes Yes	Yes Yes	No No	Yes Yes	No
7. Does the document support a good maintenance strategy for buildings and systems?	No	Yes	No	No	No
8. Does the document include design of ventilation systems ? — Mechanical — Natural	 Somehow No	 Yes No	No	 Yes No	 Somehow Yes
9. Does it take into account variabilities of : — Climate — Occupancy — Building types	 No Yes No	 Yes Yes Yes	 No Yes Yes	 No Yes No	 Yes No Yes
10. Does the document include building design ?	No	No	No	No	Somehow
11. Does the document include lighting ?	No	No	No	No	Yes
12. Does the dcoument include noise ?	No	No	No	No	No
13. Is the balancing between costs and benefits discussed ?	Yes	Yes	No	No	No
14. References	IEA, 1987	IEA, 1990, 1991, 1992b, 1993a, 1993b	ASHREA, 1989	ECA, 1992	CEC, 1992

* RUE = rational use of energy
** the highlighted initials are those emphasised in the document
[1] Minimum ventilation rates, (IEA, 1987);
[2] Demand controlled ventilation systems, (IEA, 1990, 1992)

2.2 CEN activities

The Essential Requirements (ERs) for construction products are given in the Council Directive regarding construction products (EEC, 1989). The Interpretative Documents (see 6.2.1.) create the link between the ERs and technical specifications for products, usually defined in European Standards.

The European standards will be prepared and published by CEN, the European standardization organization, according to the mandates and rules given by CEC. For the issues of indoor climate and conservation of energy the most important technical committees (TC) are the following.

2.2.1   CEN-TC 88: Thermal insulating materials and products.

This committee plans to produce standards for different insulating materials, building products and installed equipment. It deals mainly with the definition, calculation, testing and measurement of the thermal characteristics of different insulating materials e.g. mineral wool, polystyrene, wood fibre boards, cork etc. These standards will not deal specifically with indoor air quality or indoor climate.

2.2.2   CEN-TC 89: Thermal performance of building and building components.

This standard will include rules for expressing relevant thermal properties and requirements for buildings and building components, and calculations, test methods and input data for these including climatic data. Most important, for this report, are the proposed standards for the calculation of energy consumption; prEN832 provides a method for the calculation of energy use for heating in dwellings including factors for the indoor climate, e.g. air change rates and internal temperatures. The requirements for these are, however, not binding and individual countries can follow national regulations.

2.2.3   CEN-TC 156: Ventilation for buildings.

This committee is working on a number of standards relevant to a good indoor climate. Most of them are of a technical nature and relate to the specifications and testing of ventilation systems and their components. There are plans to give clear performance standards for the indoor climate factors; indoor temperatures, ventilation rates etc.

2.2.4   CEN-TC 228: Heating systems in buildings.

This committee is concerned with standards including the general performance requirements for heating systems, and guidelines for the design and installation of heating systems. Other technical CEN committees deal with specialised heating devices (eg. oil and gas boilers) but they do not deal directly with problems of the indoor climate.

2.2.5   CEN-TC 264: Air quality.

This committee is concerned with air pollution control and standards for characterization and measurement of different pollutants in the air, both indoors and outdoors, and is also dealing with methods for source characterization.

2.3 Directive 93/76/EEC to limit CO_2 emissions by improving energy efficiency

The purpose of this Directive is to limit overall carbon dioxide emissions in Member States by improving energy efficiency. This is to be performed by planning and implementing programmes in the following fields:

- providing certificates relating to the energy-consumption of buildings
- the billing of heating, air-conditioning and hot water costs on the basis of actual consumption
- private financing of energy efficiency investments in the public sector
- thermal insulation of new buildings
- regular inspection of boilers
- energy audits of (industrial) undertakings with high energy consumption

The Directive does not provide further technical details of these programmes. It specifies only that Member States shall determine the scope of the programmes on the basis of potential improvements in energy efficiency, cost-effectiveness, technical feasibility and environmental impact. It recognises the important fact that the variety of climatic, cultural and socio-economical conditions in Europe results in a number of different ways of achieving the common objective of good indoor air quality and a rational use of energy resources.

The programme should be implemented by the end of 1994 and be based largely on voluntary agreements. In view of the increasing cost of energy, the Directive, and in particular the programme for energy certification of buildings, may become a strong driving force in increasing the energy efficiency of new and existing buildings. This may lead to an increase of indoor air quality problems if energy certification is not accompanied by or includes a certification of the "healthiness" of the buildings.

3. International Regulations and Guidelines

3.1 World Health Organization (WHO)

3.1.1   WHO: Optimum criteria for ventilation, lighting and thermal conditions of the inhabitant in the context of energy economy.

The document (WHO, 1982), as the title states, covers all the aspects of the indor environment:

- indoor pollutants, health risks and ventilation requirements
- lighting requirements which vary according to the task, personal characteristics, etc.
- indoor climate (thermal comfort, humidity, air velocity, radiative temperature, heterogeneous conditions, etc.)

The stated goal is to provide a state of the art (1982) of the indoor parameters that could be affected from energy conservation measures; the report highlights the health risks that could arise from energy efficiency measures leading to the adoption of "optimum" design reccommendations that are "hardly admissible" in a comfort and health perspective. The document lacks explicit consideration of the balance of costs and benefits; no calculation models are presented.

3.1.2   WHO: Guidelines for healthy housing.

The purpose of these guidelines (WHO, 1988), is to support a sound housing policy that could help to solve basic health-related housing problems. The guidelines are addressed to Member States, Ministries of Health and Architecture, policy makers, environmental health officers, sanitarians, planners, architects and others concerned with housing hygiene.

The report is aimed particularly at slum housing and at developing middle-income countries in Europe. However it claims to be a worldwide reference for new settlements in areas of slums or otherwise insanitary housing. The Guidelines cover the technical and social requirements for mantaining housing hygiene including control measures and examples of standards. The requirements are categorized as follows: housing layout, space and density, shelter, design and construction, sanitation, indoor air quality, indoor climate, home safety. The indoor air qualty section presents the main pollutants and for each of these, the health effects and control measures. Emphasis is placed on pollutant source control. No explicit consideration is given to the relation between IAQ and energy consumption.

3.2 Standards by international organizations

3.2.1 ISO

The International Organization for Standardization has, in spite of its enormous body of standards, no standards covering the issues of indoor air quality or rational use of energy. Standard 6242 entitled "Building Construction - Expression of Users' Requirements" provides ways of specifying requirements for the indoor environment in terms of thermal, comfort, air purity, acoustical and lighting parameters without specifying acceptable limits (ISO, 1992). In standard 7730 "Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort" acceptable limits for the thermal environment are given in an annex without any mention of a rational use of energy (ISO, 1984). A similar standard does not exist for indoor air quality, but with the foundation of a new Technical Committee TC205 "Building environmental design" ISO intends to address this issue directly and cover standardization in the design of new buildings and retrofits of existing buildings for acceptable thermal and visual comfort, indoor air quality and energy conservation.

3.2.2 SCANVAC

The Scandinavian HVAC organisations (SCANVAC, 19??) have produced a voluntary Code of Practice on 'Classified Indoor Climate - Guidelines and Specifications'. It is intended to provide information needed to evaluate and specify indoor climate performance and systems (mainly heating and ventilation) based on quality requirements for indoor climate factors (thermal, indoor air and outdoor air quality, and noise level) in different quality classes. Calculations can be made to adjust parameters such as level of activity, clothing, etc, differing from those assumed as a basis for the guidelines.

3.2.3 EUROVENT

The EUROVENT (European Association of Manufacturers) has an extensive list of published documents; they deal with terminology, construction prescription, performance testing, and guide for the operation and maintenance of air handling and other HVAC equipments.

EUROVENT established a Working Group in 1990 to prepare a Document "EUROVENT - 12/1 - Elimination of a Product related IAQ Problems". The document should serve as a general guide for air handling and conditioning equipment manufacturers to improve the indoor environment. It will deal with the possible indoor air quality problems relating to products and will give practical recommendations to designers, manufacturers, installers and users.

A tentative list of product related problems to be covered in the document is as follows: 1. fans, 2. ductwork and ductwork components, 3. silencers, 4. air terminal devices, 5. filters, 6. heat exchangers, 7. humidifiers, 8. air handling units, 9. room air conditioners and fan coil units, 10. cooling towers, 11. controls, 12. installation and commissioning, and 13. maintenance.

3.2.4 ASHRAE Standard 62-1989: Ventilation for acceptable indoor air quality

The purpose of the standard (ASHRAE, 1989) is to specify both minimum ventilation requirements and indoor air quality which will be acceptable to human occupancy and should avoid negative health effects. As indicated, with the use of the term "minimum ventilation rates" the standard seeks to find a balance between indoor air quality and energy consumption in connection with ventilation. Although the major part of the text deals with indoor air quality, the recommended ventilation rates reflect the need to reduce energy costs. Previous versions of the standard prescribed lower ventilation rates and led to cases of unacceptable indoor air quality.

This ventilation standard offers an alternative procedure allowing the engineer to use whatever amount of outdoor air he deems necessary if he can show that acceptable indoor air quality is maintained. This standard relates the required ventilation mainly to bioeffluents from human beings and tobacco smoke, and ASHRAE has started to revise it to take other sources of pollution in the building into account.

The standard tends to favour mechanical ventilation, combined with the use of heat recovery systems with little consideration of passive techniques and natural ventilation and gives insufficient attention to maintenance strategies for ventilation systems. It is rather flexible as it covers a broad range of building types and takes transient conditions (e.g. variable occupancy) into consideration. Variation in human requirements are mentioned but not implemented in the ventilation requirements prescribed.

The recommendations given in this ASHRAE standard are important, as it is widely used, not only in USA, but in many other parts of the world.

3.3 International Energy Agency

3.3.1 General information

The International Energy Agency (IEA) was established in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an International Energy Programme. The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various projects aimed at predicting more accurately and optimising the energy use in buildings, including the (i) comparison of existing computer programs and calculations methods, (ii) building monitoring, (iii) indoor air quality and (iv) studies of occupancy. Some of these projects particularly related to indoor air quality, ventilation and energy are briefly described in this section.

3.3.2 IEA: Annex 9 : Minimum ventilation rates

The objective of Annex 9 was to review and, wherever necessary, to supplement current knowledge of a comfortable and healthy indoor atmosphere in order to provide a sounder basis for defining minimum ventilation rates (IEA, 1987). The report sets out in general terms the factors which need to be taken into account in dealing with indoor air pollution and discusses the concepts of ventilation efficiency and the effectiveness of pollutant removal.

The report deals in detail with the individual pollutants or pollutant groups considered to be of major importance. These are comprised of tobacco smoke, body odour, carbon dioxide, water vapour, organic compounds, radon, combustion products and particulates. Health and/or comfort effects, sources, means of source control and, in particular, the role of ventilation for controlling the pollutants are discussed.

3.3.3   IEA Annex 18 : Demand control ventilating systems

The three main objectives of the Annex 18 work were to (a) develop guidelines for demand controlled ventilation systems based on state of the art analysis and case studies for different users in different type of buildings;   (b)   develop means, methods, and strategies for demand controlled ventilating systems and (c) demonstrate application of the knowledge accumulated during the work. The results of Annex 18 work are contained in five reports (IEA 1990, 1991, 1992b, 1993a, 1993b).

The intention of a demand controlled ventilating system is to achieve more efficient ventilation by tailoring the air flow rate to time dependent needs. Depending on the application, this can lead to better energy efficiency, improved indoor air quality or both. The Source Book presents the application and the benefit of demand controlled ventilating but also the limitations and development needed. Further development is necessary, especially in the sensory field, with respect to both control accuracy and long term operation stability.

3.3.4   IEA Annex 5 : Air infiltration and Ventilation Centre (AIVC)

The AIVC was established by the IEA followed unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the AIVC is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock. The participants are Belgium, Canada, Denmark, Finland, France, Germany, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and the Unites States of America.

3.3.5   TN 35 : Advanced ventilation systems - State of the art and trends

In this Technical Note, the characteristics of 27 ventilation systems are presented (IEA, 1992a). The systems come from 16 countries, and can be used under a large variety of conditions. The criteria include (I) specific costs for installation, (ii) specific costs for operation, (iii) comfort, (iv) reliability, and (v) efficient use of energy. No system fulfils all the desired criteria. Some ventilation systems are more appropriate for some pollutants than others (e.g. local exhaust). The type of control for specific pollutant sources (humidity, CO_2, odours, etc) is specified.

3.3.6   TN 39 : A review of ventilation efficiency

The concept of ventilation efficiency is useful for quantifying the performance of ventilation systems. AIVC has produced a series of reports on this topic. This Technical Note discusses some basic questions about ventilation efficiency. Emphasis is given to the range of applicability and limitations of ventilation efficiency methods (IEA, 1993c).

3.3.7   TN 40 : An Overview of Combined Modelling of Heat Transport and Air Movement

The report investigates the techniques used in the design and research fields for the evaluation of the thermal and air flow simulations. The scope is restricted to the whole building rather than flow and heat transfer within individual structural elements (e.g. cavity walls). Considerable developments are taking place in the field of air flow and thermal simulation. Rather than present an in-depth study of these developments, this report concentrates on the rather more general aspects of the combined simulation.

3.3.8   TN 45 : Air-to-Air Heat Recovery in Ventilation

This report discusses the issues which influence the performance of heat recovery devices within typical building applications. The report is intended to cover the three main types of devices installed in

3.3.9   A Guide to Energy Efficient Ventilation

The purpose of this guide is to review ventilation in the context of both energy efficiency and achieving good indoor air quality. It is concerned primarily with providing an introduction to the topic of ventilation with particular emphasis on the needs of dwellings and commercial buildings. Numerical descriptions have been kept to a minimum, while emphasis is placed on describing ventilation and that decision making involved in selecting and planning for ventilation.

3.4   ECA guidelines for ventilation requirements in buildings

The ECA Guidelines for ventilation requirements in buildings (ECA, 1992) consider the total pollution load caused by materials in the building, occupants and their activities when recommending ventilation requirements. The goal is to protect the occupants from adverse health effects and to provide an indoor air quality which is perceived as acceptable by a large majority of the occupants.

These Guidelines do not just prescribe a given quantity of outdoor air to be supplied to a space, instead a certain indoor air quality is prescribed to avoid adverse health effects and a decision is required on the level of perceived air quality aimed for in the ventilation space. Three different comfort levels of perceived air quality are suggested. The available outdoor air quality and the ventilation effectiveness of the ventilated space are also considered. The ventilation rate required to provide the selected indoor air quality can then be calculated based on all present pollution sources, the available outdoor air quality and the ventilation effectiveness of the ventilated space. The ventilation rates required for health and comfort are calculated separately and the highest value is used for design. The information used in these guidelines on the pollution load caused by the building and on the ventilation effectiveness is based on relatively little data.

3.5   EC passive solar handbook

The Commission of the European Community has been promoting the use of solar energy. This includes support for passive solar technologies through: (a) research on fundamentals and tools (basic reference data, computer codes, handbooks, etc.), (b) quality control and demonstration (testing procedures and testing site networks; demonstration projects, etc.) and (c) information and transfer of technology (architectural competition, focused scientific and technical information).

Scientific progress is evident and a full package of data and relevant information as well as quite a large number of real projects incorporating new concepts and new construction products are available. The new publication "Energy in Architecture - The European Passive Solar Handbook" is the latest compendium of such information contained in its three main chapters: "Passive Solar Building Design Strategy", "The Environment" and "Passive Solar Building Design" (CEC, 1992).

4.   Selected National Technical Documents

Table II reviews the ways in which the selected documents cover the various aspects of IAQ and the rational use of energy in buildings. Short descriptions of the documents are given in the following.

Table II. Summary of National Energy and IAQ Regulations/Guidlines/Standards

Aspects of IAQ and RUE*	Danish Building Regulation	UK Building Regulations	CIBSE, UK	Indoor Climate & Energy - Norway	Wärmeschutz-verordnung[1)], 1994 (D)
1. Does the document cover IAQ, RUE or both ?**	**IAQ and RUE**	**IAQ and RUE**	IAQ and RUE	**IAQ and RUE**	IAQ and **Rue**
2. Does the document consider energy efficiency (design standards, etc.) ? — Thermal insulation — Boiler efficiency — Air tightness — Ventilation rate — Lighting — Passive solar — Shading — Cooling	 Yes Yes No Yes Yes Yes Yes Yes	 Yes No Yes Yes Yes No No No	 Yes Yes No Yes Yes Yes Yes Yes	 Yes No Yes Yes Yes (No) (Yes) Yes	 Yes No Yes Yes No Yes Yes Yes
3. Does the document include prediction models ?	Yes	Yes	Yes	Yes	simplified model
4. If "yes" to question 3, does the document display or reference the underlying assumptions or data ?	Yes	Yes	Yes	Yes	Yes
5. Have the heating loads been identified and guidance given on the reduction ?	Yes	No	Yes-no guidance on reduction	Yes	Yes
6. (a) Has consideration been given to pollutant source control ? (b) Are the major source categories identified and considered ?	Yes Yes	Implicit Implicit	Yes Yes	Yes Yes	No No
7. Does the document support a good maintenance strategy for buildings and systems?	Yes	No, concerned with design	Yes	Yes	No
8. Does the document include design of ventilation systems ? — Mechanical — Natural	 Yes Yes	 Yes Yes	 Yes Yes, to a limit	 No No	 No No
9. Does it take into account variabilities of : — Climate — Occupancy — Building types	 No Yes Yes	 No No Yes	 Yes Yes Yes	 Yes Yes Yes	 No No Yes
10. Does the document include building design ?	Somehow	Yes	Yes	No	Yes
11. Does the document include lighting ?	Yes	Yes	Yes	Yes	No
12. Does the dcoument include noise ?	Yes	Yes	Yes	No	No
13. Is the balancing between costs and benefits discussed ?	No	Implicit	No	(No)	Yes
14. References	Building Regulations	The Building Regulations	CIBSE	Melding HO-2/93,BE	Anonymous, 1994

* RUE = rational use of energy
** the highlighted initials are those emphasised in the document
[1)] Heat protection directive

Table II. Summary of National Energy and IAQ Regulations/Guidlines/Standards (cont.d)

Aspects of IAQ and RUE*	French Rules for Ventilations	Le Manuel du Responsable Energie (B)	Portugese Thermal Rules	Tech. Anforderungen an lüftungstechnische Anlagen, 1992	Bedarfsermittlung für lüftungstechn. Anlagen, 1992
1. Does the document cover IAQ, RUE or both ?**	IAQ and **RUE**	IAQ and **RUE**	**RUE**	**IAQ** and **RUE**	**IAQ** and **RUE**
2. Does the document consider energy efficiency (design standards, etc.) ?					
— Thermal insulation	No	Yes	Yes	No	Yes
— Boiler efficiency	No	Yes	Yes	No	No
— Air tightness	No	Yes	No	No	Yes
— Ventilation rate	Yes	Yes	Yes	Yes	Yes
— Lighting	No	Yes	Yes	No	Yes
— Passive solar	No	Yes	Yes	No	Not directly
— Shading	No	Yes	Yes	No	Yes
— Cooling	No	Yes	Yes	No	Yes
3. Does the document include prediction models ?	No	simplified models	Yes	No	Yes
4. If "yes" to question 3, does the document display or reference the underlying assumptions or data ?	---	Yes	Yes	---	Yes
5. Have the heating loads been identified and guidance given on the reduction ?	No	Yes	Yes	No	Yes
6. (a) Has consideration been given to pollutant source control ? (b) Are the major source categories identified and considered ?	Yes Yes	Yes Yes (approx.)	No 	Yes Yes	Yes Yes
7. Does the document support a good maintenance strategy for buildings and systems?	No	Yes	Yes	Yes	No
8. Does the document include design of ventilation systems ?					
— Mechanical	Yes	Yes	Yes	Yes	Yes
— Natural	Yes	Yes	Yes	No	No
9. Does it take into account variabilities of :					
— Climate		No	Yes	Yes	Yes
— Occupancy		Yes	Yes	Yes	Yes
— Building types		Yes	Yes	No	Yes
10. Does the document include building design ?	No	No	Somehow	Yes	Yes
11. Does the document include lighting ?	No	Yes	Somehow	No	Yes
12. Does the dcoument include noise ?	No	No	No	only mentioned	No
13. Is the balancing between costs and benefits discussed ?	No	Yes	Yes	No	No
14. References	AICVF, 1991, 1992	De Herde, 1992	Maldonado et al., 1989	SIA, 1992	SIA, 1992c

*   RUE = rational use of energy
** the highlighted initials are those emphasised in the document

4.1 Building regulations and health, UK

In the UK, regulations are made for the purposes of Health, Safety, the Conservation of Fuel & Power, and access for the disabled. They apply to new buildings, although in some cases they also cover conversions. The regulations consist of simple functional requirements, for example, that 'there shall be adequate means of ventilation provided for people in the building'. They are supported by 'Approved Documents' which give specific guidance on how to meet these requirements, including relevant Codes and Standards.

The Regulations deal with health risks which can be reduced by good building design, including significant pollutants such as radon, landfill gas, moisture and mould and combustion products, as well as the general requirement to provide adequate ventilation. The conservation of fuel and power is dealt with in a separate Approved Document, but the guidance has been drafted to ensure that increasing energy efficiency does not impair indoor air quality. The Approved Documents on ventilation and conservation of fuel and power were issued in revised form in July 1994, and came into force in 1995.

4.2 CIBSE guides, UK

The Chartered Institute of Building Services Engineers issues (CIBSE) comprehensive Guides on the design of building services and all aspects of the internal climate in buildings. The Guides are widely used in the UK and in other countries and cover environmental criteria for design, design data, calculation methods, design methods, installation and equipment data and reference engineering data. The Guides are aimed mainly at non-domestic buildings and include both energy design methods and ventilation, although indoor pollutants are not dealt with specifically, except for moisture transfer and condensation odours and smoking.

4.3 Indoor climate and energy use, Norway

The Norwegian authorities are currently revising their building regulations to ensure that existing and future buildings have a better guarantee of good indoor air quality. The new building regulations, with associated guide notes, should be ready for enforcement by January 1, 1996.

Since the energy consumption of buildings in Norway accounts for nearly a third of the country's total energy consumption, there is a clear need to co-ordinate the requirements for a better indoor environment with the demand for a rational use of energy. This joint approach is reflected in the new building regulations. It will include legislation for thermal comfort, indoor air quality and ventilation, insulation and energy consumption, cleaning, operation and maintenance. The regulations will meet the "Essential Requirements" in the EEC's directive on building products (EEC, 1989) and take as a starting point the "Requirements" on "Hygiene, health and the environment" and "Energy economy and heat retention".

The new Regulations will set requirements for energy consumption, providing energy savings of around 25% for the heating and ventilation of new buildings. This will be partly due to more exacting criteria on thermal insulation of walls, roofs and floors.

They will also include recommended room air temperatures, and methods for calculating ventilation rates based on the ECA report no. 11 (ECA, 1991).

4.4 German regulation to limit heat requirements (Wärmeschutzverordnung 1994)

The purpose of this regulation (Anonymous, 1994) is to limit the energy consumption in Germany, thereby reducing CO_2 production and the build-up of the greenhouse gas in the atmosphere. The regulation includes a simplified method of calculating the annual specific heat requirement of buildings as well as maximum permitted values in kilowatt-hours per square meter living area and year

(kWh/m^{2}a). The method considers heat losses by transmission and ventilation, and solar and internal gains. Although the regulation does not prescribe any value for the air exchange rate, it does suggest a value of 0.8 air exchanges per hour for use in this calculation. The loss of energy through ventilation can be reduced by heat recovery systems or heat pumps. The maximum annual requirement permitted is expected to be reduced in the future.

4.5   French regulation for dwellings

For over twenty years, French regulations have been the main force behind technological progress in ventilation. For instance, in 1969, regulations were introduced that stated that ventilation had to supply fresh air to habitable rooms and to remove stale air from service rooms (this part of the French regulation has been used continuously since) with an air change rate of approximately 1 volume/hour. The technological consequences were the use of self regulated inlets and outlets (whatever the weather - wind, temperature etc., the flows remain constant and known in each room).

After the energy crisis (1974), research on occupied dwellings concluded that almost half of the homes were over ventilated. Regulations introduced between 1982 and 1983 specified that the ventilation rate should depend on the number of habitable rooms with the possibility of a reduction during periods with a low number of occupants. One of the technical consequences of this was the development of humidity controlled ventilation systems.

Regulations also exist for office buildings. Requirements depend on the use of the room (office room, meeting room, toilets, smoking/non smoking, etc.), and the number of occupants.

In order to improve the design and installation of ventilation systems, the French Professional Association of Heating, Ventilating and Air Conditioning Engineers has prepared two guidelines (AICVF, 1991 and 1992). These documents present general principles, requirements, and practical solutions for different types of buildings (dwellings, offices, schools, etc.)

4.6   Portuguese thermal building standards

In Portugal, there is no tradition of central heating in buildings. Therefore in winter, thermal comfort is generally very poor. This discomfort is reduced by behavioural strategies (e.g. wearing heavy clothing indoors) and using localized heating devices such as fireplaces, which are very often also used for cooking and providing domestic hot water.

To improve this situation, thermal standards were introduced, firstly to control the design and installation of central heating systems, which are becoming more popular, and secondly to ensure that better thermal comfort is achieved without excessive energy usage. The enhancement of thermal comfort is of most importance followed by the need to increase the contribution of passive solar technologies.

Two thermal regulations were introduced: one relating to the thermal quality of the building itself, focused on new buildings which are designed and built without centralized heating/cooling systems; and the other aimed at enhancing the quality of the central heating/cooling systems.

The first Portuguese building thermal standards are performance based. In a country like Portugal, passive solar technologies play a very important role in satisfying the energy needs for heating. A standard that is performance oriented allows the integration of energy efficiency and the use of passive solar energy. The standard also includes performance requirements to avoid summer overheating.

The standard on heating systems addresses the calculation of heating and cooling loads required with a better insulated envelope and defines a maximum installable power for each situation.

4.7 Existing guidelines and standards with regard to the indoor environment in Switzerland; design of buildings

The basic requirements for achieving good thermal comfort in both summer and winter time are given in Standard SIA 180 (SIA, 1988a) including recommendations for the overall tightness of a building. It is important to note that the buildings should not be built as airtight as possible but should have an airtightness appropriate to the use of the building.

In addition to SIA 180 there are requirements for the building envelope to reduce the energy consumption during winter time. These requirements are defined by the cantons, which are mostly based on Guideline SIA 380/1 (SIA, 1988b).

4.7.1 Requirements for products and materials.

A basic principle of Swiss policy is the control of pollution sources, thereby achieving good indoor air quality for minimal energy use. Some steps taken to control emissions in buildings have been:

- a ban on using asbestos in occupied zones

- a limit to the allowed formaldehyde emissions of chipboard of a maximum of 10mg/100 g (Lignum CH 10)

- guidelines for protection measures against radon in buildings

- general recommendations for separating smoking and non-smoking areas.

4.7.2 Design of HVAC-Systems/Ventilation Rates.

Principles for the design, commissioning and maintenance of HVAC-Systems are given in three new guidelines by the Swiss Association of Engineers and Architects (SIA, 1992 a,b,c)

4.8 Energy management, Belgium

There is a practical guide for Energy Managers (De Herde, 1992). It presents an approach "to understand - to evaluate - to act" in order to inform users and managers wishing to improve the indoor climate and energy use.

The purpose of the document is to achieve a rational use of energy and concentrates on the approach to the problem. The main points are: building characteristics, systems (heating, lighting) and users. Ventilation (needs, efficiency, control, maintenance, etc) is part of the guide. The general strategy for achieving good indoor air quality is overviewed (source control) but not all sources are identified. Few models for calculation and prediction are presented. There are simplified models which should be of help to Energy Managers. The use of passive techniques and natural forces and the reduction of loads on the indoor climate and systems are dealt with from a Belgian point of view (for heating, cooling and lighting). The general strategy concerning pollutant sources control is briefly presented. The sources identified are mainly those linked with human occupancy.

As the document is targeted towards Energy Managers, design and construction is not the main focus here. However, one chapter is dedicated to the integrated design and construction process.

The document gives guidance on a good maintenance strategy for buildings and systems. One chapter is dedicated to preventive maintenance. Maintenance is otherwise mentioned when necessary.

Economic factors are regularly mentioned and illustrated and one chapter is dedicated to cost effectiveness.

The document presents a general approach which should be applied to any kind of buildings. The practical advice is appropriate for Belgian buildings and may not be appropriate in other areas of Europe.

Most of the present building guides are dedicated to the design and construction of new building. The Belgian Energy Management guide presents an adequate approach for existing buildings.

5. Building Performance Prediction Methods

5.1 Principal methods and their main characteristics

5.1.1 General

This section is aimed at helping to identify the usefulness of the different types of building performance prediction methods (BPPMs) to study energy use, indoor climate and occupant behaviour.

There are basically 4 different types of modelling problems (see figure I):

1. modelling the emission and absorption of pollutants
2. modelling the variation of concentration in a space or in several spaces
3. modelling the air change rates
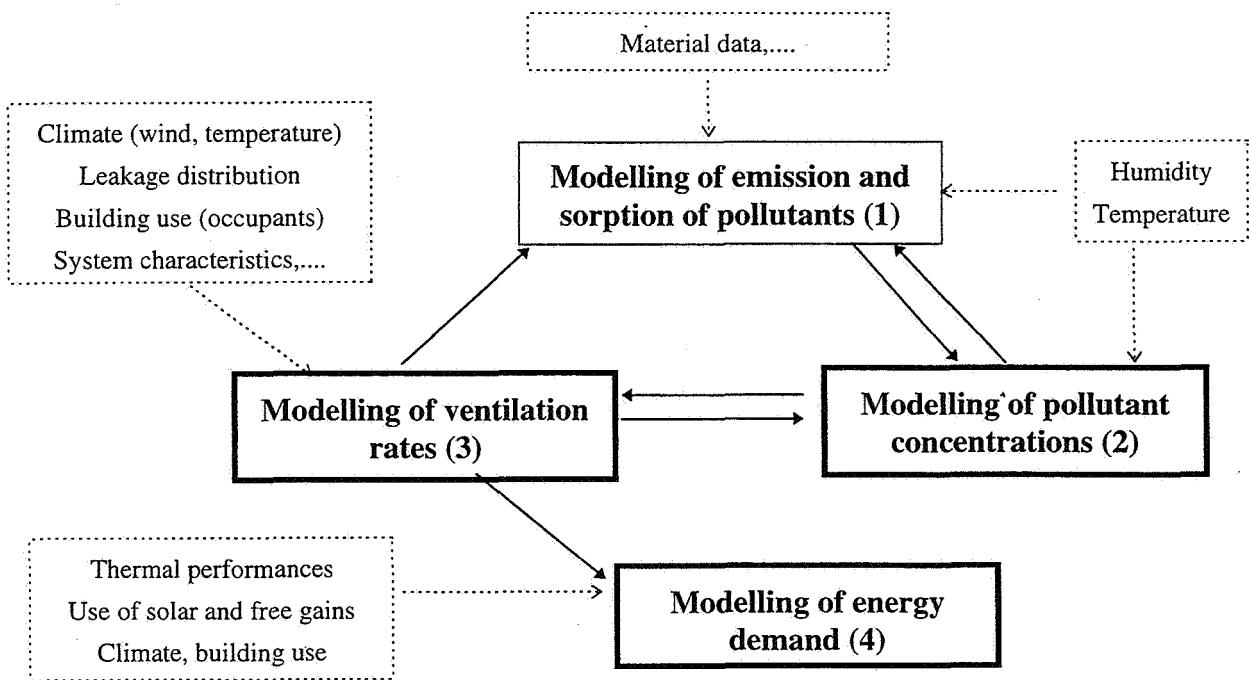4. modelling the energy need.

Figure I. Different areas of prediction modelling and their possible interactions

Following are some comments on available methods for modelling of ventilation, pollutant concentrations and energy demand.

5.1.2 Simplified methods.

These provide a partial description of the temperature field. The thermal inertia of the whole building is assumed to be concentrated in a few nodes and in some cases, disregarded. The air conditions are not usually discriminated in the different zones. Some of the simplified methods explicitly consider the

dynamic performance (CODYBA, CASAMO, CLA) while others (correlation based) provide a monthly or seasonal integration with time (Method 5000, SLR, PASSPORT, BREDEM, Consultant E-norm). They are mainly orientated to the early stages of the design and to buildings with conventional geometric, constructional or operational features.

5.1.3   Zonal models

These methods provide a fully dynamic one-dimensional description of the temperature field in the building. The air in the zones is usually assumed to be fully mixed (a single value per zone of temperature, pressure, velocity and pollutants concentration).

Depending on the method for dealing with the conduction heat transfer, there are:

- Z-transfer function type methods (e.g. DOE2, BLAST, S3PAS, TRNSYS, TASE)
- Finite difference methods (e.g. ESP, SERIRES, LPB2, APACHE)
- Electrical analogue methods (e.g. FRES, LPB4)

Some of them are able to handle HVAC performance simultaneously with the building thermal performance (for instance APACHE) or in sequential steps (for instance DOE2).

Although these methods are based on the same equations, different approaches and assumptions lead to models with different accuracies and applications. Thus, issues such as shading, natural ventilation or passive elements are treated with very different levels of detail.

Comparisons between these methods revealed a large amount of disagreement with differences ranging on average from about 20% for predictions of peak loads to as high as 66% for predictions of annual cooling loads in cases of heavy thermal capacitance. The predominant sources of disagreement appear to be in those algorithms related to the calculation of:

- interior and exterior surface convection
- interior and exterior infra-red radiation exchange
- interior solar radiation redistribution
- shading effects
- ground heat transfer

Algorithms that have been not yet tested, but which it is believed may contribute to major predictive uncertainties are:

- Interzone and intrazone natural convection
- stratification
- latent loads and moisture migration in buildings
- HVAC systems and interaction with the building.

5.1.4   Computational Fluid Dynamic (CFD) codes.

These codes provide a three-dimensional description of the local characteristics of the air, including temperature, pressure, velocity and pollutants concentration. They include codes such as PHOENIX and FLUENT and are suitable for the final stages of the design when a knowledge of the air flow patterns is crucial. For example, they can be useful to evaluate strategies involving complex interzonal air movement, natural ventilation, air distribution or exhaust systems etc.

However, they are general purpose codes (not specific to buildings) and their numerical complexity and excessive computational time makes it impractical to use them to analyse strategies based on the use of the thermal properties of the envelope or any other longterm building variable.

5.2 Usefulness of prediction modelling for IAQ

A predictive tool gives the opportunity to simultaneously study issues which can directly affect IAQ such as efficient ventilation (by displacement, natural, mixed, thermal mass/air flow interaction), the interaction between emission rates and environmental parameters (temperature, humidity and air flow in the vicinity of the pollutant source) and multicriteria comfort ranges (including temperature, humidity, air movement and pollutant concentration around the occupants).

The tool can also be used to look for strategies that provide low energy and renewable energy solutions involving components, systems and strategies for heating and cooling without impairing Indoor Air Quality.

If we assume detailed simulation methods are the best starting point, the major characteristics of an "ideal" predictive tool would be:

- A dynamic simulation model that properly accounts for the passive performance of the building.
- An explicit discrimination of the operational characteristics and requirements of every zone (occupancy and ventilation schedules etc.).
- The ability to predict local characteristics of spaces.
- The inclusion of a multicriteria comfort evaluator.
- The ability to handle natural cooling and heating techniques.
- The ability to consider advanced materials and components.
- The integration of building, HVAC systems and controllers.

5.3 Examples of energy demand calculations

5.3.1 IEA Task 12

Eight of the best national energy simulation programs for the United States and Europe were tested (BLAST, CLIM2000 DEROB, DOE2, ESP, SERIRES, S3PAS, SUNCODE, TRANSYS and TASE). The trials revealed a large amount of disagreement between the programs with differences ranging on average from about 20% for prediction of peak loads to as high as 66% for prediction of annual cooling loads in the heavy thermal capacitance cases. Even the most detailed of the above programs still contain many simplifying assumptions and legitimate differences in choice of algorithms which can lead to significant energy prediction differences.

5.3.2 TSBI3, Denmark.

TSBI3 is a PC-program for evaluating the indoor climate and energy conditions in buildings. It was developed by the Danish Building Research Institute and uses the Danish national standards of steady state heat loss calculations. For each zone the walls, floors and roof constructions are built up in layers according to the description of the materials. The structures are joined together with the windows and doors to make entire surfaces stating orientation and slope. Equipment and functions are internal loads (e.g. persons, lighting, equipment, moisture load), natural ventilation (e.g. infiltration, venting), heating and cooling radiators, and ventilation systems. Indoor climate is described by temperature conditions, daylight, air exchange, moisture balance etc. The results can be produced graphically or in a table form based on hours, days, weeks or months.

5.3.3 FRES, Norway.

FRES (Flexible Room climate & Energy Simulator) is a PC computer program for predicting thermal comfort and energy consumption in buildings (Rømen, 1993). The program has been under continuous

development since 1989, at the University of Trondheim in Norway, and the latest version (2.0) has recently been issued. The development work has been financed by, among others, the Research Council of Norway. FRES version 2.0 enables engineers and architects to investigate, for example, the energy related consequences of designing for good thermal comfort. The calculations take important parameters into account, such as: solar radiation (which in turn depends on glazing, shading control, building location and orientation); thermal stratification (which occurs in high level atria, etc.); dynamic thermal characteristics of the building's structure, such as heat capacity, and the location of insulation in the external walls and roof (internal or external); the build-up of the heating and ventilation system (fans, heat exchangers, etc.) and last, but not least, the building's pattern of use (working hours, night-time setback, weekend shutdown, etc.). It is possible to simulate any period between one day and a whole year, using either real weather data from a file or user-input design weather data. The calculations are carried out hour-by-hour, which means that the results can be studied in detail. In addition to tabular printouts with a variable level of detail, the results can be displayed graphically on the screen and sent to a printer/plotter. The graphs can show the results of the chosen parameters as a function of either chronological or cumulative time. For example, operative room temperature might be plotted hour-by-hour for a chosen day, or as a cumulative curve for the same period.

Appendix 7:   Suggested research tasks addressing the major research themes

Pollutants and sources

- Review medical literature, codes and standards to identify pollutants and safe levels. Carry out laboratory epidemiological studies on European scale to resolve uncertainties where there is cause for concern.

- Identify sources and sinks of major pollutants and evaluate methods of source control. Develop ways of measuring emissions and safe levels.

- Develop subjective criteria based on sensory evaluation for indoor pollutants in buildings, and laboratory and in-situ measurement techniques.

- Develop desk-top methods of evaluating sources and simple guidelines for practitioners.

- Evaluate the benefit/risks of materials with high/low sorption capacity.

- Standardization and harmonization of emission testing procedures has to continue at international level.   In the mean time, research and application of different techniques and methodological intercomparison should be encouraged.

Indoor climate

- Study human requirement for comfortable indoor climate, including temperature, humidity, draughts, lighting and noise. Study interactions and develop criteria. Both laboratory and field studies are required.

- More research is recommended for the health and sensory effects of VOC's mixtures as well as for some individual compounds typically present in indoor air mixtures for which little toxicological knowledge is available.

Assessments of the built environment with respect to both energy and indoor air quality & climate aspects

A number of empirical studies should be executed based on precisely formulated questions and hypotheses, where data is collected from inspections on site, technical measurements and questionnaire surveys in randomly selected buildings. The collected data is used to:

- present overall assessments of the energy efficiency and indoor air quality and climatic situation in Europe's built environment.

- test hypotheses about buildings' indoor air quality and energy efficiency and their relationships, as, e.g. presented in this report.

- find out to what extent demands recommended and stipulated in norms and standards are and can be satisfied.

- study relationships between technical characteristics of buildings and their energy use and indoor air quality.

- calculate the effects and costs of various technical measures in existing buildings to find out priorities and economical ways to improve energy efficiency and to remove health risks in the built environment.

Building services

- Develop means for personal control of light, temperature, noise, IAQ and local body heating and cooling.
- Develop draught-free ventilation techniques.
- Develop better sensors for IAQ.
- Develop electricity producing solar cells.
- Develop smart windows to utilise daylight and adjust heat transfer optionally.
- Develop passive techniques for controlling indoor climate.
- Develop new efficient and controllable low emitting ventilation systems.
- Develop demand controlled ventilation.
- Develop better filter techniques.
- Develop heat recovery techniques free of undesirable health side effects.
- Develop effective cleaning equipment for soft furnishings; furnishings less likely to harbour microbiological organisms, emit pollutants, etc.
- Develop low energy means for cooling which avoid air conditioning.

Prediction methods for buildings taking occupant behaviour into account

- Develop simulation models predicting IAQ and ventilation and other aspects of indoor climate, as well as energy performance.
- Develop simple, design tools, predicting IAQ, etc.
- Develop prediction models for local characteristics of spaces.
- Develop models predicting occupant exposure levels from pollutant emissions, humidity, ventilation and other relevant characteristics of local indoor environment.
- Develop models to simulate how engineering solutions will work in practice, including those derived from practical experience.

Commissioning, operation and maintenance of buildings

- Develop practical procedures for commissioning of buildings and quality assurance and for monitoring of their effectiveness in practice.
- Develop audit techniques for the effectiveness of building services systems and their correct operation.
- Develop means and methods of assessing and monitoring IAQ in existing buildings such as IAQ sensors, measurement techniques for specific pollutants, methods for subjective assessment of IAQ, evaluation of IAQ under different climatic and operating conditions, measurement of occupants' reactions.
- Develop audit techniques to identify, evaluate and control sources and sinks of pollutants.
- Develop practical procedures for the removal of pollutants and cleaning of furnishings, HVAC and other building service systems.
- Create local areas of improved IAQ by appropriate zoning.
- Understand the role of the occupant in the operation and maintenance and develop suitable procedures and guidelines.
- Develop means of avoiding high exposures in the early life of a building.

- Develop energy audit procedures which incorporate evaluation of their impact on IAQ and the indoor climate.

- Ensure prediction and simulation models which can be used economically with existing buildings, avoiding excessive data demands.

Changes to buildings

- Intervention study of buildings in different parts of Europe to demonstrate simultaneous improvement of IAQ and energy efficiency.

- Monitor the indoor climate in low energy buildings, effects on occupants and materials.

- Measure airtightness of buildings, effects of draughtproofing, insulation, tighter windows, etc. on airtightness and on ventilation rates.

  Monitor effectiveness of natural ventilation in commercial buildings where air conditioning has not been supplied.

Information transfer

- Investigate the effectiveness of various media in transferring information to different target audiences, and in promoting appropriate action in practice.

Appendix 8: Members of the ECA Steering Committee

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Mme Joëlle **CARMES**, Ministère de la Santé et de l'Action Humanitaire, Direction Generale de la Santé, Paris

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This report provides information and advice to policy and decision makers, researchers, architects, designers, and manufacturers on (i) strategies for achieving a satisfactory balance between good indoor air quality (IAQ) and the rational use of energy, (ii) guidelines on the use of energy in buildings and IAQ currently available, (iii) significant trends in the building sector with implications for IAQ and energy use and (iv) current research concerns.
The report discusses the relationships and potential conflicts between IAQ and the efficient use of energy in buildings and related factors such as the influence of occupancy and occupant activities, energy use and sustainability, indoor air pollution and its control, and health and comfort aspects of indoor air quality and climate. The influence of climatic conditions and their variations across Europe on IAQ and energy use, socio-economic costs of poor IAQ and its relation to the use of energy and trends for the future in the building sector are also briefly addressed. Current research concerns in the field of IAQ and energy use in buildings are highlighted and gaps in knowledge and research needs are identified.
Key elements of a strategy by which designers, engineers, manufacturers and other decision makers can achieve a good balance between energy use in buildings and indoor air quality (IAQ) are proposed. Following the recommended procedure will reduce the risk of poor IAQ and waste of energy.

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