EUROPEAN COLLABORATIVE ACTION

**URBAN AIR, INDOOR ENVIRONMENT AND HUMAN EXPOSURE**

Environment and Quality of Life

Report No 23

# Ventilation, Good Indoor Air Quality and Rational Use of Energy

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE - INSTITUTE FOR HEALTH & CONSUMER PROTECTION
PHYSICAL & CHEMICAL EXPOSURE UNIT

2003

EUR 20741 EN

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“The Unit provides scientific understanding, information and assessment tools to support the Commission services in evaluating and quantifying exposure and risk assessments for environmental stressors. Stressors include chemicals, biological contaminants, radiation and noise”.

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# Ventilation, Good Indoor Air Quality and Rational Use of Energy

prepared by

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**MANDATE:** European Collaborative Action "**Urban Air, Indoor Environment and Human Exposure**" (formerly "Indoor Air Quality & it's Impact on Man")

For more than 16 years now the European Collaborative Action ECA "Indoor Air Quality & it's Impact on Man" has been implementing a multidisciplinary collaboration of European scientists the ultimate goal of which was the provision of healthy and environmentally sustainable buildings. To accomplish this task ECA has dealt with all aspects of the indoor environment including thermal comfort, pollution sources, the quality and quantity of chemical and biological indoor pollutants, energy use, and the ventilation processes, which may all interact with indoor air quality. The work of ECA has been directed by a Steering Committee.

To provide a broader view on air pollution exposure in urban areas, both indoors and outdoors, in 1999 the ECA Steering Committee decided to put more emphasis on the links between indoor and outdoor air quality and to focus its further work under a new title "*Urban Air, Indoor Environment and Human Exposure*". The focus of the renewed activity is urban & indoor air pollution exposure assessment, seen as part of environmental health risk assessment and also considering the needs of urban and indoor air quality management. The new approach is hosted by and supporting the activities of the Joint Research Centre's Institute for Health & Consumer Protection in Ispra (Italy) dealing with Physical and Chemical Exposure.

This focussed activity will proceed within the broader framework of (i) health and comfort of the citizens, (ii) building technologies and source controls, and (iii) requirements of sustainability, energy efficiency and conservation of natural resources.

Specific examples of the working areas of ECA are:

- the relative importance of outdoor and indoor sources of pollution,
- the building-related interaction between outdoor urban air and indoor air,
- exposure to pollutants from the different urban outdoor and indoor sources and its relation to health and comfort.

By addressing such topics ECA will lay the ground for air quality management to minimise exposures to air pollutants. It will thus continue to contribute to pre-normative research needed by EC services and national authorities responsible for preventing pollution and promoting health, comfort and quality of life.

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 16051 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)
- Report No. 17: Indoor Air Quality and the use of Energy in Buildings. (EUR 16367 EN)
- Report No. 18: Evaluation of VOC emissions from building products: solid flooring materials. (EUR 17334 EN)
- Report No. 19: Total volatile organic compounds (TVOC) in indoor air quality investigations. (EUR 17675 EN)
- Report No. 20: Sensory evaluation of indoor air quality, EUR 18676/EN, 1999.
- Report No. 21: European Interlaboratory Comparison on VOCs emitted from building materials and products, EUR 18698/EN, 1999.
- Report No. 22: Risk assessment in relation to indoor air quality, EUR 19529/EN, 2000.
- Report No. 23: Ventilation, good Indoor air quality and rational use of energy, EUR 20741/EN, 2003.

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## Abstract

ECA (European Collaborative Action on, “Urban Air, Indoor Environment and Human Exposure”), 2003 Ventilation, Good Indoor Air Quality and Rational Use of Energy, Report No 23. EUR 20741 EN. Luxembourg: Office for Official Publications of the European Communities

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 good balance between good indoor air quality (IAQ) and the rational use of energy in buildings, available guidelines and assessment techniques on energy and IAQ, significant trends for the future with implications for IAQ and the use of energy in buildings; and an indication of current research issues.

## TABLE OF CONTENTS

# 1 INTRODUCTION

Ventilation plays a crucial role in relation to the indoor pollution levels but it is also of importance in relation to the management of outdoor pollution levels. The complex role of ventilation in the various pollution related processes is discussed in chapter 2.

During recent years, increased attention is given to the identification of the appropriate conditions for a sustainable built environment, including sustainable energy systems. This, in combination with the fact that an increased number of people live in cities and the increased importance of urbanisation has a clear impact on the potential of ventilation and the related challenges. Various aspects of this complex issue are discussed in chapter 3.

An important challenge for the buildings stock is to achieve appropriate indoor climate conditions. This means that certain needs are met in relation to the indoor air quality, the thermal, visual and acoustical comfort. This is discussed in chapter 4, whereby on the one hand the present knowledge is described as to IAQ and its links with other environmental factors as well as the remaining uncertainties with respect to the human demands on IAQ. From this analysis, it is clear that there are uncertainties in the needs for all the indoor climate parameters whereby the uncertainty in the indoor air quality is probably the largest.

Achieving appropriate indoor climate conditions, including good IAQ, requires in most cases the use of energy. In chapter 5, an indication of the energy use induced by the various indoor climate aspects is given. Moreover, the remaining uncertainties in the loads and needs (as discussed in §4) are translated into variations of the energy use. It appears that in modern buildings the energy use related specifically to ventilation is becoming more and more important.

In chapter 6, there is a discussion about the reasons for ventilation and of the role of standards and regulations. Specific attention is given to various aspects regarding ventilation and IAQ control. Also the European context (directives and CEN standards) is discussed.

Once ventilation requirements are specified in national standards and regulations, one could expect that these specifications are more or less met by daily practice. However, this is not always the case. In chapter 7, various field studies are reported and analysed. Moreover, information concerning the correlation between the reported air flow rates in field studies and health related characteristics is given.

Chapter 8 is focused on strategies that allow to achieve at the same time an appropriate IAQ and energy efficiency. This includes design, loads control and ventilation strategies.

The implementation of ventilation strategies for achieving appropriate indoor air quality conditions are in practice translated into the need for certain investments. The information given in chapter 9 highlights the consequences of inappropriate indoor air quality: They do not only regard health and comfort but also has major economic implications.

Based on the information given in the various chapters, an indication of priorities for actions is given in chapter 10, whereby also an indication is given about the requested efforts for carrying out such priorities and the chances for success.

# 2 VENTILATION IN RELATION TO POLLUTION SOURCES, TOTAL AIR EXPOSURE AND HEALTH

## 2.1 From pollution sources to health

The objective is to create a built environment that has no adverse health effects. One of the critical aspects of a healthy environment is an appropriate air quality.

As shown figure 1, the global chain that has to be considered is rather complicated. In the framework of this report, 3 different stages are considered : pollution sources – total air exposure - health assessment.

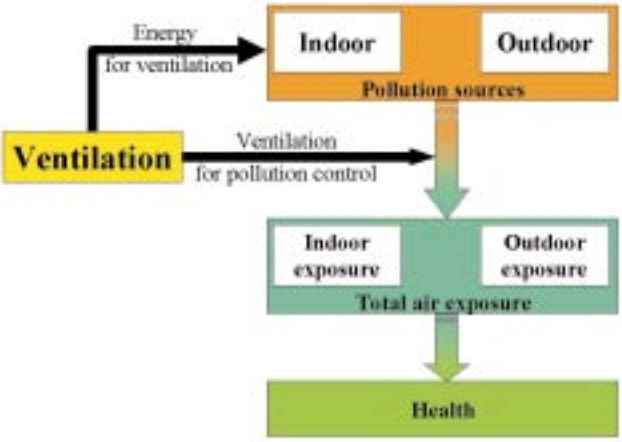


***Figure 1*** *Impact of ventilation on air pollution and total air exposure*

## 2.2 Indoor and outdoor pollution

In order to assess the total air exposure, it is crucial to take into account the indoor and outdoor exposures. On average (figure 2), people spend 90% of their life indoors and 10% outdoors. It means that the indoor pollution levels can substantially influence the total air exposure level.

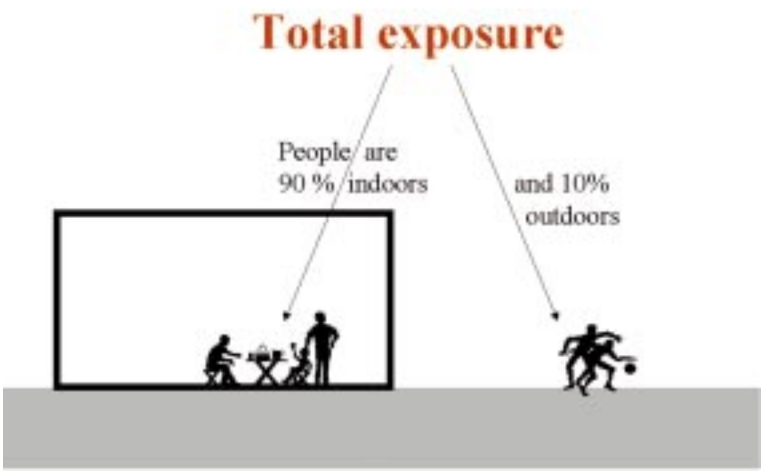


***Figure 2*** *time typically spent indoors and outdoors*

## 2.3 Parameters affecting indoor and outdoor pollution

Outdoor air pollution is mainly the result of energy conversion and use processes due to transport, industry and buildings (❶). An in depth analysis of the origin of these various pollution sources is not further analysed in the framework of this report.

The indoor pollution on itself is mainly determined by the following :

The outdoor pollution level;

- The amount of outdoor air 'imported' to the buildings by the different forms of ventilation (❷);
- The indoor pollution sources related to the occupants and their activities (cooking, copying, etc) (❸);
- The pollution from the building itself (building materials, energy systems…) (❹);
- The degree of cleaning of incoming outdoor and return indoor air (❺).

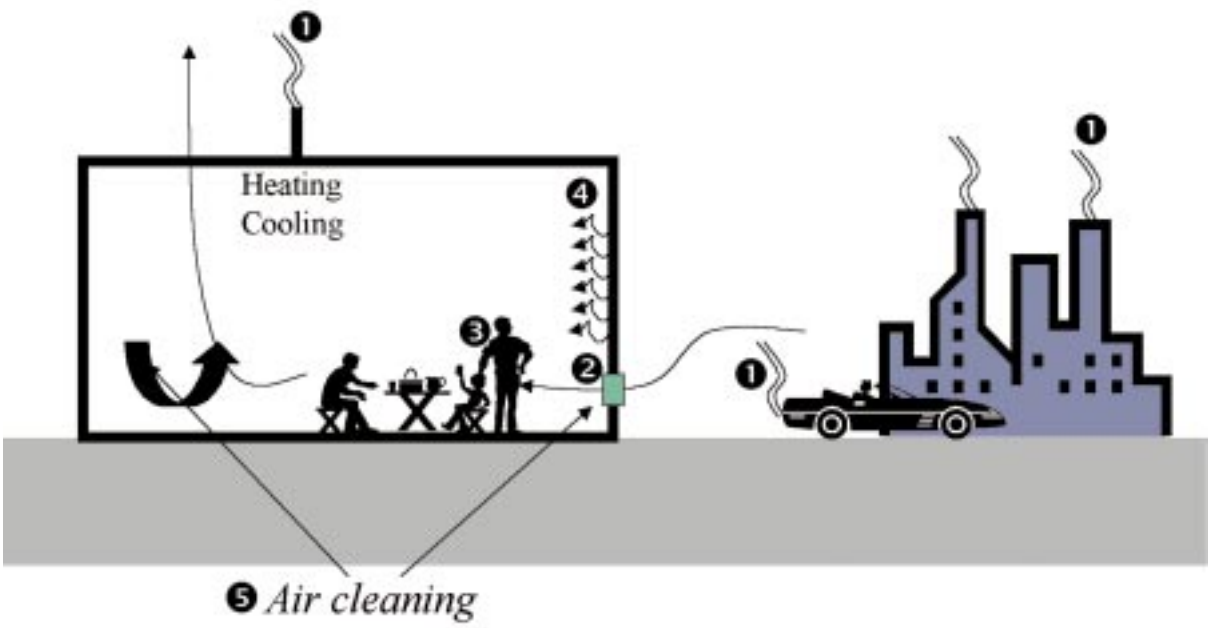


***Figure 3*** *Pollution sources for indoor and outdoor air quality*

The role of ventilation in relation to the pollution levels is substantial:

- As far as the indoor pollution levels are concerned, ventilation is on the one hand bringing the outdoor pollutants into the building but on the other hand it is lowering the concentrations of pollutants indoors due to indoor pollution sources.
- Ventilation has also an impact on the outdoor pollution level. Building related pollution sources represent about 40% of the total pollution load (figure 4). Due to the increased thermal insulation levels of buildings, including envelope tightness, the importance of the ventilation related energy use is increasing and may represent up to 50% of the total energy use of a building, particularly for certain typologies such as office buildings.

A more in depth analysis of the role of ventilation is made in the next paragraph.

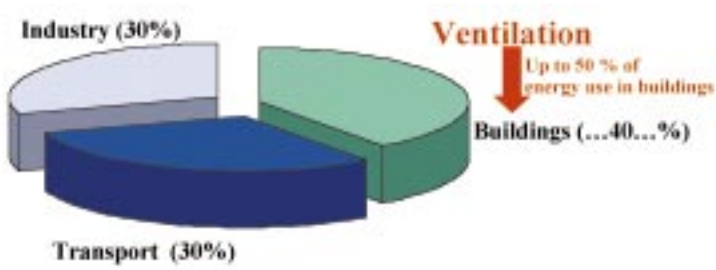


***Figure 4*** *importance of various energy users*

## 2.4 Where and how does ventilation interact?

In total, one can at least identify 5 different ways by which ventilation has an impact on the total air exposure:

- **Indoor air exposure :**
  - By bringing in outdoor air, ventilation dilutes the indoor generated pollution (❷);
  - Ventilation is the transport mechanism due to which outdoor air pollution is brought into the building (❶);
  - Air cleaning requires the transport of air through an air cleaning medium. Air cleaning can be done on the outdoor air supply and on the return of the indoor air (❸);
  - In case the HVAC system contain in its different components, including distribution ducts, sources of pollution, the HVAC system will be also a source of air pollution (❹).

- **Outdoor air exposure**
  - Ventilation in buildings requires in most cases during large parts of the year energy for conditioning the air (heating, cooling, humidification, dehumidification). In case of mechanical ventilation, there is also energy use for transporting the air. All that energy implies air pollution sources associated with its conversion, transport and use and, as such an increased outdoor exposure ( ❺).

### *2.4.1 Ventilation as transport media of outdoor pollution*

The assumption that the outdoor air is 'clean' is from a scientific point of view surely not true but it is a fact that the air on the countryside is in many places still of a rather good quality, which allows for most cases to assume that such outdoor air is indeed 'clean'. However, this is surely not the case for specific applications (e.g. clean rooms) and for certain groups of the population (e.g. people sensitive to allergic reactions).

In other places and quite often in urban environments, it is not longer evident to assume that the outdoor air is clean unless air cleaning is applied, ventilation with outdoor air brings the outdoor pollution into the buildings. In case of air infiltration (= uncontrolled air supply) through the building envelope, there may be a limited degree of air cleaning by the envelope component.

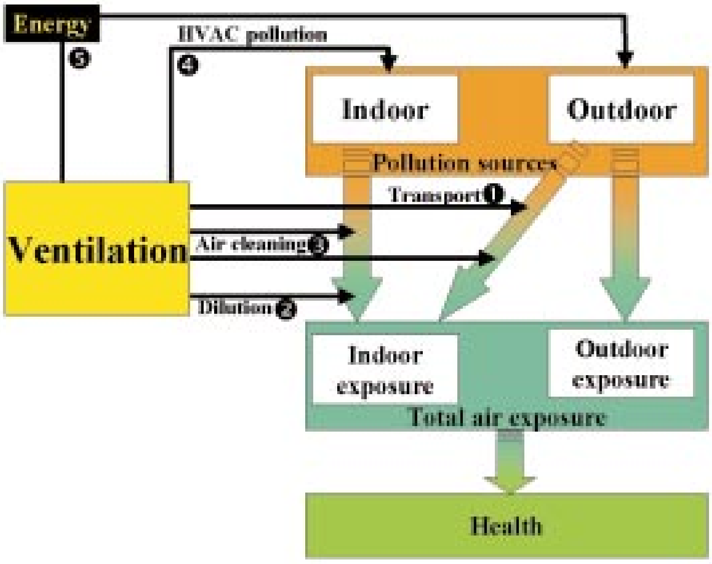


***Figure 5*** *The role of ventilation in relation to total air exposure*

### *2.4.2 Ventilation and dilution of indoor air pollution*

The supply of outdoor air will dilute the pollutants indoors. The resulting pollution concentration, or pollutants concentrations, depends on the strength of the indoor emission sources, the level of ventilation (air change rate) and the outdoor pollution concentration.

### *2.4.3 Ventilation and air cleaning*

Air cleaning is done by filtering whereby particulates and, sometimes, gaseous pollutants may be removed from the air by passing the contaminated air through a medium. Depending on the quality of the filter, the filter intercepts the pollutants while allowing clean air to pass through. Air cleaning is especially necessary when high concentrations of particulates are present or when the outside air is contaminated or some returned air is used.

### *2.4.4 Ventilation systems as source of indoor pollutants*

In principle, an air distribution system should not be a source of air pollution. However, various studies during the last decade have clearly shown that such systems can be a (major) pollution source. This is in particular the case for certain types of air conditioning systems and for the generality of ducts if not well maintained.

### *2.4.5 Ventilation as cause of energy use and increased outdoor pollution*

In most climates, the supply of outdoor air has an influence on the energy use for heating, cooling, humidification and dehumidification. In case of additional energy use, this will result in additional outdoor pollution. However, ventilation can also reduce the energy need, e.g. in case of an efficient strategy of night-time ventilative cooling.

In case of the use of fans for transporting the energy, there is also electricity use for the transport of air. Also this energy use will result in the increase of outdoor pollution.

To be said that the outdoor pollution may have different impacts according to the scale at which it will be reflected: local (city); regional ($SO_2$, $NO_x$) or global ($CO_2$).

## 2.5 Uncertainties regarding ventilation needs with respect to diluting indoor pollutants

As clearly shown in §2.4, ventilation influences in various ways the amount of indoor and outdoor air exposure. Optimum control of the air change rate is therefore important. However, there is a clear lack of precise and scientifically well argued target values in relation to the air pollution levels and, therefore also of the ventilation levels. This can be clearly illustrated by the categories identified in the CEN report CR1752 (CEN, 1998) where three categories are identified for the maximum $CO_2$ concentrations (whereby $CO_2$ is considered as a useful tracer gas for controlling the indoor pollution due to human metabolism). As is shown in figure 6, CEN considers three categories whereby the limit values differs substantially. If one takes into account that the assumed outdoor $CO_2$-level is 350 ppm, one finds a variation of 250%.

There is even less clarity in the limit values in relation to other pollution sources.

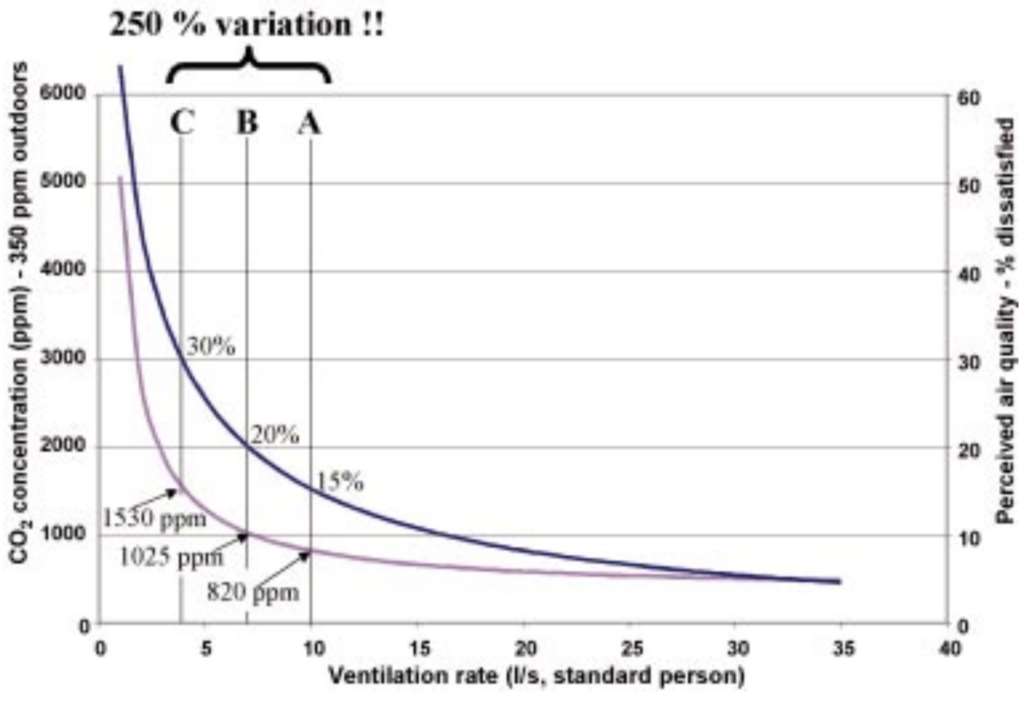


***Figure 6*** *Limit values used in CEN technical report CR1752*

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# 3 INDOOR CLIMATE AND ENERGY EFFICIENCY IN A CONTEXT OF A SUSTAINABLE URBAN ENVIRONMENT

## 3.1 Sustainability of Buildings and Urban Environment

Sustainable buildings are those that provide a liveable and healthy environment for their inhabitants and meet their needs without impairing the capacity of the local, regional and global environmental systems to satisfy the needs of future generations.

Sustainability should be achieved at the ecological, economic, social and cultural level. Ecological sustainability mainly aims to preserve resources, including energy and materials and protect the ecosystem from existing and possible future problems. Economic sustainability may be achieved by a better exploitation of resources and a decrease of the overall cost that may be achieved by minimizing the energy cost, the cost of operation and maintenance as well as the cost of a possible rehabilitation of buildings. Finally, sustainability at the social and cultural level aims mainly to provide shelter to human beings, optimise comfort and health for the building occupants and builders, discourage social exclusion, as well as to protect and preserve the social and economic values including measures aiming to protect the existing building stock, the local networks as well as the local knowledge.

Achieving sustainability in the urban environment is a compromise of different parameters and involves appropriate actions for urban management, policy integration towards a holistic planning approach, ecosystem thinking and a strong cooperation and partnership between the different actors.

Sustainable management of natural resources in buildings requires an integrated approach that should aim to the appropriate use of materials in buildings minimizing wastes, encourage the use of recycled materials, avoid using rare materials, and minimize the misuse of water. In parallel, specific energy targets like minimization of the non renewable energy use, optimisation the operational conditions in buildings and minimization of the embodied energy have to be satisfied.

Sustainability is strongly linked to social, cultural and political life in the built environment. It is vital to achieve a better environmental performance in existing buildings and to improve the quality of life of the population. This involves achievement of a better indoor air quality, avoidance of indoor contamination, as well as appropriate thermal, visual and acoustic comfort. In parallel, preservation of the local structures and social networks including historical buildings and local architectural character is a basic step in the overall objective to achieve sustainability in the urban built environment.

Urban regeneration may be a very powerful tool to meet the objectives of sustainable development through the rehabilitation of the existing building stock, the recycling of the previously developed land and the retention of green field sites. In particular, refurbishment of the existing building stock should be seen as an excellent opportunity to implement sustainability notions and a start to adopt these principles as a guide within which other considerations may trade off.

Developments of the urban environment have serious effects on the global environmental quality of our planet. Major concerns are the quality of air (§4.2), temperature increase (§4.3), acoustic quality (§4.4) and traffic congestion. Buildings are related to global changes in the increase of urban temperatures, rate of energy consumption, increased use of raw materials, pollution and production of waste, conversion of agricultural to developed land, loss of biodiversity, water shortage, etc.

Increasing urbanisation and industrialisation have deteriorated the urban environment. As a consequence of heat balance, air temperatures in densely built urban are higher than the temperatures of the surrounding rural country. The phenomenon is known as 'heat island'(see also §4.3). Except of the temperature increase, the urban environment affects many other climatological parameters. Global solar radiation is seriously reduced because of increased scattering and absorption. In parallel, wind speed and direction, in the canopy layer, is seriously decreased compared to the undisturbed wind speed. This is mainly due to the specific roughness of a city, channelling effects through canyons (see also §4.4) and also because of the heat island effect.

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings, increase smog production, while contributing to increased emission of pollutants from power plants, including sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island effect in warm to hot climates exacerbates cooling energy use in summer.

In addition to increased energy demand for cooling, increased urban temperatures affect the concentration and distribution of urban pollution because heat accelerates the chemical reactions in the atmosphere that leads to high ozone concentrations. Other sources like transports, industry, combustion processes, etc. contribute to increased pollution levels in the urban areas. In Europe it is estimated that in 70 to 80 percent of European cities with more than 500000 inhabitants, the levels of air pollution, regarding one or more pollutants exceeds the WHO standards at least once in a typical year.

Urban pollution is linked to climatic change, acidification and photochemical smog. Urban geometry plays an important role in the transport and removal of pollutants. The roughness of urban buildings and landscapes increases air turbulence enhancing thus the dispersion of pollutants. Also, if pollutants land in sheltered areas like street canyons may reside longer than they would in a windy rural environment.

The role and the impact of outdoor conditions to the indoor climate as well as the relation between the outdoor and indoor pollution are obvious notions of building physics and should not be repeated here. Numerous studies reported during the last years, show the serious impact of the outdoor environment to the indoor air quality (Godish, 1989). Solutions to indoor air pollution problems include source control, avoiding or attenuating the emission of contaminants, air cleaning and appropriate use of ventilation.

Outdoor pollution and inadequate ventilation are maybe the primary causes of poor indoor air quality in buildings. Monitoring of 356 public access buildings has shown that in approximately 50 % of the buildings inappropriate ventilation rates were the primary cause of illness complaints and poor air quality, (Wallingford K.M. and J. Carpenter, 1986). Increased outdoor concentrations affect seriously indoor concentration of pollutants. Measurements of nitrogen oxide concentrations in a hospital in Athens, (Argiriou et al, 1994), show high indoor concentrations which rise between 33 to 67 mg per cubic meter. These results are supported by the findings of the European Audit Project, (Clausen et al, 1994), that has developed assessment procedures and guidance on ventilation and source control.

The present chapter aims to investigate the impact of the urban environment on the indoor air quality and energy efficiency of buildings.

## 3.2 The Impact of Urbanisation

Cities are integrated systems that facilitate the delivery of a wide range of services and activities. Synergies among these issues generate stress to the building environment and in most of the cases, the solution of a problem is the cause of another one. This integrated approach become more clear when the built environment is considered in terms of 'stocks, flows and patterns', as defined by the Expert Group on the Urban Environment (CEC, 1994). Stocks include buildings, land, open spaces, streets and other tangible features; patterns involve all spatial and temporal patterns in urban and rural forms, neighbourhood design and street layouts, while flows includes all pressures of urbanisation, pressures on rural communities, household trends, demands for energy, transport, materials, waste, etc. The interrelated nature of almost all of the above aspects is evident, and perturbation in just one parameter may affect the other parts of the system in a non-well predictable way.

Cities are increasingly expanding their boundaries and populations, and as stated 'from the climatological point of view, human history is defined as the history of urbanisation'. Increased industrialisation and urbanisation of the recent years have affected dramatically the number of urban buildings with major effects on the energy consumption of this sector. It is expected that 700 million people will move to urban areas during the final decade of this century and half of the world's population will live in cities by the end of this century.

The direct and indirect needs for land are well represented by the notion of 'ecological footprint' defined as the land required to feed a city, supply it with timber products and reabsorb their carbon dioxide emissions with areas covered with growing vegetation. This concept help set the limits to the activities that an area can absorb in a sustainable way. Based on the calculations of Sustainable London Trust, the London's ecological footprint is close to 50 million acres, which is 125 times higher than its actual surface area. Calculations shows that the mean ecological footprint in the world is close to 1.8 ha/person, while in India is close to 0.4, in Canada is 4.3 and in USA is close to 5.1 ha/person. In addition to the above, the increased urbanisation associated with a loss of agricultural land, wilderness and green areas adds an important additional cost as new infrastructure has to be developed and the existing infrastructure in the old parts of the city is used less and thus not well amortised.

Increased urban temperatures have a direct effect on the energy consumption of buildings during the summer and the winter period. In fact it is found that during summer, higher urban temperatures increase the electricity demand for cooling and the production of carbon dioxide and other pollutants, while higher temperatures may reduce the heating load of buildings during the winter period.

In parallel, wind and temperature regime in canyons affect dramatically the potential for natural ventilation of urban buildings and thus the possibility to use passive cooling techniques instead of air conditioning.

In our days it is well accepted that urbanisation leads to a very high increase of energy use. A recent analysis, showed that a 1 percent increase in the per capita GNP leads to an almost equal (1.03), increase in energy consumption. However, as reported, an increase of the urban population by 1 %, increases the energy consumption by 2.2 %, i.e., the rate of change in energy use is twice the rate of change in urbanisation. Comparison of the energy consumption per capita for the inner and outer parts of selected cities shows that the consumption in the inner part is considerably higher. For example inner London presents to 30 % higher energy consumption per capita than the outer part of the city.

### 3.3 Priorities and strategies

The continuously increased urbanization, combined with the degradation of the urban climate and the recent upsurge of concern for the environment as well as the recent technological developments in the field of new energy technologies, defines the major priorities and considerations for urban buildings. Thus, main priorities deal with the reconsideration of the architectural and planning priorities for the urban environment. Ideas like these developed by the New Urbanism movement, (Calthorpe, 1993 and Katz 1994), based on mixed land uses, greater dependence on public transports, cycling and walking, decentralization of employment location, etc, may be further developed and applied to create a more sustainable urban environment. In parallel, addressing the urban environmental and energy problems, instead of treating their symptoms, is an absolute priority to improve the quality of the urban environment. All these are combined in a major goal aiming to achieve sustainability in urban areas. As defined by Stanners D. and Bourdeau P., (1995):

*'Sustainable cities are cities that provide a liveable and healthy environment for their inhabitants and meet their needs without impairing the capacity of the local, regional and global environmental systems to satisfy the needs of future generations'.*
According to the same authors making cities sustainable entails :

- minimizing the consumption of space and natural resources
- rationalizing and efficiently managing urban flows
- protecting the health of the urban population
- ensuring equal access to resources and services; and
- maintaining cultural and social diversity.

Strategies towards more sustainable urban environments have been defined in the Green Paper on the Urban Environment of the European Commission, (CEC, 1990). An other very important report, 'Sustainable Cities', (CEC, 1994), has explored in detail the application of sustainable development in urban areas.

Environmental quality of indoor spaces is a compromise between building physics, energy consumption and outdoor conditions. As buildings have a long life, several decades or sometimes centuries, all decisions made at the design stage have long term effects on the energy balance and the environment. Thus, the adaptation of the existing and new urban buildings to the specific environmental conditions of cities in order to efficiently incorporate solar and energy saving measures and counterbalance the radical changes and transformations of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment seems to be of very high priority.

The improvement of the indoor environmental quality in urban areas can be seen as a combination of acceptable indoor air quality together with satisfactory thermal, visual and acoustic comfort conditions. As the outdoor environment may be the main source of indoor pollution and noise, improvements in indoor environmental quality must always be seen in a combined way with possible improvements of the outdoor urban environmental quality.

The reduction of the energy consumption of urban buildings is the result of combining techniques to improve the thermal quality of the ambient urban environment together with the use of up-to-date alternative passive heating, cooling and lighting techniques. These strategies and techniques have already reached a very high acceptance at the level of architecture and industry.

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# 4 INDOOR ENVIRONMENT, HEALTH AND COMFORT

## 4.1 Introduction

The indoor environment has to fulfil two basic requirements. Firstly, the health risk should be negligible. Secondly, the indoor environment should be comfortable and pleasant. There are several environmental factors governing the perception of comfort in a space. While IAQ is an important factor, the dominating causes of discomfort in a space are of thermal, visual or acoustic nature. There is a high variation in the perception of comfort by individuals in the same environment. That is why comfort is a statistic concept. Health issues tend to be addressed in a more strict way according to the knowledge regarding the toxicology of pollutants and the epidemiology of building related illnesses. When there are symptoms for which the causal relationship cannot be identified it is said to be in presence of a 'sick building syndrome'.

In the indoor environment, two main groups of sensory perception can be identified. Both groups include perceptions which are adverse or non-adverse. The first group includes perceptions directly attributed to the surrounding physical environment (environmental perception), for example perceptions of draft and odour. The second group includes perceptions of events inside the body or on the body surface (body perceptions), for example, perceived eye irritation or dry skin, which may or may not be attributed causally to the surrounding physical environment. The senses responding to environmental exposure are not only hearing, vision, olfaction and taste, but also senses located in the skin and mucous membranes (touch, warm, cold, pain and the systems that mediate sensory irritation).

A number of studies (e.g. Leaman and Bordass (1997) have shown that an increase in actual or perceived access to control over the environment has a positive effect on comfort.

This report is clearly focusing on the issue of ventilation and indoor air quality. However, ventilation may have an impact on other aspects of the indoor environment and, vice-versa, there may be circumstances where other indoor environment parameters (strongly) influence the ventilation performances.

In the next paragraphs, a brief discussion is made in relation to the following indoor environment aspects: indoor air quality (§4.2), thermal comfort (§4.3), acoustical performances (§4.4) and visual quality (§4.5).

## 4.2 Indoor air quality

Exposure to pollutants in indoor air may cause a variety of effects. The severity of the effects covers a wide spectrum from perception of unwanted odours to cancer. The effects may be acute or develop over longer time. Some examples of health effects related with indoor air are:

- Dispersal of airborne infectious diseases
- Some micro-organisms can grow in air humidifiers and may result in pneumonia (Legionella) and "humidifier fever".
- High humidity indoors is associated with an increased growth of micro-organisms such as mould and bacteria. It increases the risk for allergy. Some asthmatic children react on exposure to mould.
- An increased risk of developing lung cancer has been linked to exposure to environmental tobacco smoke (ETS) and to radon decay products.

For some effects, clear relationships with exposure to indoor air pollution have been reported. 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.

Many chemicals encountered in the indoor air are known or suspected to cause sensory irritation or stimulation at least at high concentrations. As pointed out by the WHO (1989), many different sensory systems that respond to irritants have receptors situated on or near the body surface. Some of these systems tend to facilitate the response rather than habituate and their reactions are delayed. On the other hand, in the case of odour perception, the reaction is immediate but also influenced by olfactory fatigue on prolonged exposures. In general, the sensory systems are tuned towards registering environmental changes rather than the absolute levels. Sensory effects are important parameters in indoor air quality control for several reasons. They may appear as:

- adverse health effects on sensory systems (e.g., environmentally-induced sensory dysfunctions)
- adverse environmental perceptions which may be adverse per se or constitute precursors of disease to come on a long term basis (e.g., annoyance reactions, triggering of hypersensitivity reactions)
- sensory warnings of exposure to harmful environmental factors (e.g., odour of toxic sulphides, mucosal irritation due to formaldehyde)
- important tools in sensory bioassays for environmental characterisation (e.g., using the odour criterion for general ventilation requirements or for screening building materials to find those with low emissions of volatile organic compounds).

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.

Sensory effects reported to be associated with indoor air pollution are in most cases multisensory and the same perceptions or sensations may originate from different sources. Humans integrate different environmental signals to evaluate the total perceived air quality and to assess comfort or discomfort. However, it is not known how this integration occurs. Perceived air quality is for example mainly related to stimulation of both the nerves, trigeminus and olfactorius.

Comfort and discomfort by definition are influenced by more complex psychological factors and for this reason the related symptoms, even when severe, cannot be documented without perceptional assessments. Ventilation and health

In a recent meta-analysis of 20 field studies in office buildings involving more than 30000 subjects (Seppänen et al, 1999) reviewed the association of ventilation rates with human responses of perceptions and symptoms. Almost all studies found that ventilation rates below 10 l/s person in all building types were associated with statistically significant worsening in one or more health or perceived air quality outcomes. Some studies determine that increases in ventilation rates above 10 l/s person, up to approximately 20 l/s person, were associated with further significant decreases in symptoms or with further significant improvements in perceived air quality.

### *4.2.1 Air quality and the urban context*

Increased industrialisation and urbanisation have created important pollution problems in urban areas. Sulphur dioxide, particulate matter, nitrogen oxides, carbon monoxide, etc., affect in a direct way the human health while affect historic monuments and buildings. It is calculated that the cost for damage only by sulphur dioxide to buildings and construction materials might be in the order of 10 billion € per year for the whole Europe, (Kucera et al, 1992).

Damage from increased pollutants is evident. Analysis of the relationship between hospital admissions and sulphur oxide levels in Athens, (Plessas, 1980), found that a “ three fold increase in air pollutants doubles hospital admissions for the respiratory and cardiovascular disorders” and that “ acute respiratory illness shows the highest correlation for the $SO_2$ variable”. Levels of nitrogen oxide are particularly high in urban environments. $NO_2$ levels in San Francisco and New York exceeds 200 µg per cubic meter while in Athens the corresponding concentration is close to 160 µg per cubic meter, (OECD, 1983).

Given the increased outdoor pollution levels in many urban regions, the assumption that ‘outdoor air’ is equivalent to ‘fresh air’ or ‘clean air’ is far from evident. With respect to ventilation, it means that the following elements become of increased importance:

- The location of air intake openings

  The increased average pollution levels in urban areas are due to increased emissions from transport, industry and building related emissions. One can find around buildings big variations in the pollution levels (e.g. between front and rear side of a building). Therefore, an appropriate location of the air intake openings is becoming an important parameter. For mechanical ventilation systems, this is mainly an organisational and technical problem, whereas the situation is less evident for natural ventilation systems. As a matter of fact, the use of ductwork for air supply is less evident for natural ventilation systems.

- Air cleaning

  Air cleaning may be required for reducing the pollution levels in the supply air to acceptable levels. The technology exist for reducing particle and gas concentrations to acceptable levels, but the cost may be substantial and it will in most cases result in increased energy use due to higher pressure losses and the need of more fan power. In case of natural ventilation, air cleaning may be less evident, since the additional pressure losses may substantially reduce the air flow rates.

- Optimisation of air flow rates

  The assumption that more ventilation will result in a better indoor air quality may not be valid in urban areas if the outdoor pollution levels are high. Nevertheless it is not said that the pollutants in the supply air are the same that are generated indoors. So thee relationship between the ventilation rate and the indoor pollution emissions may play a critical role in the design process.

### *4.2.2 Indoor air quality and air flow rate requirements*

Whereas for thermal comfort, an optimum range can be defined, such situation does not exist for indoor air quality. As shown in figure 6, the number of dissatisfied people reduces with increased air flow rates. The 3 classes A, B and C as given in CEN CR 1752 (CEN, 1998) are indicated. For class A, the air flow rate (10 l/s.person) is 2.5 times higher than the required air flow rate for class C (4 l/s.person).

Whether or not other sources of pollution are taken into account will further widen the range in air flow specifications.

## 4.3 Hygro-thermal considerations for comfort and health

As far as the hygro-thermal aspects in relation to the ventilation needs, the discussion is split up in comfort (§4.3.1) and health (§4.3.2) related aspects. Furthermore, the impact of temperature on the air quality perception is discussed (§4.3.3) as well as the influence of the urban context (§4.3.4).

### *4.3.1 Comfort*

The sensation of thermal discomfort is important for the way in which people react to a space. Thermal sensation is a strong motivator and may cause the occupant to behave in a way which may contradict the needs of the ventilation requirements of the design. Ventilation can be used to control indoor temperature and humidity. Perceived air quality is related to temperature and humidity. High indoor temperature increases the likelihood of Sick Building Syndrome (SBS) symptoms:

- Temperature
  Temperature is the principal environmental variable which influences thermal sensation, but the effect of temperature can be modified by the humidity and air movement. In considering ventilation both of these factors will play a part. Temperature is frequently

controlled through the ventilation system and the needs of the indoor air quality may need to take account of need to provide a comfortable indoor temperature. Current methods of determining the indoor temperature (Fanger, 1971), (ISO/CEN 7730, 1994) have been found adequate for setting temperatures in air conditioned buildings, but have been less successful in the case of naturally ventilated building (de Dear and Brager, 2002). They predict an optimal indoor operative temperature ($T_c$) for a given outdoor temperature $T_{a,out}$ given by the equation (see figure 7)

$$T_c = 17.8 + 0.31T_{a,out} \qquad (1)$$

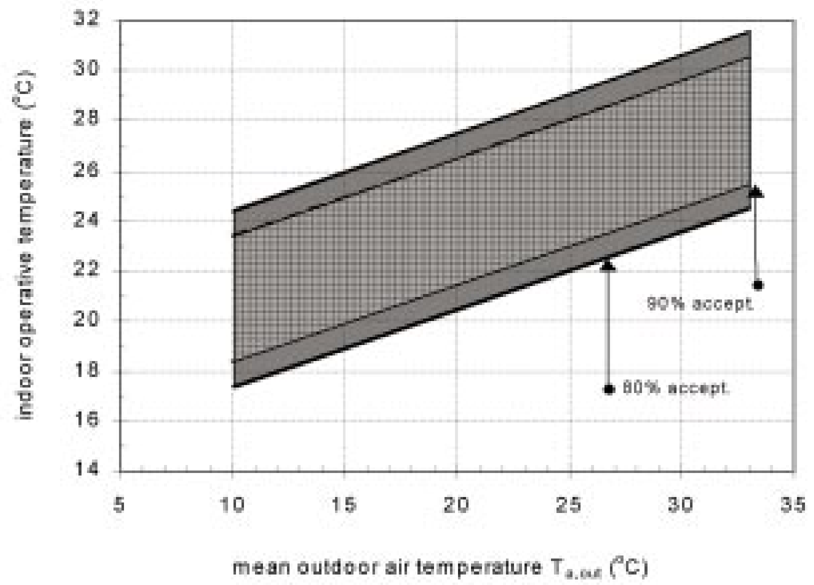


***Figure 7*** *Prediction of acceptable temperature ranges for buildings in naturally ventilated buildings (80% - 90% general comfort criteria) Source : De Dear and Brager (2002) The 80% and 90% limits are based on a ± 3.5°C and ±2.5°C bands about the optimal indoor temperature calculated from equation 1*

The findings suggest that occupants of air-conditioned and naturally ventilated buildings may require different temperatures. Another problem with current standards is that they require a knowledge of the clothing and activity level of occupants for the prediction of comfortable indoor environment. Consequently ASHRAE are considering the adoption of an additional standard for indoor thermal environments which relates indoor comfort temperatures to outdoor climate and season (Brager and de Dear 2002).

Another important trend is increased interest in the use of probabilistic comfort criteria instead of absolute thermal comfort targets. It means that a certain duration and degree of less optimal comfort conditions is allowed (e.g. the Dutch Rijksgebouwendienst applies the criterion of not more than 100 hours above 25 °C). By adopting such approach, it becomes possible to design building without active cooling which meet well defined comfort targets.

- Air movement

  The design of the ventilation system must take account of the effect which the air movement in the room will have on comfort if the occupants are not to subvert the ventilation strategy. Current standards for indoor air movement tend to assume that high air velocities and turbulence will cause discomfort from draughts. This assumes that buildings occupants are already comfortable or cool. If temperatures are higher and occupants feel hot, too little air movement cannot solve discomfort, and higher air movement may be welcome.

- Humidity
  Humidity will also be affected by ventilation and in particular the source of incoming air. For instance where outdoor air is used for ventilation in cold outdoor conditions, very low indoor relative humidity can result. This may lead to discomfort by dryness in the nasal and optical membranes and dissatisfaction with the indoor climate. In hot climates a high relative humidity, which reduces the ability to lose heat by evaporative means (sweating) can increase discomfort from overheating. And higher air movement may attenuate discomfort but not lead to reach the comfort zone.

### *4.3.2 Health*

Indoor temperature and humidity can also have an important bearing on the health of building occupants.

- Temperature
  Low indoor (and outdoor) temperatures during winter have long been associated with increased death rates – particularly among the elderly – from respiratory and cardiovascular disease. This has been found particularly among the populations of Western and Southern Europe where standards of insulation and indoor air quality in buildings tend to be lower (perhaps from a perception that these areas have less severe winters) (Eurowinter group, 1997). There is a positive trend in these figures associated with the introduction of comprehensive winter heating systems (central heating). Unfortunately the underlying poor quality of the buildings can mean that the costs of heating become prohibitive and fuel poverty (the inability to heat adequately due to high fuel costs and low income) becomes a problem. Increasingly there is concern about the effects of heat stress, particularly in relation to global warming and in Southern European states. More conscientious designers promote the use of ventilation (especially night-ventilation) as a passive means of combating overheating - rather than resorting to high-energy air conditioning strategies.

- Humidity
  The occurrence of high relative humidity in buildings – particularly when accompanied by warm temperatures - can encourage the presence of dust mites in buildings with carpets and other soft furnishings. The faeces of the dust mites are a strong allergen and the cause of asthma and other allergic diseases. High relative humidity can also be a strong factor in the growth of moulds. Moulds are not only unsightly but can also be associated with increased levels of allergic disease, probably caused by the spores which that generate.

### *4.3.3 Effect of temperature on the perceived Indoor Air Quality*

The effect of air temperature on thermal comfort is well known, but its effect on air quality is not so widely recognised. Studies have shown that warm and humid air is stuffy (Berg-Munch, 1980), and warm room air temperature in the winter causes a higher number of typical sick building symptoms than cooler air (Seppänen and Jaakkola, 1989). The relationship between the number of symptoms and temperature is close to linear in the temperature range from 20 to 26 °C (68 to 79 °F) (figure 8).

Recent laboratory experiments (Fang et al., 1998) have suggested that perceived quality of polluted air depends on the enthalpy of the air. In laboratory tests, air was polluted with emissions from typical building materials. The summary of results from a small chamber study (Fang et al, 1998) are shown in figure 9. Studies with a whole body exposure did not show as strong effect of the enthalpy of the air on perceived air quality (Fang et al., 1995). However, the influence was still very significant. Humphreys et al (2002) find that the thermal state of the subjects (as recorded by their comfort vote) was by far more influential than any particular characteristic of the environment (including enthalpy) in deciding indoor air quality. These findings suggest the use of low room air temperature and low relative humidity in the winter from a standpoint of good IAQ and energy economy.

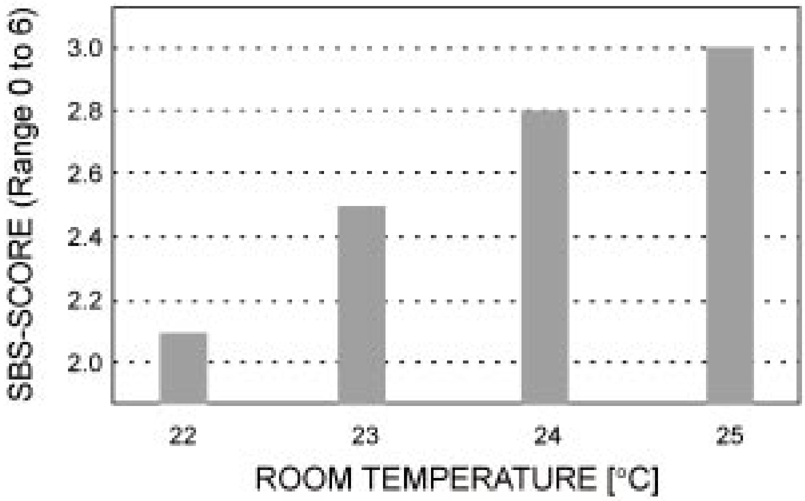


***Figure 8*** *Number of sick building symptoms depending on the room air temperature in the winter time in an office building with approx. 1000 employees. Source: Seppänen and Jaakkola (1989)*

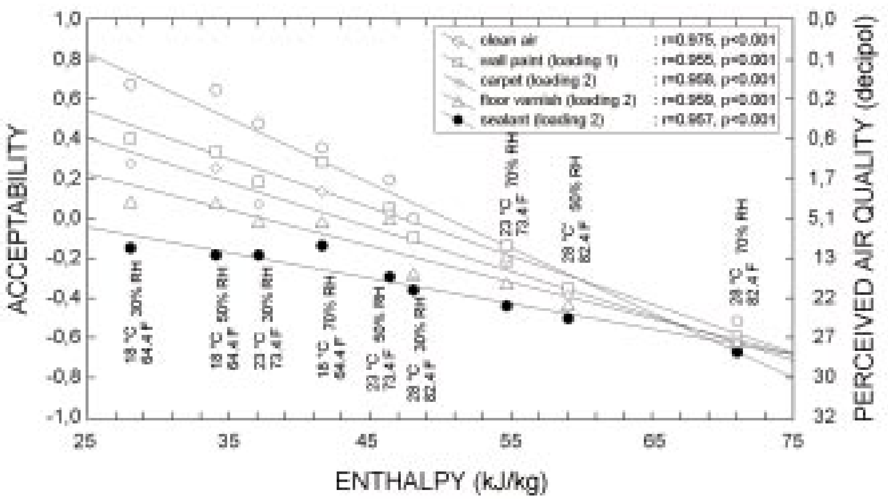


***Figure 9*** *Acceptability of air related to enthalpy at selected pollution levels of different materials Source : Fang et al. (1998).*

The target values of the air velocity in a room are also related to ventilation and energy efficiency. High velocities increase the convective heat transfer, thus the upper end of the comfort range of temperature should be used in a situation where cooling is needed, and lower end of the comfort range in a heating situation.

Typically, the average room air velocity increases with the cooling load (Fitzner 1996) and supply air flow rate. High supply air rates are thus desirable in a situation where cooling is needed, and low supply air rates in a heating situation. The air velocities can also be affected by the air distribution system, or with a local fan such as a tropical ceiling fan. Displacement air distribution systems typically result in lower average air velocities in a room than a mixing air distribution system (Fitzner, 1996).

The target value for the relative humidity of indoor air is of great significance in warm and humid climates in respect to energy consumption. An increase, for example, in the set point of the relative humidity from 40 % to 60 % has a significant impact on the energy requirements for those locations with significant cooling requirements. For example, the energy requirements of ventilation at a set point of 60 % relative humidity are only 56 % of the those at a set point of 40 % RH in Miami. (IEA/AIVC 47, 1995).

### *4.3.4 Hygro-thermal considerations and the urban context*

As far as the hygro-thermal considerations are concerned, the urban context has two major impacts :

- On the one hand, there can be a general increase in the temperature level. This phenomena is often described as the *"heat-island effect"*;

- On the other hand, there can be in dense built areas a specific micro-climate in streets which substantially influences the boundary conditions of buildings. This phenomena is also called the *"canyon effect"*.

Heat Island effect

- Air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. The phenomenon is known as 'heat island' and is due to many factors. Higher urban temperatures have a serious impact on the cooling load, that means on the electricity demand for air conditioning, which leads to increase smog production, and contributes to increase emission of pollutants from power plants, including sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Moreover, it may substantially reduce the potential of passive cooling strategies and in particular night-time ventilative cooling.

- Numerous studies have been performed to analyse and understand heat island. Most of the studies concentrate on night heat islands during the winter period, and few of the studies analyse the day period temperature field and summer heat islands :

- Data on the heat island intensity in Gothenburg, Sweden, show a well developed urban heat island of magnitude 5 °C, ranging from 3.5 °C in winter and 6 °C in summer. It is found that during the summer season on nearly all of the night hours the heat island intensity was greater than 0.5 °C and on the 40 % of the night hours it was greater than 1 °C.

- Data on the heat island intensity in Malmo, Sweden provide a mean heat island intensity close to 7 °C;

- Data from Essen, Germany give a heat island intensity between 3-4 °C for both the day and night period;
- Data from Fribourg, Germany, show that the intensity of the phenomenon is close to 10 °C.
- Data for various Swiss cities are reported (Bale and Berne) close to 6 °C, while for Biel and Fribourg was 5 °C, and for Zurich was close to 7 °C.
- Finally, the use of satellite data for Rome, provides important temperature differences between high-density urban areas and low-density urban and agricultural areas.
- Thus, it becomes increasingly important to study urban climatic environments and to apply this knowledge to improve people's environment in cities.

## Canyon effect

Wind speed in urban streets is seriously reduced compared to the undisturbed wind velocity above the buildings level. In parallel, wind direction inside the streets is almost completely different than the one measured by routine meteorological stations. Natural ventilation is one of the most effective passive cooling techniques. Natural ventilation applied in northern buildings can provide effective cooling during day and night while night ventilation is a very effective strategy in hot climates.

Appropriate design of openings to make use of natural ventilation techniques in urban environments requires knowledge of appropriate wind speed and direction data. Estimations of the real potential of natural ventilation techniques when applied in buildings located in urban canyon, have been reported by (Santamouris, 2001) for ten urban sites. Studies have concluded that during the day time, when the ambient wind speed is considerably higher than wind speed inside the streets and inertia phenomena dominate the gravitational forces, the natural ventilation potential in single and cross ventilation configurations is seriously decreased inside the streets. In practice this happens when the ambient wind speed is higher than 4 m/sec. For single side ventilation configurations the air flow is reduced up to five times, while in cross ventilation configurations the flow is sometimes reduced up to ten times. In parallel, and during the day time and when the ambient wind speed is lower than 3-4 m/sec, gravitational forces dominate the air flow processes. In this case the difference in wind speed inside and outside the street, do not play any important role and especially in single side configurations. On the contrary, during the night time the ambient wind speed is seriously decreased and is comparable to the wind speed inside the street. In this case the air flow calculated for inside and outside the street is almost the same. Finally, it is concluded that the calculated reduction of the air flow inside the street is mainly a function of the wind direction inside the canyon. When the ambient flow is almost vertical to the street axis, the flow inside the canyon is almost vertical and parallel to the window. In this case a much higher pressure coefficient correspond to the conditions outside the street, and thus a much higher flow is calculated when the ambient conditions are considered and inertia forces are dominating. When the ambient flow is parallel to the street axis, a similar flow is observed inside the canyon, thus the pressure coefficients are almost similar.

To summarise, the urban context has important considerations for the thermal comfort:

- The urban heat island effect can have measurable consequences for indoor thermal comfort if the HVAC system has not been adequately designed or if the building relies on outdoor air for ventilation or cooling

- Buildings which rely on the opening of windows for maintaining indoor comfort, can also be compromised if there is a lot of outdoor noise or pollution which makes window opening undesirable. This issue is further discussed in §4.4;

- Noisy or polluted environments can thus encourage the use of HVAC with adverse consequences for energy consumption

- Careful planning is therefore necessary of buildings in an urban context in the interests of energy conservation and the health and comfort of occupants.

## 4.4 ACOUSTICAL PERFORMANCE

### *4.4.1 Introduction*

Within the framework of a sustainable living environment, noise is an important aspect for the comfort of inhabitants of buildings with any type of ventilation system. Ventilation is one of the links between the outdoor and the indoor environment and it easily transmits noise. On top of that noise can be produced by the ventilation system itself. A proper choice on design and operation of the ventilation systems will deal with this problem. For buildings in an area burdened with outdoor noise the ventilation system has to be an integrated part of the building in order to make it possible to live and work in such place.

### *4.4.2 Transmission of noise into or within the building.*

As most of the people nowadays live in an urban environment they are often burdened with noise of our 24 hour economy and life cycle. This means noise from street, railway or air traffic, noise from the city life with its bars and outdoor as well as indoor entertainment, industrial activities and noise from neighbours.

People exposed to these noises are often indoors inside their home or some other building. It is, therefore, important to understand how environmental noises are transmitted into buildings. (WHO, 1999) The sound reduction of most real building facades is determined by the combination of several different elements. Although parts of the building façade, such as massive wall constructions, can be very effective barriers to sound, the sound reduction of the complete façade is often greatly reduced by the less effective elements such as windows, doors or ventilation openings. Also, air leakages in the building shell (due to a rather poor airtightness) can strongly reduce the acoustical insulation of the building envelope.

Inside a building noise will be generated by the installations used and the behaviour of the people or even by pets. Examples of this are the flushing of toilets, the heating installation, the noise of radio or television equipment. Often the ventilation system leads to the transmission of noise from the grill or fan, or noise can be caused by the airflow through the system. People can become so annoyed by this that they shut off the ventilation system completely. A specific way of transport of noise from one room to another room is called cross-talk. This can occur via air channels between two rooms or by the ventilation systems for collective use.

### *4.4.3 Effects of noise on health and comfort*

Noise and sounds have an important communication function in our live. Background noise, from outside, from inside the building or from installations can have a tremendous impact on this communication and with that on social live. This is especially the case for people with an impaired hearing. They can't filter out the background noise and in that way understanding of spoken text, especially in group discussions, is enormously hampered.

Also for other people background noise can be very annoying as it is tiresome to have to strain oneself to follow a conversation or to make oneself be understood. Also people are hampered in enjoying music due to background noise. It is not always the loudness of the noise that leads to annoyance, also soft noises like fans or grills from ventilation systems or music from the neighbours can lead to increasing irritation. For such noises there seems to be a 'threshold' that once the irritation starts tends to grow worse. In fact the most stressful annoyance is reported as result of noise from the neighbours.

In general noise levels in non-industrial buildings are not causing hearing damage. Other specific effects of noise are hearing loss, sleep disturbance, cardiovascular and psycho-physiological effects, effects on performance, annoyance and effects on social behaviour. The proof of an effect of noise on the hormonal system, the immune system, birth weight or psychiatric disorders is limited. For dwellings the critical effects are sleep disturbance, annoyance and interference with communication.

### *4.4.4 Acoustical performances and the urban context*

In the past decades we have seen an increase of the population and as a result of that a further urbanisation. Within the so-called 'Compact cities' this has led to an increasing load of noise at the building envelope from traffic, local industrial activities, recreation and also noise from neighbours. Also the quality of the ambient air in the urban environment might become a problem for instance in street canyons, near viaducts or tunnels or due to emissions from local industrial activities. In order to reach a sustainable living condition within the urban environment we have to seek for solutions of the problem of exposing more people to a higher noise-load and at the same time preventing unwanted health effects and annoyance. Solutions for preventing the transmission of noise and polluted air from outside to the indoor can be found in the construction of the envelope and also in the system used for ventilation of the building.

Noise in the urban environment is a serious problem. It has been calculated that 130 millions of people in OECD countries are exposed to noise levels that are unacceptable. In the WHO publication on community noise (WHO, 1999), an in depth discussion of community noise can be found.

### *4.4.5 Conclusions*

- Depending on the design of the building and the type of ventilation chosen, noise from outside or from within can be more ore less a problem for the inhabitants. For buildings in areas with a high burden on noise (more then 70 dB(A)) balanced ventilation is often the only solution for ventilation in order to fulfil the standards for noise reduction at the envelope of the building.

- Challenges for improvement are to make the right choices for the ventilation system according  the circumstances and also the wishes of the occupants regarding the noise levels. The goal is that we must be able to perform, communicate and sleep within the environment in which we choose or have to live.

- The proper design of the building  and operation of the ventilation system can lead to a better communication, more comfort, less annoyance and less health effects for everybody and especially for more sensitive or vulnerable persons. The knowledge and the technical means are mostly available now.

## 4.5 Visual Quality

In the last paragraph of this chapter, the attention is focused on visual quality. As will be further discussed, the impact of ventilation on the visual quality and/or of the influence of the visual performances on ventilation and indoor air quality seems to be rather limited. First, the various aspects in relation to visual quality is discussed followed by a brief discussion of the impact of the urban context.

### *4.5.1 Assessment of visual quality*

There have been several attempts to quantify the quality of the visual environment but none have gained acceptance. It is not surprising. Quality incorporates the concept of beauty and that only brings to mind the old adage 'beauty is in the eye of the beholder'. Debates rage as to the quality of much modern art, some people prefer older buildings, some new but few would argue that the play of light when the sunlight pours through the stained glass windows at Courbousier's church at Ronchamp is not beautiful. A shaft of sunlight can even convert a dull space into one that appears exciting. The challenge of the designer is to facilitate that beauty but within the constraint that people need to live and work in that environment . The appropriate light level will vary according to the task(s) being undertaken and so will limitations on glare (or sparkle to express the contrary notion) (e.g. CIBSE,1994). These can be obtained from national standards and codes of practice.

Poor lighting design can cause health problems such as headaches but more commonly is likely to irritate, distract, and produce lethargy.

- Natural and Artificial Light
  It is acknowledged that most people prefer daylit spaces (CIBSE, 1999). Daylighting is popular for a variety of reasons. Its colour rendering, its variability, its association with view, the strong modelling of sunlight are major reasons for this popularity. Ironically it is the variability which makes daylighting design more difficult than artificial lighting design and causes designers and clients to avoid innovative solutions. But we do need to provide environments with artificial lighting and in some cases that will be the sole source of light.

- Colour Appearance

  Whatever the spectral composition of a light source it will have a colour appearance which may be specified as warm, intermediate or cool (red through to blue), correlated colour temperature or other methods (CIBSE, 1994). The colour temperature of daylight varies widely, both with the sky type and the position of sun in the sky. The preferred colour of light source may vary from day to night and from climatic region to climatic region. A combination of different colour lamps may be used as part of a lighting scheme but is more usually found as a result of sloppy replacement practices.

  A comparison of photographs with different light sources compared to real human perception shows the adaptive ability of the eye in colour recognition through the eye attempting to strike a white balance within the local lit environment (colour constancy).

- Colour Rendering
  The light from daylight and tungsten lamps has a spectral composition close to that of a black body and is regarded as having perfect colouring rendering. This does not mean that a fabric sample illuminated by the different light sources would look the same as the colour appearance of the light sources vary, as adaptation is never complete. Discharge lamps

including fluorescents have varying colour rendering properties which may be classified according to the CIE system (CIBSE,1994). Modern triphosphor fluorescent lamps have much improved colour rendering. Poor colour rendering can lead to dull environments and low perceived brightness.

- Glare
  Glare is categorised into disability and discomfort glare although some recent research has suggested that they may be the same phenomenon (Perry,1996). The former gives rise to immediate visual impairment while the latter is more noticeable by headaches at the end of the day. Glare caused by daylight is in general more tolerated than glare from light sources (Boubekri and Boyer,1992). That does not mean that the effect is less. It probably means that higher glare is tolerated because of the preference for daylight. Otherwise the occupants could pull down the blinds and put on the artificial light. Tolerance to glare is age related (Perry,1996), research suggesting that the maximum luminance contrast in the environment to avoid glare was 1000:1 at the age of 21 but only 100:1 at the age of 50. The last twenty years has seen many new low brightness, high efficacy luminaires being manufactured. In part these have been developed as a response to disabling veiling reflections on VDU screens, which also can be a problem with daylight. Unfortunately the closer control of light distribution from the luminaires has sometimes led to duller environments because less light is directly incident on the walls.

  A major glare problem is low angle sun, the occurrence of which increases with latitude. This is difficult to deal with without total exclusion of daylight although light shelves can help.

- Flicker
  One major cause of discomfort and headaches with fluorescent lamps has been flicker at the mains frequency. This has now been overcome by the use of high frequency ballasts but the problem remains in many unrefurbished buildings. The extra cost of the ballasts has proved a deterrent in some cases

- Visual Appearance
  Research has suggested that the visual appearance of an office space is determined by the luminance and luminance pattern in a band around the horizontal line of sight (Loe et al,1994). The wall luminance is therefore important and the visual pattern on the walls should complement the office rather than be annoying or confusing.

- View
  A view is important and recognised worldwide in property prices. Where possible a view should contain foreground, middle ground and background. Corner offices in major cities with views on two aspects are reserved for the executives and buildings are consciously designed (e.g. Canary Wharf in London) with more ‘corners’.

- Season Affective Disorder and Health
  This particular syndrome, characterised by tiredness and lethargy, has been ascribed to the lack of winter daylight in the northern latitudes. It has been difficult to establish the exact biological mechanisms whereby light affects health. It is known that vitamin D and melatonin levels are related to light exposure and light can be used to reset the circadian rhythms of our bodies (Cawthorne,1995 and Bolvin et al 1994)

### *4.5.2 Visual aspects in relation to the urban context*

In as much that the potential for natural ventilation is affected by the building density, building density will inevitably affect the daylight access to buildings. In most European countries building density is governed by planning regulations and government directives to the planning agencies. In urban areas because of the availability of land and land prices themselves the height of the city has been growing. Present guidelines as to loss of daylight during redevelopment have tended to allow growing loss of daylight. These guidelines have often been produced for green field sites and suburban areas (Littlefair, 1991). There is a great need for studies of present daylight availability in the major European urban areas to develop more satisfactory guidelines.

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# 5 INDOOR CLIMATE, URBAN CONTEXT AND ENERGY USE

## 5.1 Introduction

Buildings provide shelter and retreat to human beings while define our well being and quality of life. As Winston Churchill said: 'We shape our dwellings and afterwards our dwellings shape our lives'. The same is true of the streets, estates, villages, towns and cities we live on, (Smith et al, 1998). In addition to the social impact of buildings, the economic one is very important as well. The building industry has a pivotal place in the economy and is one of the biggest economic sectors. Only in Europe, building's related business represent a yearly turn over in the order of 460 billion €, (Palz et al, 1992).

Buildings are the most important energy consuming economic sector. Primary energy consumption of buildings, all over the world, is close to 19 millions barrels of oil per day and represents almost the entire daily production of OPET countries, (Flavin and Durning, 1988).

Energy consumption in the building sector is characterised by a dynamic evolution. Although that needs and consumption rates are very different in the various areas of the planet, absolute consumption figures are mainly determined by living standards, economic growth rates, actual energy prices, technological developments, weather conditions and increased population.

Trends and scenarios on the future energy needs foresee a significant increase of the absolute energy consumption together with a considerable change of the actual structure of demand. Thus, In order to define the technological priorities for the building sector, a deep knowledge is required of the characteristics that determine, in the major geographic regions, the environmental quality in buildings and the corresponding energy consumption.

Buildings in the European Union countries presents a primary energy consumption close to 740 Mtoe, (CEC, 1990), or a final energy consumption close to 357 Mtoe, which is close to the 40 % of the total energy consumption, (CEC, 1996). Buildings are responsible for about 18 % of the total $CO_2$ emissions, 10 % of the CO, 6 % of the $SO_2$, and 4 % of the NOx emissions, (CEC, 1995), while in selected countries buildings accounted for the 7.5 % of the annual CFC's use, (Butler, 1989). Most of the energy spend in the building sector is for space heating, 70 % of the total energy consumption for domestic buildings and 55 % for commercial and office buildings, followed by electrical appliances and hot water production (CEC, 1995b).

In the European Union, the energy consumption of buildings has remained quite constant with an average yearly growth of 0.1 % over the period 1985-1994. Although, for some countries primary energy consumption of buildings has been reduced during the last years as a result of intensive energy conservation measures, primary energy consumption in Southern Europe continues to growth mainly due to the important penetration of air conditioning equipment, (Santamouris and Argiriou, 1994). However, the energy standards in European buildings are far from ideal. Only in UK, it is estimated that there are at least 8 million homes which are inadequately heated, most being the dwellings of poor households, (Boardman 1991 and Jacobs, 1996).

Therefore buildings have a serious effect on the environment while the environment has a serious effect on buildings. This is apparent with the traditional architecture and less obvious with the internationalisation of the construction. Environmental quality of indoor spaces is a compromise between building physics, energy consumption and outdoor conditions. As buildings have a long life, several decades or sometimes centuries, all decisions made at the design stage have long term effects on the energy balance and the environment.

Recent upsurge of concern for the environment in combination with the technological developments in the field of solar energy utilisation and energy efficiency combined with a continuously increased urbanisation, defines the major priorities and considerations for the building sector. Thus, main priorities are:

- The improvement of the indoor environmental quality. This can be seen as a combination of acceptable indoor air quality together with satisfactory thermal, visual and acoustic comfort conditions.
- The reduction of the energy consumption of buildings by using up-to-date alternative passive heating and cooling techniques optimising the use of solar resources combined with cooling strategies based on improved thermal protection of the building envelope, and on the dissipation of building's thermal load to a lower temperature heat sink. These strategies and techniques have already reached a very high level of architectural and industrial acceptance.
- The adaptation of urban buildings to the specific environmental conditions of cities in order to efficiently incorporate solar and energy saving measures and counterbalance the radical changes and transformations of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment.

None of the above can be seen as isolated areas of concern. The interrelated nature of the parameters defining the efficiency of buildings requires that theoretical, experimental and practical actions undertaken at the various levels should be part of an integrated approach.

## 5.2 Energy use of Urban Buildings

Buildings are the largest energy consumer in cities. Data on the energy consumption of various European cities (table 1), shows that the consumption of the residential sector varies between 48 % in Copenhagen to 28 % in Hanover of the end use energy consumption of these cities. At the same time, buildings of the commercial sector absorb something between 20-30 % of the final energy consumption of the cities, while the electricity consumption in cities varies widely with a mean value close to 5700 kWh per year, (Stanners and Bourdeau, 1995).

| City | Residential (%) | Commercial (%) | Industrial (%) | Transport (%) | Total (GJ/capita) |
|---|---|---|---|---|---|
| Berlin | 33 | 29 | 15 | 23 | 78 |
| Bologna | 36 | 21 | 11 | 32 | 67 |
| Brussels | 43 | 29 | 5 | 23 | 94 |
| Copenhagen | 48 | 26 | 6 | 20 | 78 |
| Hanover | 28 | 25 | 26 | 21 | 112 |
| Helsinki | 34 | 23 | 9 | 34 | 89 |
| London | 36 | 24 | 11 | 29 | 89.10 |

***Table 1*** *End Use energy consumption in selected European cities*
*Source : (ICLEI 1993, LRC 1993, IBGE 1993)*

In the next sections, the impact of outdoor and indoor climate on energy use is discussed (figure 10). As far as the outdoor climate is concerned (§5.3), the attention is focused on the specific impact of the urban context. With respect to the indoor climate (§5.4), the impact of the comfort level on the energy use is discussed.

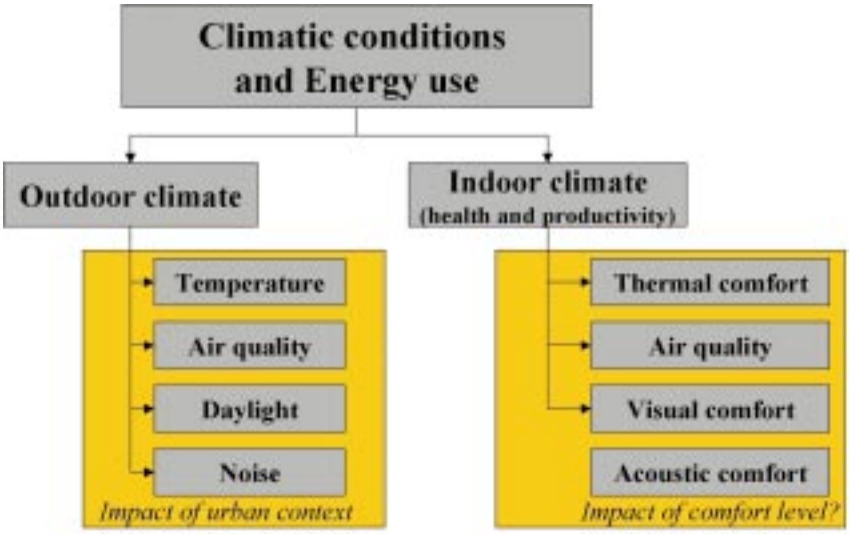


***Figure 10*** *Outdoor climate and indoor climate characteristics strongly influence the energy use of buildings*

## 5.3 The impact of the urban climate on energy use

The specific characteristics of the urban climate have in different ways an impact on the energy use of buildings. First of all because of the specific temperature conditions in urban environments (§5.3.1), secondly because of the specific air quality conditions in urban conditions (§5.3.2). Also the acoustical characteristics of the urban environment clearly can influence the energy use of buildings (§5.3.3) and there can also be an impact due to the specific conditions in relation to lighting (§5.3.4).

### *5.3.1 Temperature aspects*

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings, increase smog production, while contributing to increased emission of pollutants from power plants, including sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island effect in warm to hot climates exacerbates cooling energy use in summer. As reported, (EPA, 1992), for US cities with population larger than 100000 the peak electricity load will increase 1.5 to 2 percent for every 1 F increase in temperature. Taking into account that urban temperatures during summer afternoons in US have increased by 2 to 4 F during the last forty years, it can be assumed that 3 to 8 percent of the current urban electricity demand is used to compensate for the heat island effect alone. Comparisons of high ambient temperatures to utility loads for the Los Angeles area have shown that an important correlation exists. It is found that the net rate of increase of the electricity demand is almost 300 MW per F. Taking into account that there is a 3 F increase of the peak temperature in Los Angeles since 1940, this is translated into an added electricity demand of about 1.5 GW due to the heat island effect.

Extended urban climate measurements have been carried out in Athens, Greece during the period 1996-1999. Almost thirty temperature and humidity stations have been installed in and around Athens measuring ambient temperature and humidity in a hourly basis since June 1996. The collected data have been used to calculate the distribution of the cooling and heating needs of a representative office building for all locations where climatic data were available. It is found that the cooling load at the centre is about the double than in the surrounding Athens region.

Apart from increased energy loads for cooling of buildings, high ambient temperatures increase peak electricity loads and put a serious strength on the local utilities. Thus, knowledge of the possible increase of the peak electricity load due to higher urban ambient temperatures may be very important. Simulation studies have shown that much higher peak cooling loads correspond to the central Athens area. For a set point temperature equal to 26 C, the highest peak load of the reference building is calculated close to 27.5 kW while the minimum one is close to 13.7 kW. Thus, the impact of higher urban temperatures is extremely important and almost doubles the peak cooling load of the reference building. Finally, a very important decrease of the efficiency of conventional air conditioners, because of the temperature increase, is reported. It is found that the minimum COP values are lower to about 25 % in the central Athens obliging designers to increase the size of the installed A/C systems and thus intensify peak electricity problems and energy consumption for cooling.

Heat island studies in Singapore reported by Tso, (1994), show a possible increase of the urban temperature close to 1 C. According to the reports if there were to be similar changes in temperatures 50 years from now, the anticipated increase in building energy consumption, mainly in air conditioning, is of the order of 33 GWh per annum for the whole island. Studies reported by Watanabe et al, (1990/91), analysing the land temperature distribution and the thermal environment of the Tokyo metropolitan area have shown that a much higher energy consumption corresponds to the central Tokyo area.

Increase of the energy consumption in the urban areas put a high stress to utilities that have to supply the necessary additional load. Construction of new generating plants may solve the problem but it is an unsustainable solution while it is expensive and takes a long time to construct. Adoption of measures to decrease the energy demand in the urban areas, like the use of more appropriate materials, increased plantation, use of sinks, etc, in association with a more efficient use of energy, involving demand side management techniques, district cooling and heating, etc. seems to be a much more reasonable option.

### *5.3.2 Air quality*

In many urban environments, the outdoor air quality is lower than on the country side. As such, achieving a certain level of indoor air quality requires more ventilation (as dilution) and/or more air cleaning. In both cases, there will be in most cases an increase in the energy use.

In practice, standards and regulations often don’t take the outdoor air quality in consideration when specifying minimum air flow rates. As a result, there will be in daily practice often no extra air flow rates due to the poor outdoor air quality. However, more appropriate performance specifications may in the future effectively result in higher air flow rates and/or an increased need of air cleaning.

### 5.3.3 Acoustical aspects

The noise level has no direct impact on the energy use of buildings. Nevertheless, it indirectly can have a major impact on the energy use for cooling and/or on the thermal comfort level in summer. Night ventilation can be a very effective strategy for improving thermal comfort in summer and/or eliminating or strongly reducing the energy use for cooling. However, if too high noise levels occur (as is common in many urban environments), intensive night ventilation may not be an appropriate strategy. As such, the typical noise levels in urban environments may influence also the energy use of buildings.

Higher outdoor noise levels may also drive certain decision makers to the use of mechanical air supply instead of natural air supply.

In the framework of the IEA (International Energy Agency) project annex 27, an in depth analysis of the relation between outdoor noise levels and the feasibility of using certain types of ventilation systems and/or their impact on the requirements of the acoustical performances of other parts of the building envelope has been studied. The results are presented in a whole range of matrices. (IEA, 2000). The matrices provide information about the consequences of using the ventilation systems on the required acoustic qualities of the other construction parts of the facades to achieve a given noise reduction in noisy outdoor environments. With the matrices it is possible to select a specific ventilation system in combination with certain sound proofing constructions to achieve these conditions. It is also possible to make a comparison of combinations, for instance. an inferior sound proofing ventilation system in combination with good sound proofing constructions versus an excellent sound proofing ventilation system in combination with normal sound proofing constructions. Another further possibility of improving noise reduction is to limit the net surface area of the ventilation openings.

### 5.3.4 Daylight availability

There are no clear links between the specific urban conditions in relation to the availability of daylight and the energy use for ventilation and indoor air quality control. However, it is clear that there often are lower daylight levels in dense urban environments. This may result in more intensive use of artificial lighting and therefore an increased energy use.

## 5.4 Indoor climate specifications and energy use

### 5.4.1 Thermal comfort requirements and energy use

As far as non domestic buildings are concerned, the range in acceptable thermal comfort specifications during the heating season is relatively small. Increased room temperatures will result in increased energy use. It is important to mention that in large, well insulated office buildings in mild climates, the heating season can become very short in combination with relatively long periods of active cooling (if applied). In such circumstances, an increase in room temperatures can shorten the period of required cooling. As a result, the net balance (lower cooling demand in combination with a higher heating demand) might result in only a small variation of total energy use.

Recent work (McCartney and Nicol 2002) has suggested that considerable energy savings can be made where a variable set-point is used in an air-conditioned building using the natural tendency of building occupants to dress and behave in a different way depending on outdoor conditions.

For summer comfort, the situation is more complex. The crucial factor is whether or not the building is air-conditioned. In cases where no air conditioning is applied, it is clear that the thermal comfort specifications have no impact on the energy use. Whether or not they will be reached will entirely depend on the building design and operation. As is discussed in §4.3, there is an increased interest for applying dynamic and probabilistic thermal comfort criteria.

### *5.4.2 Impact of air flow rate requirements on energy use*

As discussed in §4.2.2., a very large variation in air flow rate requirements exist. In practice, even larger variations can occur (see e.g. figure 6). The impact of a variation of the air flow rate requirements on the energy use can be very high . This has been studied in various projects.

A recent study in the framework of the European TIP-Vent project on the impact of ventilation upon energy consumption of residential and service buildings (Leal et al, 1999) shows that the choice of the airflow rates can have tremendous energetic consequences. For office buildings, national regulations and standards in Europe recommend airflow rates from 0.4 $l/s.m^2$ to 1.8 $l/s.m^2$ while field measurements (Roulet et al, 1995) showed real outdoor airflow rates up to 5 $l/s.m^2$ (figure 11). Changing the ventilation rate from 1$l/s.m^2$ to 5 $l/s.m^2$ can triple the yearly energy consumption (for heating, cooling and operating fans) of a small office building in a moderate climate (Belgium) (figure 11). This influence can even be greater in a severe climate (Sweden).

The situation can be strongly different in very large, well insulated buildings with high thermal loads. In such case, increased ventilation rates might not lead to a strong increase in the energy use and they may in certain air conditioned buildings even lead to a reduction in the energy use because of a lower cooling demand.

Moreover, the use of energy efficient technologies (heat recovery, demand controlled ventilation,…) can also in low energy buildings substantially reduce the increase in energy use when increasing the ventilation rate. Therefore, improved indoor air quality conditions don't necessarily mean a substantial increase in energy use.

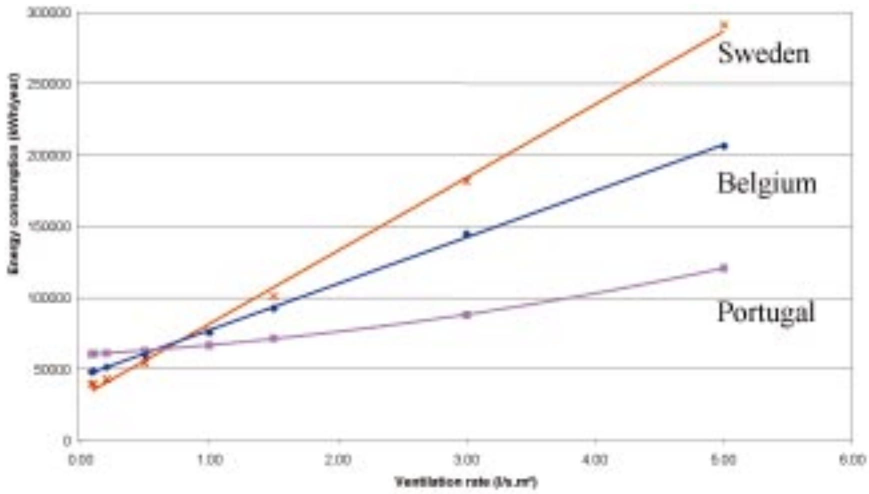


***Figure 11*** *Relation between ventilation rate and yearly energy consumption for heating, cooling and fans of a low energy office building (mechanical ventilation during working hours) (Leal et al, 1999)*

### 5.4.3 Acoustical comfort requirements and energy use

The requirements with respect to the acceptable noise levels can limit or exclude certain passive cooling strategies and therefore influence the energy use of buildings.

### 5.4.4 Impact of visual comfort related parameters on energy use

Among the parameters which influence the visual comfort conditions, the required lux level is probably the most important one. With the exception of daylit buildings which are only used during daytime, higher lux levels will require more energy use for lighting.

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# 6 IAQ IN VENTILATION STANDARDS AND REGULATIONS: STATUS AND CRITICAL POINTS

## 6.1 Introduction

The construction of buildings, the installation of ventilation systems,… are economic activities which often involve large amounts of money and major responsibilities. It is important that the client and the supplier (building contractor, ventilation firms,…) clearly agree on the expected performances of the building, of the system,… In order to create a building environment which aims to meet the requirements of the client as well as of the society, it is preferable that for each project the needs are explicitly stated and that one counts not too much on so-called implied needs.

Standards and regulations can be a very good tool for handling the requirements of society. Regulations are mandatory and therefore applicable to all projects covered by the regulation, whereas this is not always the case with standards.

### *6.1.1 Reasons for ventilation*

Standards should be based on a clear philosophy (figure 12). Ventilation of buildings in general may be done for several reasons, the most important is to remove or dilute the indoor generated pollutants and supply fresh air for human beings.

Pollutants from people who produce human effluents, as well as emissions from smoking, combustion, building materials, furniture, house hold and cleaning products, the ingress of soil gasses has to be removed from the building. Ventilation is also needed to reduce the exposure from air borne microbes causing infectious diseases.

Other reasons for ventilation may be e.g. humidity control to:

- prevent growth of dust mites;
- prevent from microbiological growth in the building structures: walls, floors, ceilings;
- prevent the building constructions from damages;
- control the pressure levels in building to prevent pollutants from spreading

Moreover ventilation nowadays can also be used for so called “free cooling”. This is a way to control temperature, by ventilate the room with quite high how rates to remove heat from the building to outside.

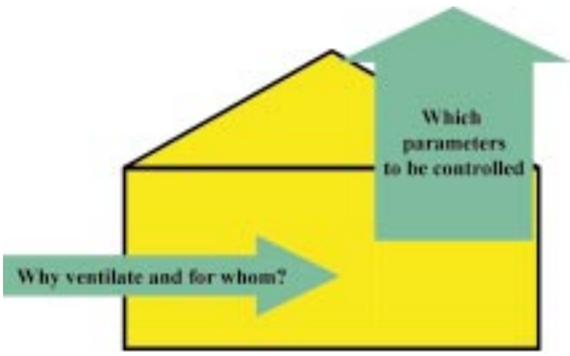


***Figure 12*** *Reason for ventilation*

### 6.1.2 Ventilation, IAQ and energy use

Ventilation is an important parameter for the indoor air quality in buildings. In general the more ventilation the lower the exposure to pollutants from inside. Hence ventilation also has its energy consequences. In case heating or cooling is required, the energy penalty is the most important reason to minimise the amount of ventilation air. (see Figure 13).

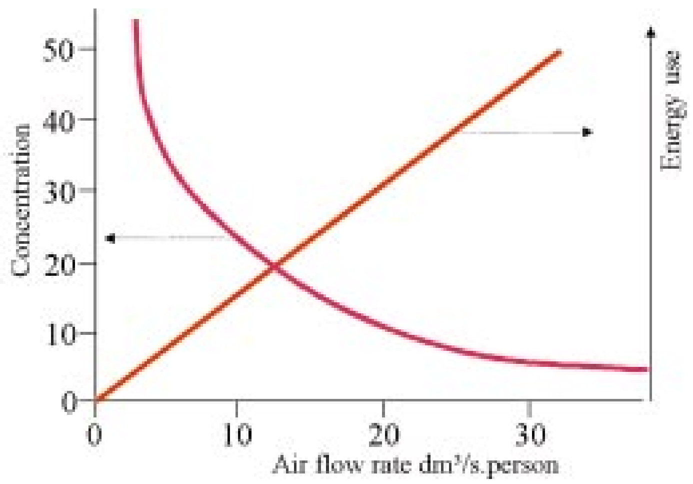


***Figure 13*** *Typical relation between ventilation rate, concentration and the energy use for ventilation*

### 6.1.3 Ventilation and infiltration

Apart from the purpose provided ventilation there is also transport of air through the air leakage of the building envelope. This is normally called infiltration. In some standards the infiltration may be part of the required ventilation, whereas in other standards infiltration is explicitly excluded. From the energy point of view, the reduction of infiltration is important. For indoor air quality considerations, there is a clear distinction between ventilation and infiltration. Infiltration is uncontrolled so one can't guarantee the flow rate. In general, it can be stated that the level of infiltration should not significantly effect the energy nor the air flow rates.

## 6.2 Policy in standards and regulations related to ventilation

### 6.2.1 Prescriptive versus performance based approach

Most standards and regulations are descriptive. It basically means that the requirements are not expressed in terms of maximum allowable exposure levels but in terms of variables which are assumed to have a certain link with the allowable exposure levels, e.g. flow rates in case of mechanical ventilation systems, cross sections of natural air supply openings,…

There clearly is a need to develop more performance oriented regulations and standards. The process of evaluation of health effects due to pollutant sources in building is quite complex (figure 14). On the one hand we have the pollutant originating from several sources in and outside the building. On the other hand there is the human being, which is partly exposed to contaminated outdoor air and partly to contaminated indoor air.

The total exposure depends among other things on:

- Source strength, varying in time and location
- The distribution of time people spent outdoors and indoors in different locations

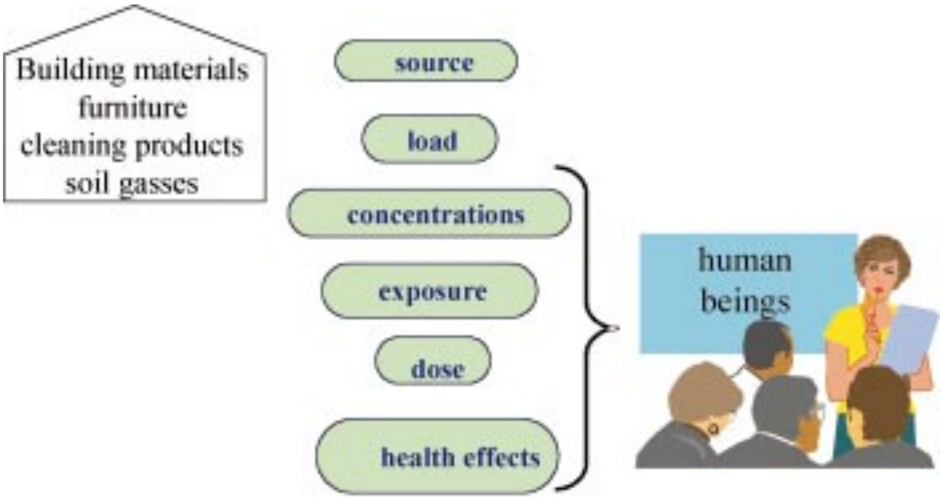


***Figure 14*** *From pollutant source to health effects*

Most existing standards and regulations require flow rates based on assumed pollutants and their acceptable levels of concentration. The absolute highest level of performance approach may be to define the maximum effect of pollutants on the health and well being of people. This last high level approach is practically almost impossible to exploit.

The best practice nowadays is probably the exposure of people as the underlying model for a performance based approach. So, during design and use of the building in practice to one should consider:

- all possible indoor pollutant sources;
- the time different people spent in different buildings indoors and within the building in the different rooms and outdoor on several locations with different concentrations;
- from that data evaluate the total exposure.

A two-component approach to determine the ventilation rates based on pollution loads has been introduced in the recent Addendum 62n (ASHRAE 62n, 2001) to ASHRAE standard Ventilation for Acceptable Indoor Air Quality. The strength of the sources associated with occupants is taken proportional to the number of occupants, while the source strength of building materials and furnishing is taken proportional to the room size, which is characterised by the floor area.

### *6.2.2 Evolution in philosophies and needs concerning assessment of ventilation related performances*

It is clear that the boundary conditions for specifying the requirements in relation to ventilation have clearly evolved during the last decades. For decades, the needs concerning IAQ (figure 15 ❷) and the required ventilation rates were based on laboratory experiments (figure 15 ❶), e.g. von Pettenkofer in 1860. $CO_2$ was recognised as an appropriate marker of IAQ due to body odour.

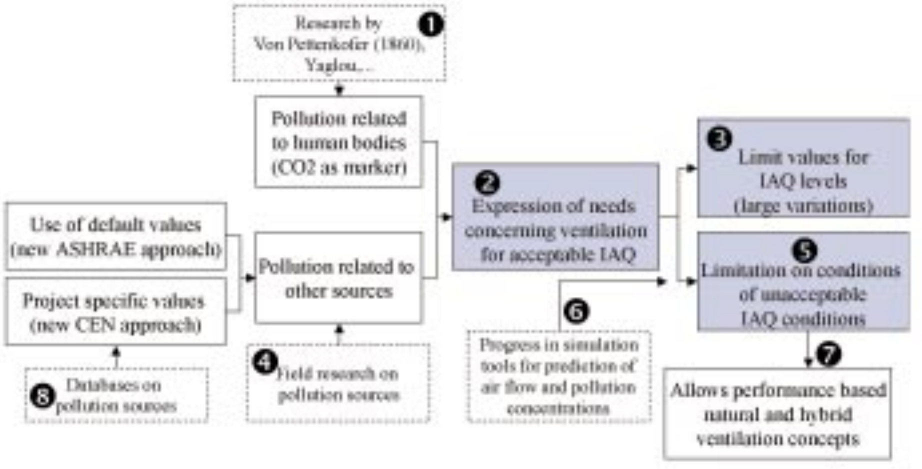


***Figure 15*** *Schematic representation of various approaches for expressing ventilation needs*

The majority of the present standards and regulations are still based on this approach and limit values for IAQ levels (figure 15 ❸) were directly related to pollution by persons, e.g. in terms of maximum $CO_2$ levels.

In the eighties and the nineties, field research (figure 15 ❹) has gained in importance. Various studies have highlighted the importance of other pollutions sources in many types of buildings.

Although there is still a lot of discussion concerning the most appropriate approach for handling these other sources, there is at present a consensus that these sources are important. As a result, the required air flow rates for achieving a 'similar level of IAQ' have to be increased.

In order to deal with the non-occupancy related pollution sources, it is important to quantify these sources.

It is interesting to observe two tendencies:

- One approach is to handle these pollution sources by adopting default values. The motivation for this approach is the fact that it is far from evident to quantify the various sources (as mentioned before). ASHRAE adopts this concept.

- The other approach is to quantify the various pollution sources. This approach is foreseen by CEN. It requires appropriate databases (figure 15 ❽).

A further development (and quite similar as for thermal comfort assessment) is the use of a probabilistic approach (figure 15 ❺). It assumes that it is allowed to have during limited periods IAQ conditions below the target values. In order to allow such approach, it is important to have appropriate prediction tools (figure 15 ❻) which allow to estimate the IAQ conditions in non-steady state conditions.

Such developments in assessment methods (and related requirements in standards and regulations are important for allowing performance based approaches for e.g. natural and hybrid ventilation concepts (figure 15 ❼). It is essential to have in the future performance based approaches in order to allow a correct comparison between various systems and also for allowing innovative systems (e.g. hybrid ventilation, demand controlled systems,…)

## 6.3 Requirements for natural ventilation devices are very strongly influenced by (often rather arbitrary) assumptions

### *6.3.1 General*

Natural ventilation is one of the possible strategies for controlling the indoor air quality. The aim of natural ventilation devices is to guarantee that there is, within certain limits, the possibility for an acceptable indoor air quality. It is important to recognise that requirements concerning natural ventilation devices are not only determined by the expectations with respect to the indoor air quality (see figure 16, left part) but also by a whole range of other assumptions:

- First of all, several assumptions (see figure 16, middle part) have to be made for translating IAQ requirements into air flow rate requirements. These assumptions are the same for mechanical and natural ventilation strategies.
- Then, there are a number of specific assumptions (see figure 16, right part) needed in order to derive requirements concerning the natural ventilation devices. These assumptions (stated or implied) include:
  - Assumptions concerning boundary conditions:
    - Climate related data (temperature, wind, local shielding,…)
    - Building data: airtightness, leakage distribution,…
    - Occupants: occupancy profile, window use, reaction on draught,….
    - …
  - Assumptions concerning acceptable periods of rather poor indoor air quality
    It is clear that it is impossible to guarantee with a natural ventilation system under all weather conditions excellent indoor climate conditions. One has therefore to define the maximum allowable deviations.

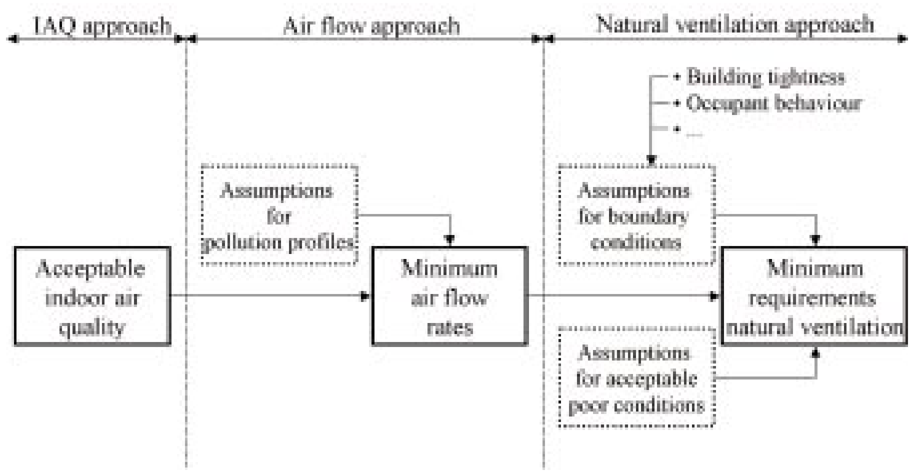


***Figure 16*** *From an IAQ approach to requirements concerning natural ventilation: a succession of assumptions...*

### 6.3.2 *Impact of priorities in the considerations concerning natural ventilation*

In order to illustrate the previous statements, the philosophy is applied to the requirements found for natural air supply openings. In figure 17, one finds in the middle of the figure a series of possible considerations and/or points of attention. Basically, all of them seems to be quite reasonable but they don't lead to the same requirements. In the left part of the figure, a series of considerations is used for defining a set of priorities (which will result in a series of requirements). In the right part of the figure, the same is done, whereby the other considerations are taken as priorities. Both sets of priorities look rather reasonable, but the consequences for the ventilation characteristics are completely different. The left set is quite well in line with the underlying assumptions for the building regulations in France, whereas the right set is quite close to the approach adopted in the Netherlands and Belgium.

Both set of priorities can be considered as a set of needs which defines the quality of the components. It is clear that it is not possible to make a ranking of both quality concepts.

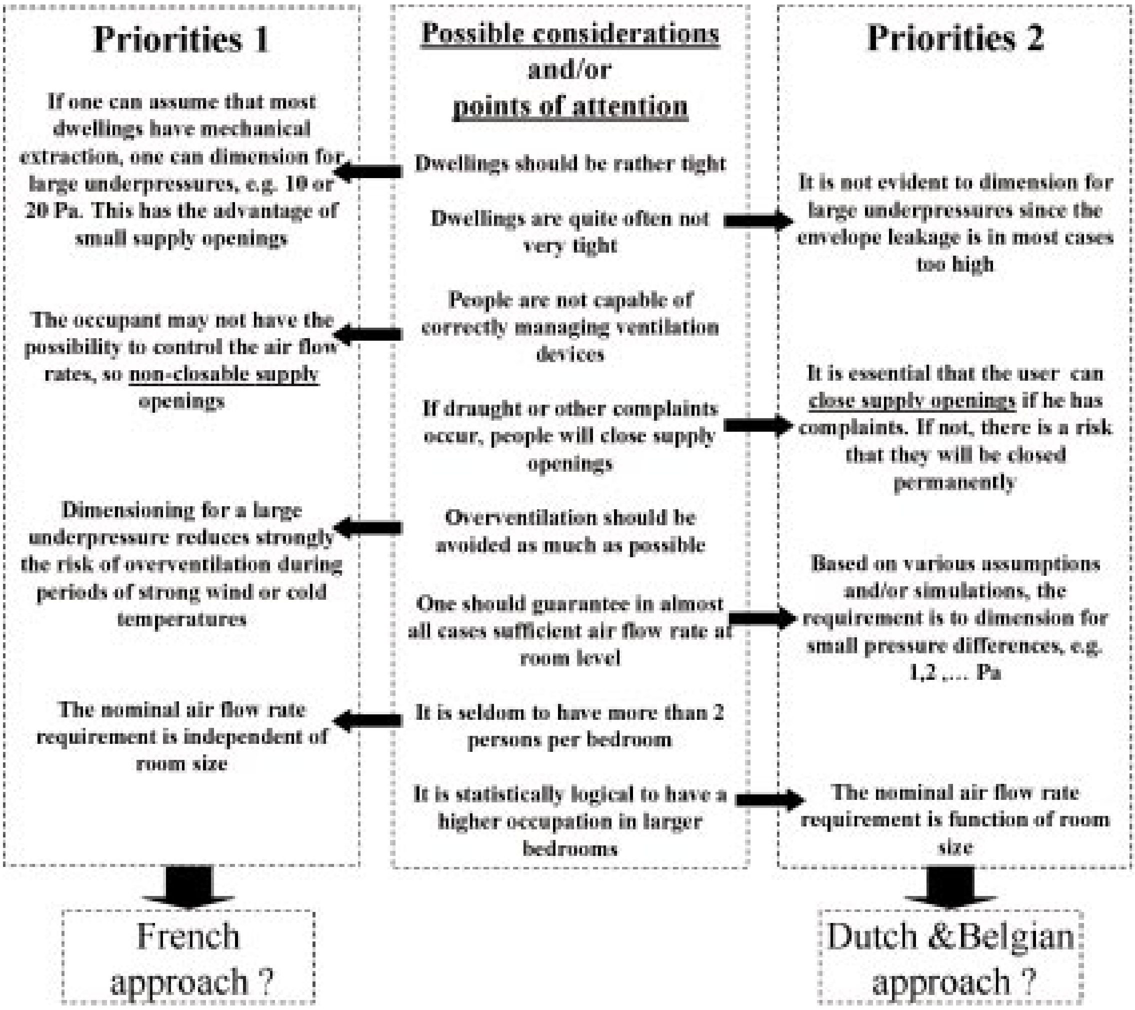


***Figure 17*** *Example how, for a given set of rather logical considerations and points of attention, differences in priorities lead to completely different requirements for quality (Wouters, 2000)*

Another interesting example which clearly shows the wide variation in ventilation related requirements is synthesised in figure 18 and table 2, where the requirements for natural air supply openings are expressed as function of the floor area.

The key observation is the fact that various tendencies are observed :

- In certain countries, the requirement is function of floor area, whereas it is a constant value in other countries;
- The units for expressing the requirements differs substantially: the reference pressures vary from 1 to 20 Pa, in the UK the requirement is still expressed in $mm^2$ open section;
- Certain countries impose non-closable supply openings whereas other don't allow it;
- In one country, the air supply requirements are function of the type of air extraction;
- In absolute terms, very large differences are found: for a 7 $m^2$ bedroom, there is a variation of a factor 3.7 whereas for a 14 $m^2$ bedroom the variation is a factor 6.8.

| | **Belgium** | **France** | **Netherlands** | **UK** |
|---|---|---|---|---|
| Air supply closable? | Obligatory | Not allowed | Obligatory | Required according guidance in Approved Document I |
| Dimensioning principles | Air flow proportional with floor area<br>1 $dm^3/s.m^2$ floor area<br>for $\Delta P$ = 2 Pa | Fixed value | Air flow proportional with floor area<br>0.9 $dm^3/s.m^2$ floor area<br>for $\Delta P$ = 1 Pa | Fixed value |
| Mechanical exhaust | | | | |
| ≤7 $m^2$ bedroom | 7 $dm^3/s$ at 2 Pa | 30 $m^3/h$ at 20 Pa | 7 $dm^3/s$ at 1 Pa | 8000 $mm^2$ |
| 14 $m^2$ bedroom | 14 $dm^3/s$ at 2 Pa | 30 $m^3/h$ at 20 Pa | 12.6 $dm^3/s$ at 1 Pa | 8000 $mm^2$ |
| Natural exhaust | | | | |
| ≤7 $m^2$ bedroom | 7 $dm^3/s$ at 2 Pa | 45 $m^3/h$ at 20 Pa | 7 $dm^3/s$ at 1 Pa | 8000 $mm^2$ |
| 14 $m^2$ bedroom | 14 $dm^3/s$ at 2 Pa | 45 $m^3/h$ at 20 Pa | 14 $dm^3/s$ at 1 Pa | 8000 $mm^2$ |

***Table 2*** *Comparison of air supply requirements in various countries (Wouters, 2000)*

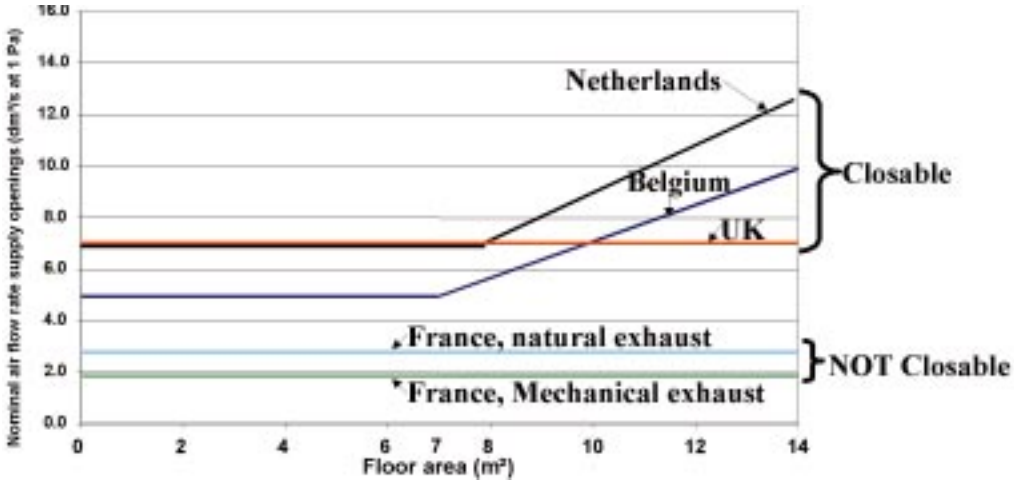


***Figure 18*** *Comparison of requirements for air inlets in bedrooms (Wouters, 2000)*

## 6.4 Present situation in guidelines, standards and regulations

A very wide variation in air flow specifications is found. On the one hand, there are major differences between countries (§6.4.1) and on the other hand there are in some cases also major variations as function of time (§6.4.2).

### *6.4.1 Variation between countries in air flow requirements*

Ventilation standards throughout Europe but also world-wide differ considerably as well as in philosophies and ways to express the ventilation target as in the comparable values. In figure 19 the variation in requirements is presented for dwellings, whereas in figure 20 the variation is presented for office buildings.

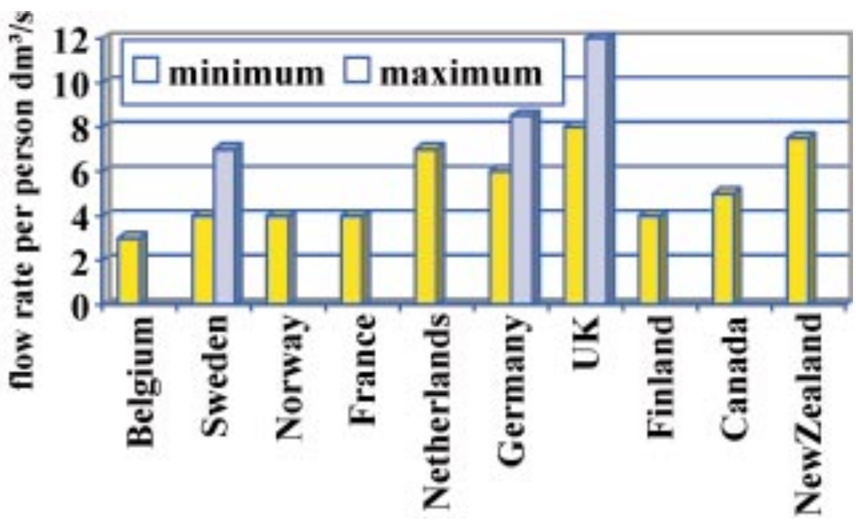


***Figure 19*** *Required flow rates per person for dwellings in standards (TIP-Vent, 2000)*

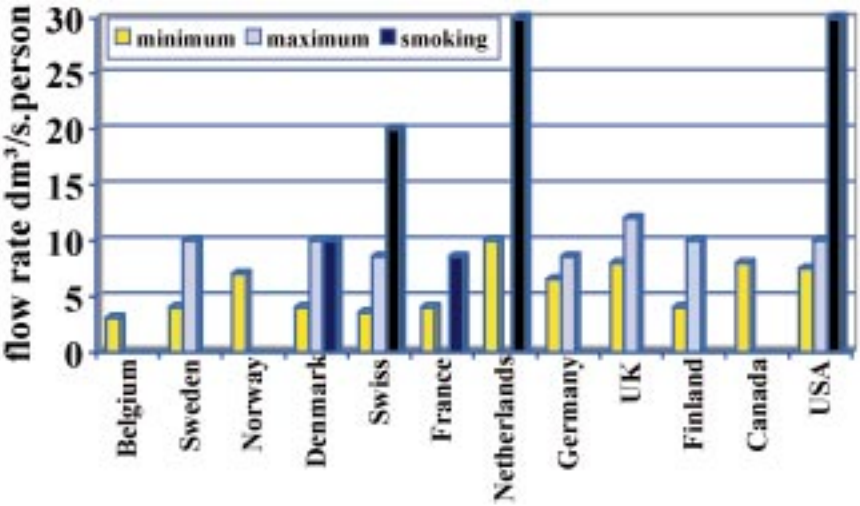


***Figure 20*** *Required flow rates per person for offices in standards (TIP-Vent, 2000)*

Another example is the approach developed in the framework of CEN TC 156. The uncertainty in the real indoor air quality needs is clearly illustrated by the fact that the IAQ and ventilation targets in relation to occupants related pollution varies by 250% from 4 to 10 $dm^3$/s.person. If one take into consideration smoking, the variation is even larger. See table 3.

| Category | Required ventilation rate (l/s per occupant) | | | |
|---|---|---|---|---|
| | No Smoking | 20% | 40% | 100% |
| A | 10 | 20 | 30 | 30 |
| B | 7 | 14 | 21 | 21 |
| C | 4 | 8 | 12 | 12 |

***Table 3*** *Required ventilation rates in CR 1752*

### *6.4.2 Variation of ventilation requirements as function of time*

The air flow requirements found in standards are the result of a weighing of various concerns e.g. air quality, health, energy, productivity,... This weighting process can be strongly influenced by external factors (e.g. oil crisis in the seventies), new findings of research (e.g. impact on health and productivity),...

Giving the lack of precise knowledge on some of these facts, it is not surprising that the air flow requirements in standards may vary considerably as function of time. ASHRAE 62, of which each revision is the outcome of an intensive review process, is a good example. In figure 21, the evolution of the air flow requirements per person are presented, whereby the major discussion items are indicated. Major variations occur as function of time.

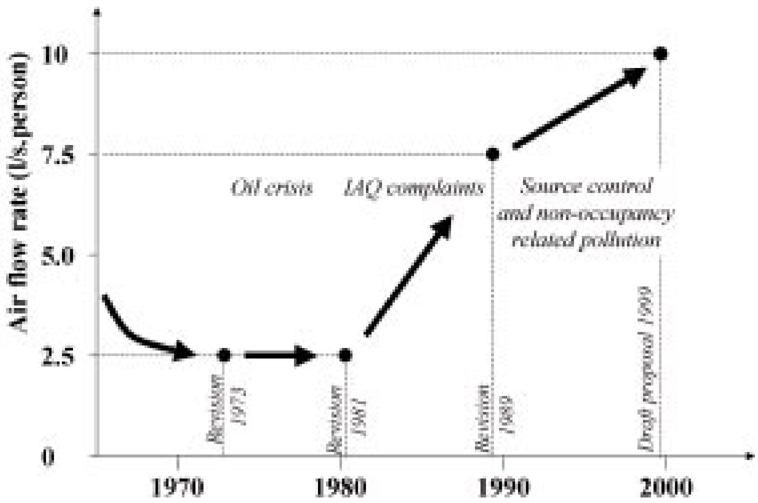


*Figure 21* Evolution of requirements in ASHRAE 62

## 6.5 Standards and regulations in relation to energy efficient ventilation

Standards and regulations can be an important instrument for stimulating energy efficient ventilation systems. The performances of ventilation systems are not only determined by the design, but also by the performances of the components used in the installation, the quality of the installation and the operation and maintenance of the system (figure 22).

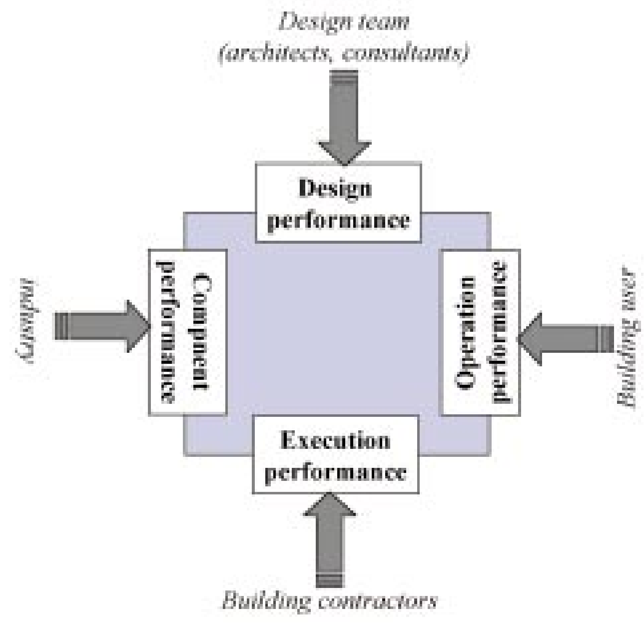


*Figure 22* Various performance related aspects of ventilation systems

As far as the type of requirements are concerned, a major distinction can be made between

- standards and regulations which directly focus on the energy efficiency of the ventilation systems and/or its components and
- standards and regulations which pay attention to the overall energy efficiency of buildings. This latter approach is also called the ‘energy performance approach’.

Examples of standards and regulations which directly focus on energy efficient ventilation:

- airtightness performances of ductwork;
- airtightness performances of the building envelope;
- specific fan power;
- efficiency of heat exchangers.

Standards which focus on the total Energy Performance of a building are not directly stimulating energy efficient ventilation but, as far as measures in energy efficient ventilation are competitive with energy efficiency measures in other areas, can strongly stimulate the use of energy efficient ventilation technology (demand controlled ventilation energy efficient fans good airtightness of buildings and ductwork, correct control of air flow rates....).

For the countries of the European Union, this latter approach will become mandatory in 2006. The European Energy Performance Directive (EPD)(CEC, 2003) indeed requires that all member states will have assessment methods in line with this philosophy whereby minimum performance requirements have to be met by new buildings and also for major renovations of large buildings.

The EPD specifies the following minimum requirements for the assessment methods:

"*The methodology of calculation of energy performances of buildings shall include at least the following aspects:*

> a. *thermal characteristics of the building (shell and internal partitions, etc.). These characteristics may also include air-tightness;*
> b. *heating installation and hot water supply, including their insulation characteristics;*
> c. *air-conditioning installation;*
> d. *ventilation;*
> e. *built-in lighting installation (mainly the non-residential sector);*
> f. *position and orientation of buildings, including outdoor climate;*
> g. *passive solar systems and solar protection;*
> h. *natural ventilation;*
> g. *indoor climatic conditions, including the designed indoor climate.*"

## 6.6 Standards and regulations at European Union level

In the previous paragraphs and chapters, several references have been made to European standards (called CEN standards) as well as European Directives (in particular the Construction Product Directive and the Energy Performance Directive). In this paragraph, further explanation is given.

### *6.6.1 European legislation and European Directives*

The European Union has, according to the Single European Act and the Maastricht Treaty, the possibility to take certain legislative measures in relation to energy efficiency of buildings. Various possibilities exist: directives, mandates, regulations and decisions.

A directive is a legislative instrument within the European Union which is binding for Member States with regards to the objective to be achieved but which leaves to the national authorities the choice of form and methods used to attain the objectives which were agreed on at EU level within their domestic legal systems.

For this publication, 2 directives are of particular importance:

- *The Construction Product Directive*
- *The Energy Performance Directive*

- **Construction Product Directive**

  Paragraph 71 of the White Paper on completing the internal market, approved by the European Council in June 1985, states that, within the general policy, particular emphasis will be placed on certain sectors, including construction. The removal of technical barriers in the construction field, to the extent that they cannot be removed by mutual recognition of equivalence among all the Member States, should follow the new approach set out in the Council resolution of 7 May 1985 which calls for the definition of essential requirements on safety and other aspects which are important for the general well-being, without reducing the existing and justified levels of protection in the Member States.

  The Construction Product Directive (CPD) dates from 1989. The 6 essential requirements specified in the CPD provide the basis for the preparation of harmonised standards at European level for construction products.

  The 6 essential requirements are :

  1. Mechanical resistance and stability;
  2. Safety in case of fire;
  3. Hygiene, health and the environment;
  4. afety in use;
  5. Protection against noise;
  6. Energy economy and heat retention

  Several of these requirements directly (e.g. n° 3) or indirectly deal with indoor air quality and ventilation.

- **Energy Performance Directive**

  As already mentioned in §6.5, this directive was adopted in 2002 and requires from the member states a series of actions in relation to the energy efficiency of buildings. The requirements are specified in article 1 of the Directive :

*"This Directive lays down requirements as regards:*

*(a) the general framework for a methodology of calculation of the integrated energy performance of buildings;*

*(b) the application of minimum requirements on the energy performance of new buildings;*

*(c) the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;*

*(d) energy certification of buildings; and*

*(e) regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old."*

The EPD mainly deals with the energy related aspects. However, there is also explicit attention for the indoor climate aspects. In article 4, the following specification is given:

> *"… Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings are set, based on the methodology referred to in Article 3. When setting requirements, Member States may differentiate between new and existing buildings and different categories of buildings. These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation,…"*

### *6.6.2 European standards*

Three bodies are responsible for the planning, development and adoption of European standards:

- CENELEC (European Committee for Electrotechnical Standardisation) for electrotechnical issues;
- ETSI (European Telecommunications Standards Institute) for most of the Information and Communications Technologies;
- CEN (European Committee for Standardisation) for all other sectors.

CEN is a legal association, the members of which are the National Standards Bodies of nineteen European countries and six associates (organisations representing social and economic interests at European level).

The CPD mandates the following organisations for carrying out specific activities:

– CEN and CENELEC for preparing and adopting the standards.

– EOTA (European Organisation for Technical Approval) for preparing the technical approvals.

As a result of the CPD, a large number of actions have started up in the framework of the European Committee for Standardisation (CEN). The ventilation related aspects are mainly handled in Technical Committee 156, whereas some of the energy related aspects are covered by Technical Committee 89.

The procedure for approval of European standards is rather complicated and falls outside the objective of this thesis. However, it is important to mention that the adoption of standards does not require unanimity but that it is based on a weighted voting principle. For more info: www.cenorm.be.

The following observations are important:

- The CPD and EPD are part of the European legislation. European standards resulting from the CPD have to be implemented at national level. It is an obligation for the member states to implement these standards at national level.

- The European standards themselves don't automatically have an impact on the building sector and on the individuals in the member states. Only if a standard is used for specifying a certain performance level, (e.g. in the framework of a national legislation, by being part of project specific requirements,…) it becomes part of the requirements for quality.

- The EPD does not contain requirements for the European citizens but for the member states. Each member states must set up the required regulations and related activities.

- The increased importance of European standards put a high pressure on CEN in order to deliver all required assessment procedures. An example is the general recognised role of night ventilation as part of an overall strategy of passive cooling. At present, there is not yet a sufficiently refined procedure at CEN level nor is such procedure in preparation. This situation, in combination with the requirements due to the EPD may mean in practice that the potential benefits of night ventilation will not be rewarded in the legislation by many member states.

## 6.7 Synthesis

At present the majority of the standards are directly or indirectly still based on the early research findings by Pettenkofer and Yaglou whereby human biofluents (with $CO_2$ as tracer) are the basis. Although this common starting point, there are very wide variations in the various standards with respect to the air flow specifications. This can be partly explained by the relative weight given to various considerations, whereby external factors (e.g. oil crisis and environmental considerations) as well as new findings of research (e.g. impact on health and economic impact of poor indoor air quality) are not receiving the same importance in all countries.

Source control and/or ventilation for non-occupancy related pollution sources is receiving at present attention in most standardisation committees. However and although nearly everyone agrees that these pollution sources should be considered. there is not yet a consensus for dealing with this kind of pollution. The fact that interest in this kind of pollution is only a recent phenomena can be explained by on the one hand the increased occurrence in buildings of materials and systems with high pollution loads (carpets. cleaning products, HVAC systems,...) and on the other hand by increased scientific knowledge.

The majority of the present standards and regulations are mainly descriptive and rarely performance based. One of the challenges for the future is to replace these descriptive approaches by performance based concepts.

As far as the type of energy related requirements is concerned, there are clear benefits of having requirements in terms of the overall energy efficiency of buildings. The new European Energy Performance Directive will impose such approach for all European Union member states.

## 6.8 References


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# 7 VENTILATION RELATED PERFORMANCES IN DAILY PRACTICE

## 7.1 Introduction

In this chapter, the discussion is focused on the situation in daily practice. What do we know about the availability of ventilation systems in buildings? To what extent are the performances of these systems in line with the requirements? What are attractive possibilities for improving the performances of ventilation systems in daily practice?

## 7.2 Availability of ventilation standards and regulations

There clearly are uncertainties with respect to the indoor air quality and ventilation requirements for buildings. However, this cannot be used as an argument for not having standards and/or regulations. Nevertheless, there are still countries and/or regions in Europe which have no appropriate standards or regulations.

## 7.3 Application of the applicable standards and regulations in practice

### *7.3.1 Availability of ventilation systems*

In principle, one can expect that new or retrofitted buildings which have to be in line with applicable ventilation standards and regulations, will have an appropriate ventilation system. However, this is not always the case.

As an example, figure 23 shows the availability of ventilation systems in Flemish dwellings constructed between 1990 and 1995. Although a Belgian ventilation standard exist since 1990, not more than 10% of new dwellings have ventilation provisions.

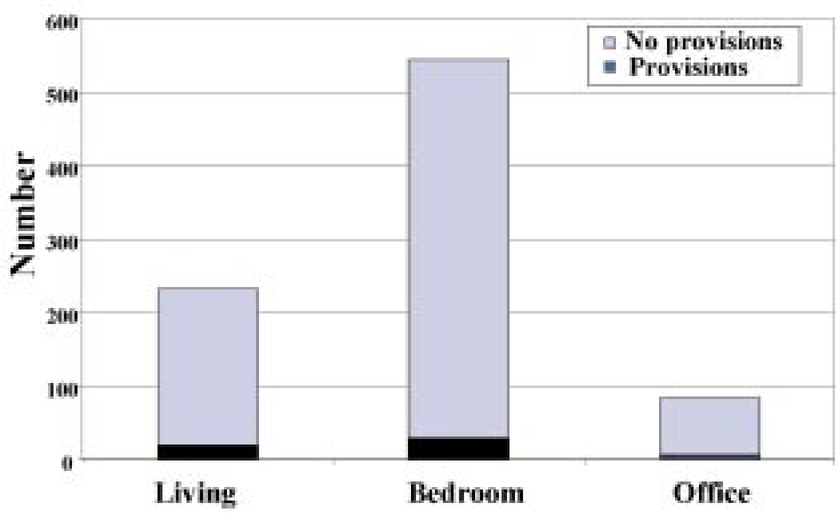


***Figure 23*** *Majority of Flemish dwellings have no air supply previsions*
*Source: BBRI (2000)*

Therefore, it is not sufficient to have good standards and regulations, it is also important to develop a coherent framework for the implementation of these standards and regulations.

*7.3.2 Air flow performances of ventilation systems in daily practice*

In this paragraph, attention is focused on some critical performances of installed ventilation systems. Based on the results of 3 studies, it is possible to draw some conclusions.

*1. Air flow rates of mechanical ventilation systems in Belgian dwellings*

As mentioned in the previous paragraph, few new Flemish dwellings have a ventilation system. The results presented in figure 24 clearly show that the fact of having a mechanical ventilation system is not a guarantee that an appropriate air flow rate is achieved. When compared with the values specified in the Belgian standard, most of the toilets have very high air flow rates whereas the majority of the bathrooms have too low air flow rates.

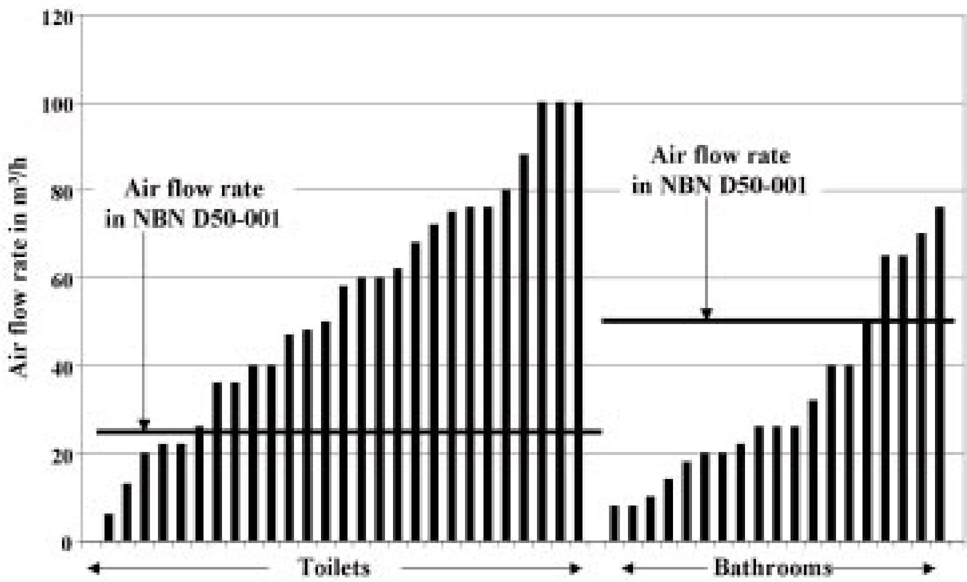


***Figure 24*** *Measured air flow rates in Belgian bathrooms and toilets with mechanical extraction*
*Source: BBRI (2000)*

*2. Air flow rates in Scandinavian dwellings*

Belgium has not a long tradition in ventilation for IAQ control and very different from the situation in e.g. the Scandinavian countries. In the beginning of the nineties, a very extensive study of the Swedish dwelling stock was done in the framework of the ELIB study. Part of the study concerned the measurement of the average air flow rates based on passive tracer gas measurements. As shown in figure 25, a substantial part of the dwellings are underventilated.

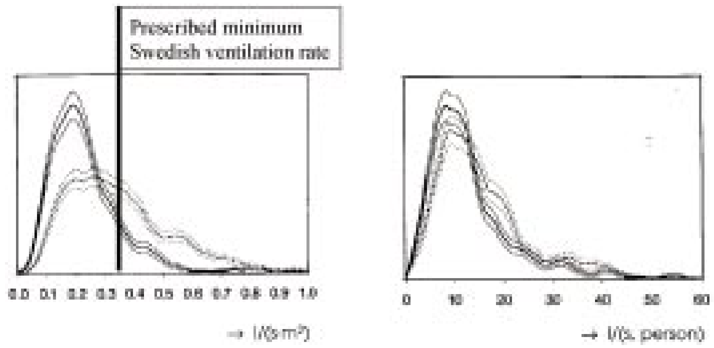


***Figure 25*** *Estimated frequency functions of the ventilation rate in a representative sample of single-family houses (full lines) and multi-family houses (dotted line) in Sweden. Thin lines indicate the ranges of uncertainty*
*Source: Norlen(1993)*

Similar measurements have been carried out in other Nordic countries. The results are summarised in table 4.

| Type of building and ventilation system | Ventilation (l/s.m²) | | | |
|---|---|---|---|---|
| | Sweden (n=1143) | Finland (n=242) | Denmark (n=123) | Norway (n=344) |
| **Single family houses, detached and semi-detached** | | | | |
| Natural ventilation | 0.23 | 0.28 | 0.24 | 0.47 |
| Exhaust ventilation | 0.24 | 0.31 | 0.38 | 0.44 |
| Balanced ventilation | 0.29 | 0.35 | - | - |
| **Apartment building** | | | | |
| Natural ventilation | 0.33 | 0.43 | - | 0.51 |
| Exhaust ventilation | 0.39 | 0.47 | 0.40 | 0.42 |
| Balanced ventilation | 0.40 | 0.42 | - | - |

***Table 4*** *Measured air flow rates in Nordic dwellings*

From the Norwegian study, it seems possible to obtain an indication of the impact of new legislation. As shown in figure 26, the air change rate in recent Norwegian dwellings has substantially increased and this is probably mainly due to the new Norwegian legislation.

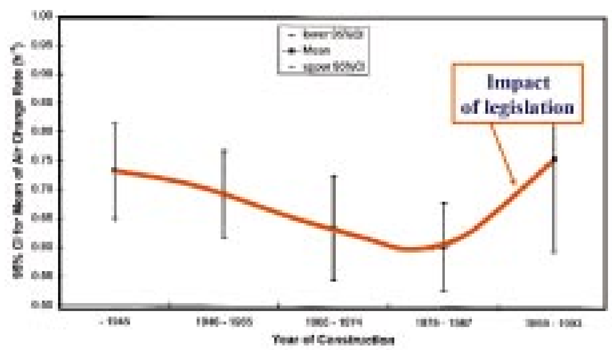


***Figure 26*** *Air change rate (h-1) mean and 95%-confidence intervals of mean for Norwegian dwellings according year of construction*
*Source: Øie (1998)*

*3. Air flow rates in Finnish office buildings*

In the Helsinki area, the air flow rates have been measured in 33 office buildings (figure 27) (Teijonsalo et al., 1996). It is a clear example of on the one hand a wide variation in average air flow rates between the various buildings and on the other hand of a wide variation of the air flow rates between offices in the same building.

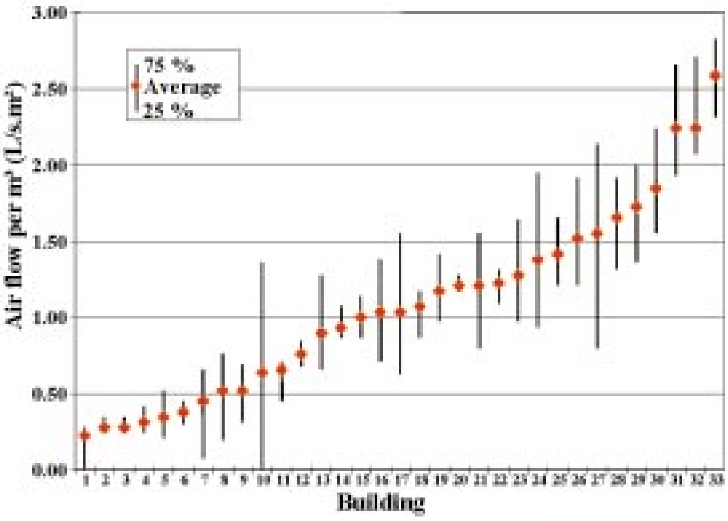


***Figure 27*** *Air flow results for 33 office buildings in Helsinki area*
*Source: Teijonsalo(1996)*

These 3 projects clearly support the conclusion that the fact of having standards and/or regulations is not sufficient for achieving appropriate air flow rates.

## 7.4 Quality of ventilation systems with respect to indoor air quality and energy efficiency: the example of ductwork airtightness

In order to achieve ventilation systems with good performances with respect to indoor air quality and energy efficiency, it is important that the system design, component performances and the quality of execution is of a correct level (figure 28). Practice shows that this is not always the case. An interesting example of ventilation technology is ductwork airtightness. In the framework of the SAVE-DUCT project, air distribution systems were tested in Belgium, France and Sweden (figure 29).

On average, poor to very poor results were found in Belgium and France. On average, 20% of the air flows are lost in Belgium and France because of poor ductwork airtightness. Such poor airtightness can lead to too low air flow rates at room level or will result in unnecessary energy losses for heating and fan use.

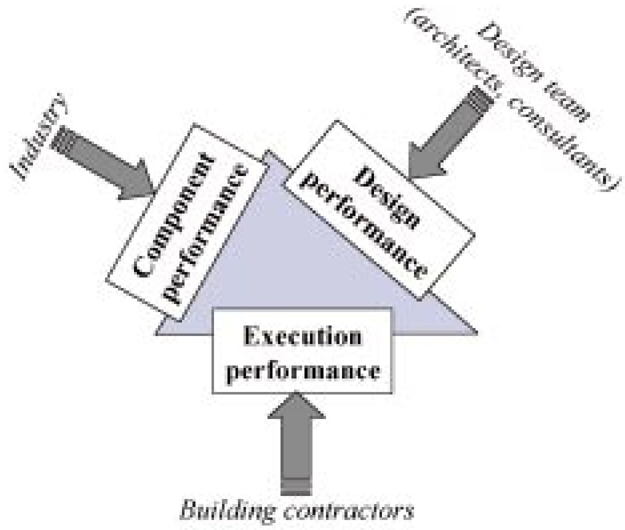


***Figure 28*** *Crucial aspects in relation to performances of ventilation systems*

Very good results were measured in Sweden. As is discussed in §7.7.1, the good Swedish results are mainly due to the fact of specific requirements in Sweden.

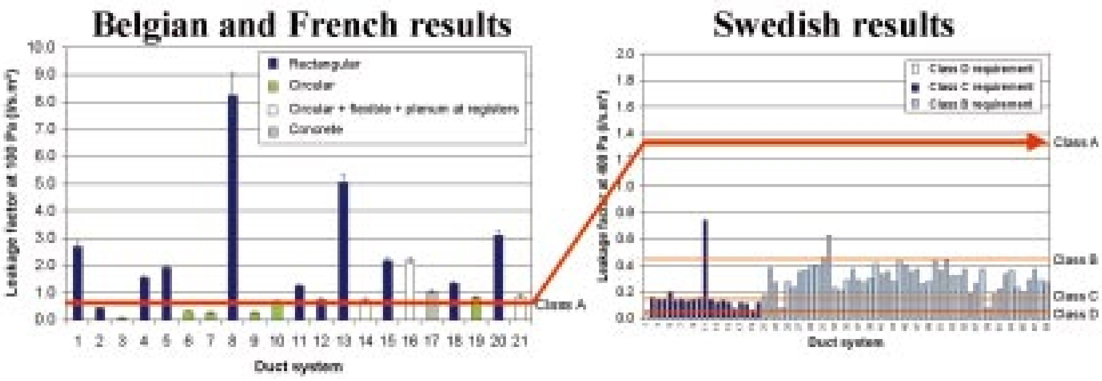


***Figure 29*** *Comparison of airtightness of ductwork in Belgium, France and Sweden*
*Source: Carrié (1999)*

## 7.5 IAQ related aspects

A recent meta-analysis (Seppänen et al., 1999) of ventilation studies in non-residential buildings found that ventilation rates below 10 $Ls^{-1}$ per person were associated with a significantly worse prevalence or value of one or more health or perceived air quality outcomes. Studies further show that increases in ventilation rates above 10 $Ls^{-1}$ per person, up to approximately 20 $Ls^{-1}$ per person, are sometimes associated with a significant decrease in the prevalence of SBS symptoms or with improvements in perceived air quality. Data from multiple studies also indicate a dose-response relationship between ventilation rates and health and perceived air quality outcomes, up to approximately 25 $Ls^{-1}$ per person; however, available data are not sufficient to quantify an average dose-response relationship.

Based on these results, it is predicted that in office buildings or similar spaces constructed using current building practices, ventilation rates maintained above 10 $Ls^{-1}$ per person will, on average, result in significantly reduced occupant symptoms and better perceived air quality.

Ventilation rate increases above 10 $Ls^{-1}$ per person up to 20 $Ls^{-1}$ per person may continue to reduce symptoms and improve air quality, but these benefits are currently less certain and they are likely to decrease in magnitude as ventilation rates continue to increase. New or revised ventilation codes and standards may need to weigh the available evidence for occupant benefits at higher ventilation rates against the incremental costs of increasing ventilation. This process would be new, as minimum ventilation rates in existing codes and standards do not substantially reflect health data.

Furthermore, buildings in practice often fail to deliver even the minimum ventilation rates required by current or previous building. Low ventilation rates usually do not violate building codes and standards, which generally specify minimum rates for ventilation system design but not for system operation. New or revised building codes and standards may need to specify minimum ventilation rates during building operation to maintain acceptable levels of occupant health and satisfaction.

## 7.6 Research needs

Limitations in existing data make it essential that future studies better assess health, productivity and comfort due to changes in the ventilation rate range between 10 and 25 $Ls^{-1}$ per person. Future research should be based on well-controlled cross-sectional studies or well-designed blinded and controlled experiments. The most effective studies will include high quality measurements of ventilation rates, ample study power to detect effects considered of public health importance, and if possible, improved measures of adverse occupant outcomes; e.g., more sensitive or more objective assessment tools.

In addition to new studies of ventilation effects on occupants, we also need studies to specify the causative agents of adverse health outcomes. The most effective strategies to improve indoor air quality (e.g., source removal) cannot be specified before the agents and their sources are known. When this information is available the ventilation rates necessary to control exposures can be calculated, and rational decisions made between effectiveness of source control and adjustment of ventilation.

## 7.7 Mechanisms for improving the performances of ventilation systems in daily practice

There is no doubt that the ventilation performances are in practice in many cases not at all in line with the specifications found in the standards and regulations. Therefore, it is important to consider appropriate mechanisms for achieving a better compliance.

In this paragraph, a brief description is given of a few interesting procedures which have a major impact on performance improvement in daily practice.

### *7.7.1. Stimulation of good system performances after installation*

As mentioned in §7.4, remarkable differences exist in ductwork airtightness between on the one hand Belgium and France and on the other hand Sweden. The major explanation is the fact that there are in Sweden since 1972 specifications concerning ductwork airtightness. Since then, the requirements have been progressively increased. This fact in combination with a systematic control at site by the building contractors has resulted in:

- A systematic good airtightness level of new ductwork systems;
- A major progress in component and system technology by Swedish manufacturers.

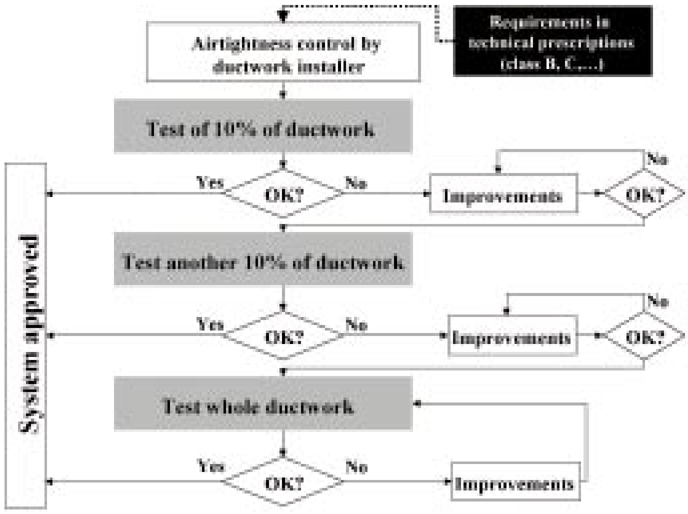


***Figure 30*** *Principles of Swedish inspection procedures for ductwork airtightness*

### *7.7.2 Stimulation of correct operation and maintenance*

Practice shows that the performances of a ventilation system can substantially change during its lifetime. Therefore, without appropriate maintenance and control, it is not evident to assume a correct functioning.

In Sweden, inspection visits of ventilation systems are mandatory since 1993 (OVK – Obligatorisk Ventilations-Kontroll, see table 5) and it seems that this has resulted in an increased awareness of poor system performances and at the same time a substantial improvement of the performances of these ventilation systems.

| Buildings | Last date for first inspections of existing building | Inspections intervals | Inspector qualifications |
|---|---|---|---|
| Day-care centres, schools, health care centres, etc. | 31 dec. 1993 | 2 years | K |
| Blocks of flats, offices, with balanced ventilation | 31 dec. 1994 | 3 years | K |
| Blocks of flats, offices, .. with mechanical exhaust | 31 dec. 1995 | 6 years | N |
| Blocks of flats, offices,... with natural ventilation | 31 dec. 1995 | 9 years | N |
| One- and two-family houses & balanced ventilation | 31 dec. 1995 | 9 years | N |

***Table 5*** *Requirements for performance checks of ventilation systems in Sweden*
*Source: The Swedish National Board of Housing, Building and Planning (1992)*

Several lessons can be learned from the Swedish AMA and OVK experiences:

- A coherent control system can lead to a very substantial improvement of the performances in practice;
- A coherent control scheme can be a very strong initiator for product development without leading to a substantial increase in total costs;
- Control procedures should not necessarily only rely on activities executed by governmental or neutral organisations. Building contractors can be actively involved.

### *7.7.3 Stimulation of energy efficiency ventilation systems*

Practice in many countries shows that many decision makers have little interest for the energy efficiency of their ventilation systems. An energy performance regulation allows to give a very strong stimulus for improving energy efficiency of buildings, including ventilation related performances. Such regulations exist at present in France and the Netherlands and are under development in other countries.

## 7.8 Conclusions

- There are still several countries and regions without clear standards or regulations concerning the ventilation requirements.
- The fact of having standards or regulations is not necessarily sufficient for achieving a wide-scale application of ventilation systems
- In practice, the air flow rates vary in many cases substantially whereby values far below as well as far above the standard values are found.
- Relation between air flow rates and IAQ
- Specific regulations and control procedures can substantially improve the performances of ventilation systems, as well with respect to the air flow and IAQ performances as with respect to energy efficiency of the systems. Such control schemes must not necessarily rely on governmental officials nor should the total cost be high.

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# 8 STRATEGIES FOR AN APPROPRIATE IAQ AND ENERGY EFFICIENCY

## 8.1 Context

The requirements for good indoor air quality and energy efficiency have often been considered to conflict with each other. This is based on the assumption that good indoor air quality requires more and more energy through more ventilation. This is not completely true. The results of the European Audit project showed that buildings with lower specific energy consumption also had a lower prevalence of sick building symptoms (Roulet et al., 1995).

The challenge today is to find the right compromise that allows at the same time for good IAQ and highly efficient energy. That means that the first objective, i.e., good IAQ, as a relevant part of the indoor environment, shall not be obtained at the expenses of the outdoor environment, be it at the local/regional or at the global level.

On the other hand the problems of health, comfort and productivity related to indoor air quality will certainly acquire a bigger dimension in the future. This as a consequence of the enhancement of the socio-economical conditions of growing layers of the population and because of the expansion of the HVAC systems and, in particular, due to the fact that this expansion will happen to a large extent without the appropriate designing, selection and maintenance conditions.

So, what seems to be truly the challenge today is not just the technological progress within the present context and culture but the vision that can be at the service of mankind assuring good IAQ and less use of unfriendly primary energy resources.

## 8.2 Strategies

The major strategies for good IAQ have been identified:

- Control of pollution source (e.g. Restrictions in use or encapsulation)
- Local extract ventilation
- General ventilation
- Air cleaning

All of them have been in use, probably based on not always clear criteria. If the problem were only to know how appropriate has been the balance in the use of each one of those strategies, the answer would be that there have not been rules or procedures fully justified and implemented on how to establish that balance. Therefore, there is the need for the establishment of criteria to select on which strategy shall the priority be put on. However, there is a wide consensus that source control is the most effective way to improve indoor with many air pollutants such as tobacco smoke, radon, many volatile organic compounds and particulate matter.

So, from what is said above a general strategy for the future will be based in two major avenues for IAQ:

- source control at all levels;
- better ventilation systems.

The future, in tune with the overall trend towards sustainability, will ask, besides all technological progress, for more effort on the strategy on source control. The challenge presented above becomes then formulated in more precise terms: how to explore the potential of source control techniques at all levels and better ventilation systems to assure at the same time good IAQ and low use of *unfriendly* primary energy.

This, of course, besides and in addition to the progress that can be expected at all levels on the energy technologies.

## 8.3 Source control

Source control means the action or group of actions that lead to avoid the emissions at the place they would have been liberated or to confine the source of indoor air pollution before the emissions reach the whole space. There are very simple common examples. It is the case of the kitchen or of the WC where an exhaustion system prevents the polluted air from being mixed with the incoming air.

Another example regards the specialisation of some rooms for certain activities (smoking, copying, etc) precluding the need for a special dilution in wider spaces that don't need to be affected by those sources.

But source control at all levels means much more than that and implies eventually a basic attitude in tune with the concept of sustainability, which shall influence the whole urban design process and can be underestimated by the mechanical engineers as experts intervening at the extreme end of the line.

Source control shall be an objective:

a. in the urban design of the city itself, be it a new quarter or a retrofitting project, in order to reduce the needs for energy and, for instance, to facilitate the aeration of the building and surroundings;

b. in the design of the building itself at every single decision regarding the space distribution and orientation, the use of materials and its needs for energy; and

c. in the selection of all building products in tune with the specific requirements of the Construction Products Directive 89/106 (CEC, 1989).

In the context of this strategy every decision must be referred to the most updated criteria regarding sustainability which favours the appropriate use of each technological solution in the softer way.

## 8.4 Better performance of ventilation systems

In this area of intervention, there are three major alternatives:

In respect of ventilation systems the focus should be in the following areas

- The appropriate selection of the ventilation rates (§8.4.1);
- Clean and hygienic ventilation systems (§8.4.2);
- Cleaning of the air (§8.4.3);
- The maintenance of the ventilation systems (§8.4.4)

### *8.4.1 The appropriate selection of the ventilation rates*

A key issue in the performance of ventilation is the selection of ventilation rates established on the base of the dilution of pollution loads of the room and on the cleaning capability of ventilation air. Ventilation air can be supplied to rooms through mechanical ventilation systems or with the help of natural forces such as wind pressure and the buoyancy effects caused by air temperature differences between indoor and outdoor air. In the latter case, ventilation operates through openings which dimension, location and conditions of operation have to be better defined and controlled, and integrated in the whole building design.

Ventilation air supplied to the spaces can be a mixture of outdoor air and recirculated air or entirely outdoor air. The option of recirculated air is only possible with mechanical ventilation and emerged under the need of reducing the energy associated to the heating/cooling of the incoming air.

Ventilation does not directly affect occupant health or perception outcomes, but the rate of ventilation affects indoor air pollutant concentrations that, in turn, modify the occupants' health or perceptions. However, it has been shown in a recent meta-analysis of the studies on ventilation rates and health effects that ventilation rates below 10 L/s per person is increases adverse health effects, and increase of ventilation rates up to 20 L/s per person alleviate the adverse health effects and perception (Seppänen et al. 1999). This applies in the buildings with present construction practice. The results may change in the future with improved building practices.

The air pollutant concentrations in a given space depend on several factors other than the air flow rate. In principle, steady state concentrations in a well-mixed indoor space can be calculated from the following simple equation

$$C_{in} = C_s + [(S/V)/(\lambda_v + \sum \lambda_{other})] \qquad (1)$$

where $C_{in}$ = the indoor concentration,

$C_s$ = the concentration in the air entering the space,

S/V = the indoor pollutant generation rate per unit air volume,

$\lambda_v$ = the ventilation rate equal to outside air flow rate divided by indoor volume,

$\sum \lambda_{other}$ = the sum of all other indoor pollutant removal rates.

In practice, the situation is not as simple as suggested by the equation. The indoor pollutant emission rate (source strength) is usually not well known and not even constant. Indoor pollutant source strengths are highly variable among buildings, and considered the biggest cause of the variation in pollutant concentrations among buildings. Pollutants may be adsorbed by room surfaces during high concentration periods and desorbed again into the air during low concentration periods.

n many buildings, ventilation rates are not constant. For example, ventilation systems may not operate at night, and during operation rates of ventilation may change with internal heat loads or with outdoor air temperature. Pollutant concentrations may not reach equilibrium until several hours after ventilation rates stabilize. Thus, the indoor air quality is also dependent on operation schedule of the ventilation system. Additionally, the concentration of pollutants in the air entering the space is affected by five major factors: (1) the level of pollutants outdoors; (2) possible recirculation of return air; (3) the location of outdoor intake relative to outdoor air pollution sources; (4) pollution sources in the air handling system; and (5) pollutant removal from supply air by filters, sorbents, or deposition on duct surfaces.

The quality of the outdoor air has a significant effect on the cleaning capacity of ventilation air and should be taken in consideration while designing the ventilation. The air quality may vary depending on the time of the day in urban areas, for example the pollution from traffic is usually higher in the daytime as pollution from industrial sources and energy production is more constant over the time. The ventilation rates should reflect this variation.

### *8.4.2 Clean and hygienic ventilation systems*

The recent results of some work on the field have shown that HVAC systems can be relevant sources of indoor pollution *(Bluyssen et al. 1996, Bjorkroth 1998)* So, the systems themselves, whatever sophisticated and technologically advanced the systems may seem to be today, can fail in what regards the assurance of good IAQ, mostly by deficient running and maintenance conditions. Better components and systems have to be developed to maintain the good supply air quality during the life time of the ventilation system.

### *8.4.3 The cleaning of air*

Another possibility to control the indoor air quality is the removal of particles and gasses with air cleaning. The cleaning technology is widely used to remove the pollutants from the intake air used in ventilation or in cleaning the indoor air by circulating the air through a filter. However the cleaning efficiency of the filters is variable with their quality. The availability of different options regarding filters asks for the need for the establishment of criteria and rules on how to select and size the appropriate filter for each specific service.

There is also some controversy about the efficiency of filters in particular in what regards the potential for incubating microorganisms and emitting smelling odours.

The removal of gaseous pollutants from the air is possible but not cost effective with the present technology.

It seems that in the near future the indoor air quality cannot underestimate the role of air cleaning technology, which, together with the source control strategy will alleviate the pressure on the ventilation strategies.

### *8.4.4 Maintenance of ventilation systems*

The proper operation of a ventilation system is of great importance. This has been stressed already in the ASHRAE standards (ASHRAE 62 1989 and ASHRAE 62R 1996) and in many other national standards.

The use of a building may change during its life span several times. The requirements for the indoor climate may also change simultaneously. Unfortunately the indoor climate systems are not always adjusted accordingly, which may result in problems with indoor climates.

Buildings tend to get technically more complicated, and also require more skilful labour to operate them. Unfortunately, the building operators are not always trained properly to perform their tasks, which may lead to poor operation of the building and a deteriorated indoor climate. A typical mistake in operation, for example, is saving in heating costs by reducing ventilation rates or operation hours of ventilation. This may result in serious indoor climate and moisture problems in the long term. Poor maintenance may result in serious failures in the operation of a ventilation system which again may lead to the problem of deteriorated indoor air quality.

In the Swedish mandatory program for testing and examination of ventilation systems, only 34 % of 5,625 systems evaluated passed the test criteria which was mainly based on regulations that applied when the system was brought into operation (Engdahl, 1998). Systems without satisfactory operational and maintenance instructions had 50 % more faults in performance compared with those with satisfactory instructions.

Advanced requirements for the maintenance of the air handling systems are given in the recently published German guidelines (VDI 6022, 1997). It gives recommendations for the maintenance schedule for air handling systems providing good indoor air quality, and sets the requirements for the training of the building manager and service personnel in good hygiene.

Outdoor air quality is still getting worse in many European cities, even though, it has improved during the past years in most large cities in the USA. It may be advisable to temporarily reduce outdoor air supply rates below the minimum levels during the occupied periods when outdoor air contaminant concentrations exceed acceptable criteria for ventilation air and the filtration capacity of the ventilation system (ASHRAE 62R, 1996).

## 8.5 Ventilation systems

It is common to classify ventilation systems in 2 categories: (a) natural ventilation and (b) mechanical. A third system is the hybrid ventilation, which intents to combine the features of natural and mechanical ventilation.

### *8.5.1 Natural ventilation*

In the leakage based natural ventilation system air enters into and exits from the building through building envelope. No specific devices or openings are provided for ventilation. Ventilation rates vary with weather conditions, mainly depending on the wind. Buildings have typically openable windows. This type of ventilation is used commonly in United Kingdom and Central Europe.

Passive stack ventilation systems have intended exhaust openings in rooms, outdoor air enters the building through building envelope or intended openings for ventilation in building envelope. Driving forces of ventilation are wind and thermal difference between indoor and outdoor air. Buildings have typically openable windows. Exhaust fans may be used in the rooms with high pollution loads. This type ventilation has been used in Nordic and Eastern European Countries.

Risks in the performance of ordinary natural ventilation include the following: no particle filtration, poor indoor temperature control, outdoor noise, inability to pressurise or depressurise buildings, low ventilation rates in some weather conditions and with tight building envelope.

Primarily during the last decade, major developments in the characteristics of natural supply and exhaust openings have taken place (figure 31), e.g. supply and exhaust openings with very good acoustical performances, self-regulating devices, humidity controlled supply and exhaust openings,… More recently, systems have been developed which includes electronic sensors and actuators for optimal air flow control. Moreover, research is taken place for achieving heat recovery and air cleaning (BRECSU, 1999).

### *8.5.2 Mechanical ventilation*

Buildings with mechanical ventilation have fan powered supply air to and exhaust air from the rooms. Supply air may be heated depending on demand but not humidified or cooled. Ventilation system may have heat recovery from exhaust air. System may recirculate also return air. Windows may be sealed or openable. These systems are common in countries with moderate or cold climate where air conditioning is not always needed to maintain thermal comfort most part of the year. Technical details of these systems for good performance are described in a European draft standard (CEN, prEN 13779, 2003).

Risks in the performance of mechanical ventilation include the following: HVAC-components may be dirty when installed or become dirty and release pollutants and odours; poor control of indoor temperature due to absence of cooling; low humidity in winter; noise generated by forced air flow and fans; draft caused by forced air flows. If the system has mechanical cooling the additional risk factors are introduced by cooing coils: condensed moisture in the system (e.g. cooling coils and drain pans) and potential microbial growth; biocides used to treat wet surfaces such as drain pans. In systems with air recirculation some additional risks are introduced: indoor-generated pollutants are spread throughout the section of building which air handling system serves; higher air velocities which increase risk of draft and excessive noise; supply ducts of HVAC-system may become contaminated by indoor generated pollutants.

During the last decade, major developments have taken place of further refined, e.g. various kinds of demand controlled ventilation, systems with improved air flow characteristics at room level (e.g. displacement ventilation), heat recovery systems with efficiencies up to 90%, major developments in fan characteristics (e.g. direct current fans with frequency control), low pressure air distribution systems,…

Both basic strategies for a proper ventilation can be used but some important points have to understood and taken care to avoid the adverse effects of the ventilation system itself.

- In naturally ventilated buildings the air enters into the building through building envelope and driven by natural forces. In that kind of system the building itself is a part of the ventilation system, and the design of ventilation has to be integrated in the building design from the early stages of design. To take maximum advantage of natural forces. It is important to realise that in the ordinary natural ventilation system outdoor air enters in the building without any conditioning in respect of pollutants, temperature and humidity, and may cause draft, high pollutant concentration and noise level due to noise from outdoors. Heat recovery from the exhaust air in naturally ventilated buildings is very difficult, and leads to higher energy consumption than mechanical ventilation with heat recovery.

- In mechanically ventilated buildings the ventilation air is conditioned before it is supplied to the rooms via the duct system. Because of supply and exhaust air fans the system is more flexible in respect of building design, and more energy efficient if heat recovery is used. However, studies in many European countries have shown that mechanical ventilation systems may cause adverse heath effects, the reasons of which are not yet well known, but the following have been suspected: air handling system is a source of pollution, moisture in air handling system causes the mould growth, system generates and transfers noise, ventilation air supply is poorly controlled, occupants cannot influence the ventilation. These issues have to be solved to achieve good indoor air quality.

### *8.5.3 Hybrid ventilation*

Hybrid ventilation systems are in the framework of IEA 35 defined as (Heiselberg, 1998):

- "Hybrid ventilation systems can be described as systems providing a comfortable internal environment using different features of both natural ventilation and mechanical systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two-mode system. The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent systems with control systems that automatically can switch between natural and mechanical mode in order to minimise energy consumption and maintain a satisfactory indoor environment."

As shown in figure 31, hybrid ventilation can be considered as a strategy aiming to achieve an optimal combination of natural and mechanical ventilation.

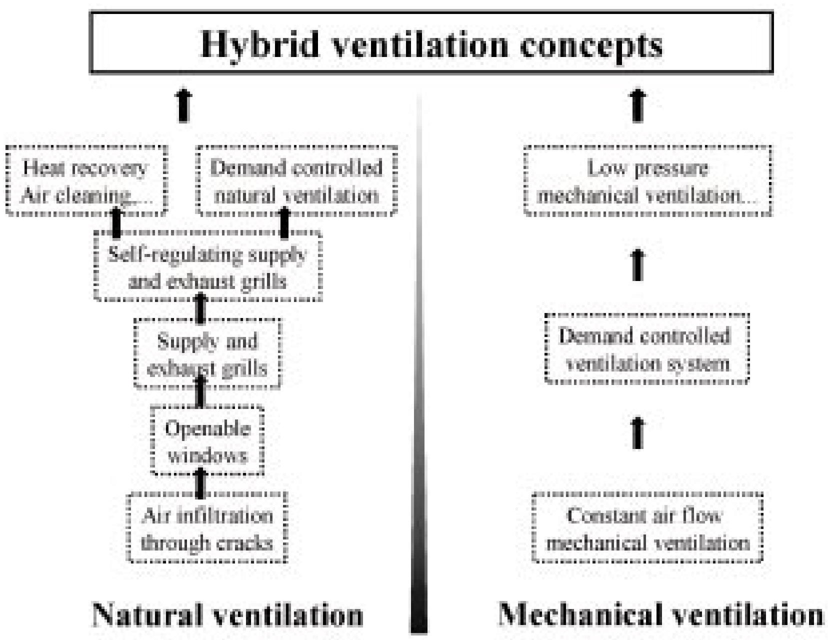


***Figure 31*** *The future?: merging the best of natural and mechanical ventilation*
*Source: Wouters (2000)*

## 8.6 Summary of existing technologies for good IAQ and energy efficiency

It is obvious that there is a need for research and development in the areas of source control, rationale selection of ventilation rates, cleanliness of ventilation systems, cleaning of air and many other aspects of air quality, however, there are already several technologies and methods can already be applied, and should be used more. These ventilation technologies and strategies are summarised in table 6. (Seppänen 1998) A major parameter in the equation (1) above is the sources of pollution. The strength of sources depend on the type of the building and activities in the building. The ventilation rates should be based on the strength of the sources. This means that the latter shall be well documented in advance in order to allow for the appropriate source control. Also the design and construction process should be developed so that the sources are known when the ventilation is designed, and ventilation rates selected. This has to be made progressively possible. in practice but it is possible to set limits for emissions by classification of materials and other sources, and when the classified materials and sources are specified the ventilation rates can be selected to guarantee the selected indoor air quality level.

| Strategy or Technology | Phase of the technology | Indoor air quality | Estimated energy Savings in ventilation |
|---|---|---|---|
| Target values for Indoor climate | available | improved | Up to 60 % depending on climate |
| Particulate filtration of intake air | available | improved | Minor effect on fan power |
| Chemical air Cleaning | developing | improved | up to 100% in ventilation, increase in fan power |
| Balancing of air flows | available | improved | 10-20% |
| Better ventilation Efficiency | available/developing | improved | up to 50% |
| Location of air intakes | available | improved | no effect |
| *Heat recovery for* | | | |
| Large buildings | available | no effect | up to 70% in heating |
| Houses | available | no effect | up to 50% in heating |
| Demand controlled Ventilation | available/developing | no effect | up to 30-40%, up to 50% in large spaces |
| Control of specific Pollution sources | available | improved | Depends on application |
| Control of material Emissions | developing | improved | up to 50% |
| Task ventilation | available/developing | improved | 10-30% |
| Local exhausts | available | improved | depends on application |
| Natural ventilation and Free cooling | available/developing | improved | up to 60% |
| Operation and Maintenance | available/developing | improved | high (depends on initial level) |

***Table 6*** *Summary of ventilation strategies for better indoor air quality and energy efficiency*

## 8.7 Design, installation and commissioning

Good performance of ventilation depends on the whole chain of the building process: targets levels, design, manufacturing, installation, commissioning, operation and maintenance. The final result is as good as the weakest link in the chain. Thus it is important to develop the entire chain.

European community needs performance standards for ventilation. The standards should be based on the accepted indoor air quality, possibly offering various categories of indoor air quality for the use of individual building owners. In addition to the performance standards, prescriptive guidelines are needed for designers and manufactures. These guidelines has to be derived from the performance standards. Essential for these guidelines is the focus on indoor air quality. Hygiene of mechanical system has to be an essential contents of these guidelines, some national guidelines has already been published (VDI 6022, Finnish Classification (FiSIAQ, 1995)).

IAQ in buildings is affected by several partners in the construction process. The final result depends on particularly on the architectural and mechanical design. It is also affected by main contractor, mechanical contractor and several subcontractors. In this complex process it would be beneficial to appoint a person who is responsible of the IAQ in the process.

The performance of ventilation has to be verified in before the building is taken in the use. This commissioning procedure should be developed rapidly, and it should include IAQ and energy performance of ventilation systems(this activity has been initiated already by REHVA). The commissioning procedure should include proper balancing of air flows. The experience has shown that that with proper commissioning better IAQ and energy efficiency has been achieved, and the extra cost of proper commissioning is paid pack by reduced energy consumption in a few months.

## 8.8 Operation and maintenance personnel

Proper operation and maintenance of ventilation is extremely important for IAQ and energy consumption. Proper operation and maintenance requires a qualified personnel and technical plan. It would be beneficial to designate a person who is responsible for IAQ in all larger buildings. The person should have also proper training for the task. These requirements are presented already in some national guidelines (VDI 6022). The requirements for the maintenance have been also presented in VDI 6022, and in the draft documents of CEN technical committee 156.

Periodical inspection of ventilation systems should also be considered, The Swedish obligatory inspection system has revealed that many ventilation systems do not operate as intended (Engdahl, 1998)

## 8.9 Recommended actions

Based on the discussion above the following action items are proposed to improve IAQ and energy performance of ventilation.

1. Performance standards of ventilation supported by the prescriptive guidelines derived from the required performance

2. Research and methods of taking the outdoor air quality in the account in design and operation of ventilation

3. More information on pollution sources in buildings, and technologies to control the sources

4. Information and methods of analysis for building owners focused on the health and productivity consequences of IAQ

5. Information programs for public focused on of the health consequences of ventilation

6. Research on the actual ventilation rates and simultaneous health and comfort effect of IAQ in existing buildings

7. Research and new technology for cleaning the indoor air and the outdoor air for ventilation

8. Research and development of design tools for IAQ and ventilation calculations

9. Commissioning procedure for ventilation systems focusing on IAQ and energy efficiency

10. Requirements for the qualification on operation personnel of buildings

11. System for appointing a responsible person in design and construction phase for IAQ

12. System for appointing a responsible person in operation phase for IAQ

13. System for periodical inspection of IAQ and ventilation systems

14. A system for IAQ audits of existing buildings.

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# 9 INDOOR AIR QUALITY AND ECONOMIC IMPLICATIONS

## 9.1 Introduction

This chapter discusses the following items:

First of all, there is a general discussion about the relevance and the difficulties for assessing the economic implications of varying the indoor climate specifications.

Then, the various types of cost impact are briefly discussed :

- Effects at individual level (health, well being)
- Effects for the building owner (losing tenants,…)
- Effects at company level (absence, lower productivity,…)
- Effects for society (example Finnish data)

## 9.2 The economic impact of poor IAQ

Many decisions on governmental energy policies are based on economical models, such as cost benefit analysis. However, it is difficult to frame the results of the social health and behavioural studies of IAQ in ways that can be easily incorporate into these economical analyses. Such a calculation would need to consider the social costs for IAQ induced illness, direct medical costs and disabilities, as well as the loss of productivity and material and equipment damages. In addition to these, there are secondary costs related to discomfort and annoyance caused by deteriorated IAQ which appears, for example, as lowered real estate market values (WHO, 1994).

This makes it very difficult to carry out economical calculations on the total cost for the society at large exposed to deteriorated IAQ. The "total social cost" is a quantitative expression of the impact of deteriorated IAQ on economic activity, health and well being. Ideally, one would like to express the expenditure, inconvenience and drawbacks of deteriorated IAQ in a single, monetised figure, but as of today, no appropriate estimates have been available for the quantitative aspects of unsatisfactory indoor environment (Hanssen, 1997).

The potential economic impact of indoor air pollution is quite high, and is estimated in the tens of billions of € per year. Such impacts include direct medical costs and lost earnings due to major illness, as well as increased employee sick days and lost productivity while on the job. Labour costs alone are estimated to be 10 to 100 times greater per square meter of office space than energy and other environmental control costs (EPA, 1989).

In the United States, the per-employee productivity loss attributed to IAQ problems currently is estimated to be 3 percent (14 minutes/day) and 0.6 added sick day's annually (Brooks, 1992). Thus from a profit and loss standpoint, remedial actions to improve IAQ where productivity is a concern are likely to be cost effective even if they require an expensive retrofit.

In Norway, the authorities estimate the societal costs related to deteriorated IAQ are in the order of 1 to 1.5 billion € per year (Pillgram Larsen, 1991), or about 250 to 350 € per inhabitant. This estimate includes costs related to adverse health effects requiring medical attention and does not include reduced working efficiency or job-related productivity losses.

If this is representative of Europe, the total costs related to inadequate IAQ are immense. However, these figures only must be considered as approximations because the calculation methods are rather dubious and not very well developed.

## 9.3 Benefits from good IAQ

In spite of all calculation uncertainties, improving IAQ in domestic and non-industrial commercial buildings is probably one of the most profitable investments society can make. The National Energy Management Institute produced a study that inventoried all commercial buildings in the United States and categorised them by degree of IAQ problems (Indoor Air Quality Update, 1994).

The buildings fell into five categories:

1. Healthy

   *always meets ASHRAE 62-1989 and ASHRAE 55-1992 during occupied periods and less than 20 percent of occupants express dissatisfaction.*

2. Generally healthy

   *meets ASHRAE standards during most occupied periods.*

3. Unhealthy, source unknown

   *fails to meet ASHRAE standards during most occupied periods, more than 20 percent of occupants express dissatisfaction, increased occurrence of sick building syndrome (SBS) symptoms and undiscovered problems in HVAC systems.*

4. Unhealthy, source known

   *fails to meet ASHRAE standards during most occupied periods, more than 20 percent of occupants express dissatisfaction, increased occurrence SBS symptoms and known problems in HVAC systems.*

5. Positive SBS or BRI

   *more than 20 percent of occupants complain of SBS symptoms and one or more cases of building related illness (BRI).*

Using published data, the researchers determined that the U.S. commercial building stock falls into five categories as listed in table 7 (IAQ Update, 1994) (NEMI,1994).

The researchers calculated that in buildings that go from one category to another, workers could experience productivity gains of between 1.5 percent to 6 percent. The 6 percent figure will be for buildings with SBS/BRI that go the healthy category.

| Category | Estimate |
|---|---|
| *1. Healthy* | 20 percent |
| *2. Generally Healthy* | 40 percent |
| *3. Unhealthy, Source Unknown* | 20 percent |
| *4. Unhealthy, Source Known* | 10 percent |
| *5. Positive SBS or BRI* | 10 percent |

***Table 7*** *Classification of U.S. Commercial buildings (IAQ Update/NEMI 1994)*

If the expected productivity per employee is set to 50,000 €/year, 1.5 percent to 6 percent productivity gains equals 750 to 3,000 €/year per person. This represents an investment possibility of approximately 7,000 to 27,000 € per employee (calculated on the basis of annual compounding and annuity a=0.11, N=15 years expected lifetime and interest rate R=7 percent). If it is assumed that A=25 $m^2$/worker represents an investment possibility of 270 to 1,100 €/$m^2$. Compared to the total building cost, which often is in the range of 1,000 to 2,000 €/$m^2$, this is remarkable.

Many efforts to improve general IAQ of work environments can be implemented at little or no cost. However, some environments will require increased energy, operation, and maintenance costs to mitigate IAQ problems effectively (Brooks, 1992).

The office building and equipment cost comparatively little when compared with the enormous cost of salaries and staff benefits. Yet, it appears that due to many cost-saving exercises in the construction, layout and operation of a new building, employers suffer far greater costs due to employee ill health. In the future, the focus should not just be placed on the effects of heavy industry on workers' health, but also on the "safe" office job as a potential source of stress and ill health, given the increasing role of this type of workers' health (Lewis, 1992).

The economical benefit of good IAQ should be obvious. On the other hand, if indoor climate is deteriorated by a senseless "energy-saving" policy, bad HVAC design or malfunctioning installations due to poor maintenance or lack of commissioning, "low cost buildings" can cost society and business life much more than they gain form energy or other savings. This is because salaries and wages often are the most significant of all ownership and operations costs.

## 9.4 An example of the cost of poor IAQ for a building owner

The cost of discomfort or bad IAQ is not only a problem for the employer; it also may be a serious event for the building owner. Included in a newsletter edited by Frank A. Lewis (Lewis, 1992) is an illustrating example of the costs related to losing a tenant (table 8). The figures are based on a study done by the Building Owners and Managers Association (BOMA).

The study reveals that if a tenant lodges a major complaint regarding building comfort to the building manager at least three times in one year, there is a 52 percent chance the tenant will move out at the end of the lease. Further, the newsletter presents an estimate of the cost of losing a 5,000 sq. ft (500 $m^2$) tenant at 20$/sq. ft (200 €/$m^2$)-gross rent in a 100,000 sq. ft (10.000 $m^2$)building:

The $150,000 total costs represent $1.50/sq. ft of lost revenue or 1.5 years of rent. In addition, there could be an additional loss of revenue from non-occupancy due to lack of use.

| | | |
|---|---|---|
| 6 months vacancy | $ 50,000 | 100 /$m^2$ |
| 6 months rent concession | $ 50,000 | 100 /$m^2$ |
| Brokerage fees | $ 20,000 | 40 /$m^2$ |
| Retrofit costs | $ 30,000 | 60 /$m^2$ |
| **Total costs** | **$150,000** | **300 /$m^2$** |

***Table 8*** *potential costs due to comfort complaints (Lewis, 1992)*

Furthermore, this example shows that the owner risks losing in the marketplace. Today, many building owners are using superior comfort as a way of differentiating their building form others in the recent highly competitive real estate market. Thus, the owner is missing a tremendous opportunity by not providing a comfortable and quality environment for his tenant.

## 9.5 The effects of IAQ on employee performance and productivity at work

The relationship between indoor environment and a worker's health has been the subject of research for some years, but there has been comparatively little research which examines the total effect of IAQ on human well-being, employee performance and productivity at work. In order to assess healthy buildings in terms of performance and productivity, it is necessary to consider a variety of measures that might be used as indicators of an effect on productivity.

According to David Wyon (Wyon, 1993), the following measures were recommended at an ASHRAE Workshop in Baltimore in September 1992:

- Absence from work, from workstation; unavailable on telephone
- Health costs, including sick leave, accidents, injuries
- Observed downtime, interruptions
- Controlled independent judgements of work quality, mood, etc.
- Self-assessments of productivity
- Component skills, task measures, speed, slips, accuracy
- Output form pre-existing work-groups
- Total unit cost per product or service
- Output change in response to graded reward
- Voluntary overtime or extra work
- Cycle time from initiation to completion of discrete process
- Multiple measures at all organisational levels
- Individual measures of performance, health and well being at work
- Time course of measures and rates of change

Obviously, absence from work represents a 100 percent loss of productivity, but also bad or deteriorated IAQ may reduce performance at work in a substantial way. This, in turn, may result in a considerable loss of productivity and business outcome (Fisk, 1997), (Wargocki, 1998). Consequently, good indoor air quality is good business. Labour cost is estimated to be 10 to 100 times greater per square meter of office space than energy and other building operational costs.

## 9.6 Benefits for society

Improving the indoor air quality in domestic and non-industrial commercial buildings is probably one of the most profitable investment society and the business world can make. As an illustrative example, Seppänen and Palonen (Seppänen, 1998) have estimated the total effects of poor indoor climate on national economy in Finland to be approximately 18 billion FIM as shown in table 9.

<table>
<tr><th colspan="2" rowspan="2">Building type</th><th>Maintenance</th><th colspan="2">Refurbishment<br>Mould Radon</th><th>Energy</th><th colspan="2">Costs of poor indoor climate</th></tr>
<tr><th>Annual cost</th><th colspan="2">One-time cost</th><th>Annual cost</th><th colspan="2">Annual cost</th></tr>
<tr><td colspan="2">Houses</td><td>12.7</td><td>2.9-3.5</td><td>0.5-1.5</td><td>7.2</td><td>7.0</td><td>Mould allergies</td></tr>
<tr><td colspan="2">High rise residential buildings</td><td>11.0</td><td>3.5-7.7</td><td>Included in above cost</td><td>3.1</td><td>0.2</td><td>Radon cancers</td></tr>
<tr><td colspan="2">Office and Adm. Buildings</td><td rowspan="4">26.3</td><td rowspan="4">13.0</td><td></td><td>0.8</td><td>2.7</td><td>Decrease in efficiency, Absenteeism</td></tr>
<tr><td colspan="2">Schools</td><td></td><td>0.7</td><td>3.0</td><td>Poor learning</td></tr>
<tr><td colspan="2">Hospitals</td><td></td><td>0.3</td><td>?</td><td>Hospital infections</td></tr>
<tr><td colspan="2">Assembly buildings</td><td></td><td>0.2</td><td>0.5</td><td></td></tr>
<tr><td colspan="2">Other buildings</td><td></td><td></td><td></td><td>1.9</td><td>4.2</td><td>ETS</td></tr>
<tr><td rowspan="2">TOTAL</td><td>FIM</td><td>50</td><td>19.4<br>24.2</td><td>0.5-1.5</td><td>14.2</td><td>17.6</td><td></td></tr>
<tr><td>E</td><td>?</td><td>?</td><td>?</td><td>?</td><td>?</td><td></td></tr>
</table>

***Table 9*** *Cost due to poor indoor air quality (in Billion Finnish Marks, last line in Billion )*

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# 10 PRIORITIES FOR ACTIONS, REQUESTED EFFORTS AND CHANCES FOR SUCCESS

## 10.1 Global ambition

The ambition is to achieve a building environment which provides healthy and comfortable indoor air quality conditions and which is moreover compatible with concerns on sustainable development and, more specifically, energy efficiency of the built environment.

## 10.2 Primary goals

The primary goal of ventilation is to maintain healthy indoor conditions.

By the year 2015, people in the European Region should live in a safer physical environment, with exposure to contaminants hazardous to health at levels not exceeding internationally agreed standards (WHO 2000a, 2000b). Indoor air quality is one of the major physical determinants of public health. It also has a decisive impact on comfort and productivity.

Specific goals for IAQ are needed and should be developed further for the special circumstances and spaces. "IAQ for people" should mean good IAQ for all people in the region, at all costs and at any time. It should not only protect "typical" people against "typical" loads, but also protect the somewhat more sensitive persons.

The goal of ventilation should be to provide healthy IAQ and satisfaction for the occupants (ECA 1996). In addition, IAQ should promote productivity and protect the building, installations and furnishings.

Ventilation systems and their performance should not give adverse side-effects to humans, buildings or the environment; ventilation merely should give benefits. The goal for ventilating the European building stock should be expressed in measurable terms and the date for its achievement should be specified.

By the year 2015 all negative side effects of ventilation should be avoided, and ventilation in all buildings is adequate to control pollutants to acceptable level from health standpoint. The optimisation of ventilation is done based on ambition levels with comfort and productivity in European countries depending on their economical resources and priorities.

Ventilation rates and the energy consumption is know throughout the Europe by building type and location, ventilation practices with best over all economy are identified and described in European and national standards and building codes.

## 10.3 The contribution of building ventilation to global sustainability

Ventilation in urban buildings should support all dimensions sustainable development (ecological, cultural, economical and social) for present and future generations of occupants, by

- advancing the health and well-being of building occupant;

- optimising energy use and first cost with comfort and productivity;

- minimising indoor and outdoor exposures to pollutants and other agents with adverse health effects;
- decreasing life-cycle costs by avoiding adverse health effects, energy waste and unnecessary costs for operation, maintenance and rehabilitation of buildings;
- avoiding the use of rare materials and encouraging a sensible recycling of other materials;
- avoiding the use of materials and substances hazardous to the environment;
- not causing unwanted side-effects like noise, draught, added air pollutants, or spreading indoor or outdoor generated pollutants;
- helping to maintain building and city designs and structures which are vital to social and economic values and social networks among individuals;
- helping to preserve historical buildings and environments as well as respecting local architectural traditions in a cautious and aesthetic balance with new building and system designs;
- designing and operating buildings and systems so that they make sensible use of climate and natural forces and can be adapted (over centuries) for shifting demands.

## 10.4 Strategies of ventilation for good IAQ and energy efficiency

A key strategy for the management of IAQ consists of developing a comprehensive, scientifically sound and thoroughly considered action plan which targets both new constructions and existing buildings (WHO 2000a, 2000b). An important element in that strategy is a ventilation strategy, which reconciles good indoor air quality and rationale use of energy. Many technologies are available to achieve the both objectives simultaneously (Seppänen 1998, 2002).

Most important in reducing the risk of poor IAQ and waste of energy is to lower the pollutant loads on the indoor environments. Therefore, the control of avoidable pollutant sources is the first priority in maintaining healthy and comfortable indoor environment. More efforts are needed to satisfy this demand.

In a large portion of existing residential buildings in some regions of Europe, the pollution loads are higher than acceptable and/or the ventilation rates are lower than should be accepted from a public health point of view. A strategy should be developed for the best means of combining source control, ventilation and affordability.

People are sometimes more satisfied in buildings with natural ventilation than with air conditioned buildings. In air conditioned buildings SBS symptom prevalence seem to be significantly higher than in naturally ventilated buildings (Seppanen and Fisk 2002). The reasons for that are not clear yet but the opinions expressed warrant that the precautionary principle is being used. Clearly, both natural and mechanical ventilation present risks for unwanted side-effects. Therefore, ventilation system should take maximum advantage of natural forces, be supported by adequate space designs (e.g., enough ceiling height) and by other sinks in the building, and be supplied by mechanical systems where other solutions do not provide a satisfactory IAQ. The development and use of integrated “hybrid” systems, using the beneficial properties of both ,should be encouraged.

The use of ventilation systems should not be hampered by draught or noise (neither originating indoors nor by the exhaust outlets). As these may be reasons to turn the ventilation completely off , and create indoor quality of moisture problems simultaneously. On the other hand, much noise from outside the building cannot be abated if there is not an adequate mechanical ventilation system installed.

To simplify the task of the customers and occupants of buildings for selecting an adequate quality level of IAQ to order in the design phase, a simple classification systems for IAQ should be developed.

The development of a European standard on IAQ/ventilation is much needed. The standard should focus on performance oriented, functional requirements, and on performance indicators. The proposed 1752 CEN standard partly had this purpose but it was not approved. However, it was approved as a technical report (CR 1752). The principles of this report are partly implemented in ventilation daft standard CEN prEN 13779 It gives four categories for ventilation rates for users to select.

## 10.5 IAQ in ventilation standards

There is a huge dispersion in recommended ventilating air rates. However, the evidence is convincing that low air rates are associated with adverse health effects, discomfort and impaired productivity. In fact, meta-analyses indicate that the risk for such problems appear already below 10 l/s per person (Seppanen et al. 1999, Wargocki et al. 2002). The adverse health effects seem to alleviate in office buildings up to ventilation rate of 20-25 l/s per person. In cold climate where ventilation rates typically are lower than in warm climate the minimum ventilation rate in residential buildings seem to be 0.5 ach (air changes per hour). In warm climates the ventilation rate should be higher due to higher outdoor air humidity and its lower moisture transfer capacity.

The relation between indoor environment and airborne transmission of infectious diseases is shown in several studies Fisk (2000,2001). He concluded that improvements in the indoor environment may reduce the sick leave due to infectious diseases up to 9-20 %. The prevalence of infectious diseases seem be affected by the ventilation as summarized by Seppänen et al. (1999). Milton (2000) found that higher ventilation rates were associated with reduced short term absence, much of which is caused by respiratory illnesses.

One should pay attention to all the various performances of ventilation systems, not just the airflow: risk for noise, allergy, maintenance problems. Several hygienic aspects of ventilation systems are included already in some national guidelines (FiSIAQ 2001, VDI 6022, ASHRAE 62) and in the international draft standards (CEN prEN 13779). Performance standards for ventilation are needed and should be supported by prescriptive/technical standards as well. Similar building simulation tools as are present for thermal environment and ventilation should be also developed for indoor air quality calculations. Attempts to base ventilation rates on pollutant loads have been made in Europe CEN CR 1752 and in the US (ASHRAE 62n) but not used in practice due to missing tools and data for emission rates.

## 10.6 Indoor climate specifications and economic implications

The potential cost to society of poor indoor air quality is high (Fisk and Rosenfeld 1997). Poor "energy saving" strategies, bad HVAC design, malfunctioning installations, poor maintenance or lack of commissioning may cost more to society and business life than what is gained from energy or other savings. Actually some calculations show that that annual cost of deteriorated indoor climate may be higher then the heating cost of the same buildings (Seppanen 1999).

In reverse, improving the indoor air quality in institutions and domestic and commercial buildings is probably a most profitable investment (Fisk and Rosenfeld 1997). Building owners should use superior comfort, i.e. with respect to IAQ, as a way of differentiating their building from others. Programs should be established for building owners focused on the health, comfort and productivity consequences of IAQ.

It has been demonstrated in experimental studies that performance in office tasks may be improved by 1.5-6 % when IAQ is improved. These results are appealing, and are validated in respect of thermal environment (Federspiel at al. 2002, Niemela et al. 2001, 2002) but need more validation in respect of other parameters such as ventilation rates and pollution loads. Improvements in productivity and performance has been demonstrated also for personal control over the environment, day-lighting, window-opening and improved IAQ. For conclusive evidence on the performance effect of IAQ further studies are needed.

A puzzling fact in some instances, is that people report themselves more satisfied with natural ventilation than with air conditioning and mechanically ventilated buildings this is the issue which may have major effect of the whole building design as natural ventilation has to be integrated into the architectural design from the beginning of the design process.

A critical issue is how one should deal with the bad outdoor air quality in many large European cities where guideline values for the protection of health are repeatedly exceeded. In such instances cost-effective means for air cleaning/filtering are badly needed. Actually several laboratory studies have shown that currently used filtration methods may create additional air quality and mould growth problems (Bluyssen 2001).

A completely new aspect is the use of ventilation systems in the case of sudden release of hazardous pollutants in buildings and close to the buildings. Ventilation system can be used in spreading intentionally hazardous substances in the building (Moscow hostage drama in October 2002) or protecting the occupants from outdoor generated pollutants by pressurising the building by clean air.

## 10.7 Education, information and training

Programs should be installed for informing the public on the health benefits of ventilation and hazard of inadequate ventilation. An important group to be trained is the building operation personnel and facility management. The Swedish compulsory ventilation inspection system has shown that often the failure to pass the inspection is due to bad maintenance or missing maintenance instructions (Engdahl 1998). The survey in problem buildings in the US has shown also the linkage between dirty and badly maintained ventilation systems and typical sick building symptoms (Sieber et al. 1996) Some national guidelines already exist for this purpose. VDI 6022 sets the requirements for training of building operators and management in respect of building hygiene. Similar requirements exist also in Japan. These practices should be reviewed utilised in developing education programmes.

## 10.8 Quality assurance

The need for quality control of ventilation and IAQ should be emphasised through the whole process from design to operation. The experience (Engdahl 1998) from the Swedish compulsory inspection system of ventilation systems shows that malfunctioning of the ventilation is due to inadequate commissioning. The new European directive on Energy performance of buildings was published in January 2003 (CEC, 2002). It requires also regular inspection of air conditioning systems of buildings. As the ventilation is often integrated with air condition in systems it is very important that ventilation systems are also included in those inspections in respect of air quality, not only in respect of energy efficiency.

Efficient systems should be provided and enforced for commissioning ventilation systems with respect to IAQ and energy efficiency, for periodical inspection of IAQ and ventilation, and for IAQ audits of existing buildings.

Clear responsibilities for IAQ should be established; in all steps from outside air through building, systems, human activities to room IAQ and operation and maintenance. There is a need for a responsible “body” for IAQ, or for shared and overlapping responsibilities, or for sufficiently increased margins in all steps. A combination of commercially attractive and practical methods as well as control by authorities should be strived for (“soft” and “tough” means in combination).

Quality assurance programs on ventilation should be used to a greater extent and experiences be compared.

## 10.9 Recommendations

Proper ventilation technology should be further developed for all building types and climatic conditions in respect of health, wellbeing, productivity and environmental impacts. Better information on the performance of existing system is needed for development work. The ventilation technologies should take advantage of climatic conditions, natural forces and methods to control pollutants sources. Maximum advantage should be taken from the available and developing energy efficient technologies. These technologies include improved effectiveness at removing contaminants (improved ventilation efficiency), air flow control by air quality, heat recovery from ventilation air, integration of ventilation with building envelope, and hybrid ventilation. Technology development should cover both natural and mechanical ventilation systems. The attention should be paid to improve the operation and performance of existing systems. Building with sensitive population like schools need specific attention. Health aspects should not be compromised by energy conservation. Guidelines and standards with different levels of comfort and first cost should be developed. Climatic and cultural variations should be considered in these guidelines.

## 10.10 Recommendations for practise

1. Essential to have clear standards, guidelines or regulations for all Regions in Europe, a CEN standard is urgently needed.

2. Professional training and certification programmes are needed for designers and builders of ventilation systems.

3. Existing building stock should receive more attention in improvement in remodelling, and refurbishment of ventilation especially in respect of balancing of air flows and ventilation efficiency.
4. Cleanliness and hygiene of existing ventilation systems should be improved including the potential problems related to moisture in the systems.
5. Actions with respect to maintenance and use of ventilation system should be encouraged.
6. Decision makers should pay attention to life cycle cost of ventilation including health of wellbeing of occupants and environmental impacts.
7. European health and patient organisations such as the European Federation of Asthma and Allergy should be encouraged and supported to participate in the educational and information work on ventilation practise for good IAQ.
8. Ventilation in European schools should be improved essentially to protect pupils and from pollutants which may have life time effects.
9. Flexibility of systems to adapt to changing uses of the building is needed, and should be developed.
10. Individual control of ventilation for improved well-being should be encouraged.

### 10.11 Recommendations for preparation work

1. Encourage and support European engineering organisations such as REHVA (Federation of European Heating and Air Conditioning Associations) to develop guidelines for best practice of ventilation design, commissioning, operation and maintenance.
2. National bodies should collect statistical information of air flow rates and energy use of ventilation in buildings as available for Scandinavian countries.
3. Ventilation and IAQ criteria should be developed as an essential part of the criteria of sustainable buildings.
4. Procedures for regular inspections of ventilation systems should be developed as an essential part of the energy or IAQ audits or inspection of air conditioning systems.
5. Procedures for energy certification should be extended to IAQ and ventilation related aspects.
6. Inventory and evaluation of existing mechanisms (and their impact in practice) and pragmatic mechanisms for dealing with source control.
7. Development of training and certification programmes for building operation personnel.
8. Good means are needed for the better commissioning of ventilation systems focusing on IAQ and energy efficiency, on the economic savings linked to appropriate commissioning should be studied.
9. Tools should be developed for demonstrating benefits of good ventilation and IAQ to building owners.
10. Labelling method for clean component and systems should be investigated. Criteria for clean components should be developed.

## 10.12 Research needs

1. Research on the actual ventilation rates and energy use in different type of existing buildings and simultaneous effects on IAQ, health, well-being and productivity.

2. Focused research on the linkage between properties of air handling system and human responses (air conditioning vs. natural ventilation).

3. Measured performance of good naturally ventilated buildings and their properties including human responses.

4. Develop and evaluate improved strategies and systems to control ventilation rates, including demand-controlled systems using pollutant sensors for indoor and outdoor air quality and more accurate measurement of air flow within the system.

5. Research and new technology for cleaning the indoor air and the outdoor air for ventilation.

6. Research and development of design tools for ventilation and IAQ calculations.

7. Research on how to get maximum benefit of climate and natural forces in providing adequate ventilation, and how to integrate this in building design.

8. Research how to protect building occupants against the sudden release of toxic substances in buildings.

9. More research on characterisation of pollution sources in buildings, and technologies to control the sources and their effect on health, wellbeing and productivity.

10. Increase effectiveness of ventilation at removing contaminants using computer simulations and measurements.

11. Effects of IAQ on health and productivity should be studied further and existing laboratory results validated. How performance improvements are being attributed to IAQ should also be studied in more detail.

## 10.13 Conclusions

1. Considering the energy impacts and the potential benefits to be gained with better ventilation, much more research should be supported to develop environmental friendly ventilation methods for better indoor air quality and climate. This work should include a strategy for the best means of combining source control, ventilation and affordability.

2. Collect more information on actual ventilation rates and energy use in different type of existing buildings and simultaneous effects on IAQ, health, well-being and productivity in all climatic regions of Europe to evaluate the guideline values for ventilation rates.

3. European guidelines for best practice in ventilation are needed to improve building practice and regulations as a basis for the implementation of the EC Building Products Directive. Professional organisations like REHVA should be encourages and supported in this work

4. It is strongly recommended that the specification process of the Energy Performance Directive and Building Products Directive will be continued and accelerated.

5. Performance standards for ventilation are needed and should be supported by prescriptive/technical standards as well. Similar tools as are present for temperature should be developed for IAQ.

6. Procedure for periodical inspection of IAQ and ventilation systems should be developed including the remedial action programme for improvement of hygiene and performance of ventilation. Its integration with energy audits or regular inspection of air conditioning systems should be investigated.

7. Encourage and initiate information programs for public focused on of the health consequences of ventilation.

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