VENTILATION, GOOD INDOOR AIR QUALITY AND RATIONAL USE OF ENERGY

Peter Wouters, Christophe Delmotte
Belgian Building Research Institute, Brussels, Belgium
Peter.wouters@bbri.be; Christophe.delmotte@bbri.be

1. INTRODUCTION

Since the end of the eighties, 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 aim of ECA Report N° 23 was 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. This paper highlights some of the results of this report. At the end of the paper, there is also information about the Air Infiltration and Ventilation Centre.

2. VENTILATION IN RELATION TO POLLUTION SOURCES, TOTAL AIR EXPOSURE AND 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 in figure 1, the global chain that has to be considered is rather complicated.

In the framework of this paper, 3 different stages are considered: pollution sources – total air exposure - health assessment.

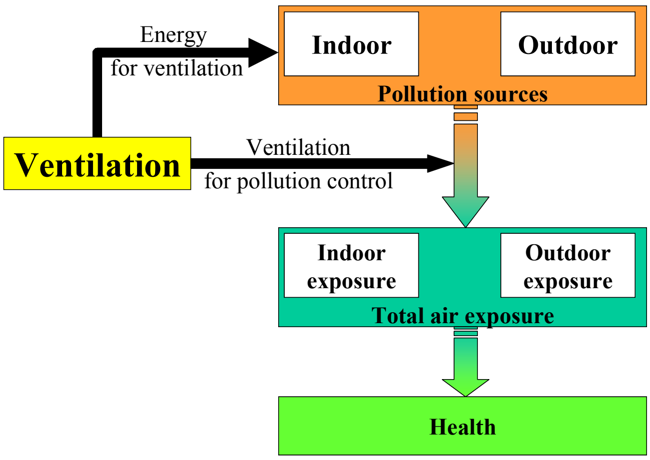

figure 1: Impact of ventilation on air pollution and total air exposure

2.1 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.

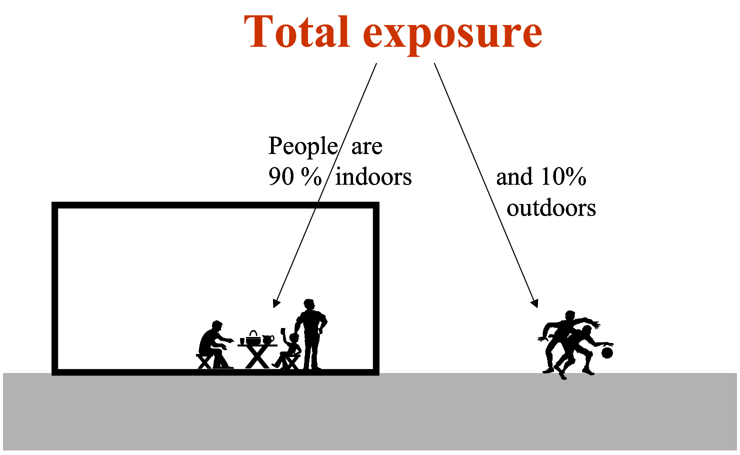

figure 2: Time typically spent indoors and outdoors

2.2 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).

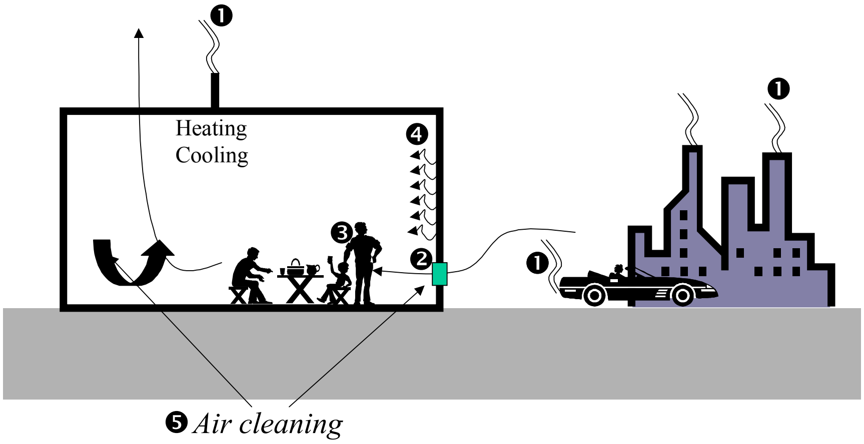

figure 3: Pollution sources for indoor and outdoor air quality

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.

  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.

3. INDOOR ENVIRONMENT, HEALTH AND COMFORT

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.

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 paper 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 ECA report N° 23, a discussion is made in relation to the following indoor environment aspects: indoor air quality, thermal comfort, acoustical performances and visual quality.

4. INDOOR CLIMATE, URBAN CONTEXT AND ENERGY USE IN URBAN ENVIRONMENTS

Buildings are the largest energy consumer in cities. Data on the energy consumption of various European cities shows that the consumption of the residential sector varies widely, e.g. 48 % in Copenhagen and 28 % in Hanover of the end use energy consumption of these cities.

The specific characteristics of the urban climate have in different ways an impact on the energy use of buildings:

· Specific temperature conditions in urban environments:
  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. For US cities with population larger than 100.000, the peak electricity load will increase 3 to 4 percent for every 1 °C increase in temperature.

· Specific air quality conditions in urban environments:
  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.

· Acoustical characteristics of the urban environment can influence the energy use of buildings.
  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.

5. STANDARDS AND REGULATIONS REGARDING VENTILATION PERFORMANCES

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 $C0_2$ 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 European Energy Performance of Buildings Directive imposes such approach for all 25 European Union member states.

6. AIR FLOW PERFORMANCES OF VENTILATION SYSTEMS IN DAILY PRACTICE

The fact of having standards and/or regulations is not sufficient for achieving appropriate air flow rates. This is illustrated by the following 3 examples.

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 4 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.

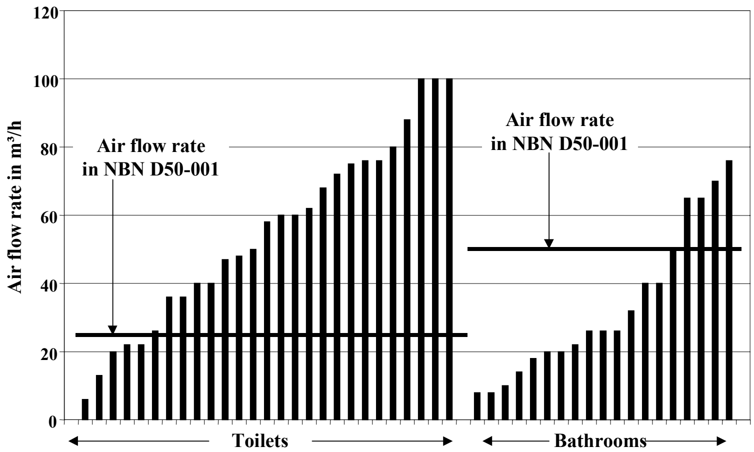

figure 4: Measured air flow rates in Belgian bathrooms and toilets with mechanical extraction - Source: BBRI (2000)

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 5, a substantial part of the dwellings are underventilated.

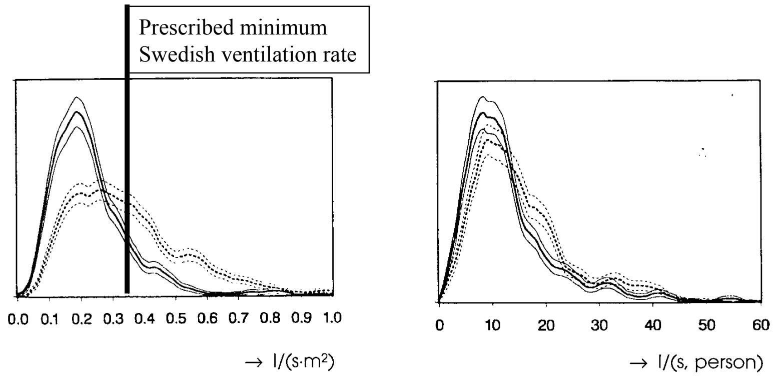

figure 5: Estimated frequency functions of the ventilation rate in a representative sample of single-family houses (full lines) and multi-family houses (dotted line) in Sweden. Thin lines indicate the ranges of uncertainty - Source: Norlen(1993)

Similar measurements have been carried out in other Nordic countries. The results are summarised in table 1.

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 1: 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 6, the air change rate in recent Norwegian dwellings has substantially increased and this is probably mainly due to the new Norwegian legislation.

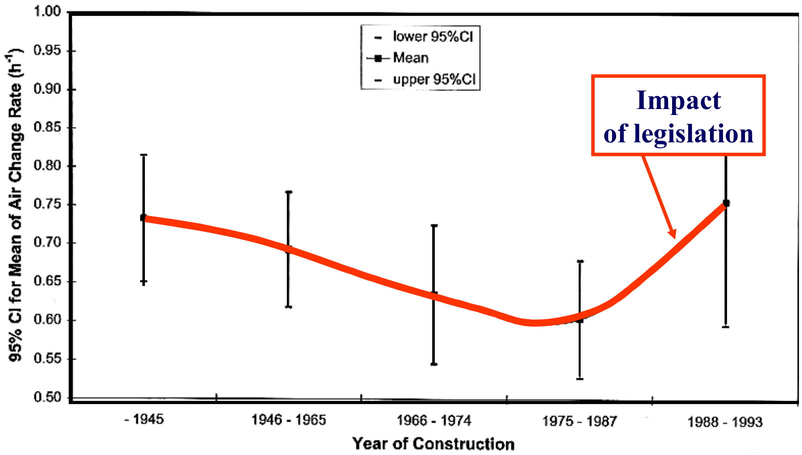

figure 6: Air change rate (h-1) mean and 95%-confidence intervals of mean for Norwegian dwellings according year of construction – Source: Oie (1998)

3. Air flow rates in Finnish office buildings

In the Helsinki area, the air flow rates have been measured in 33 office buildings (ref.). 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.

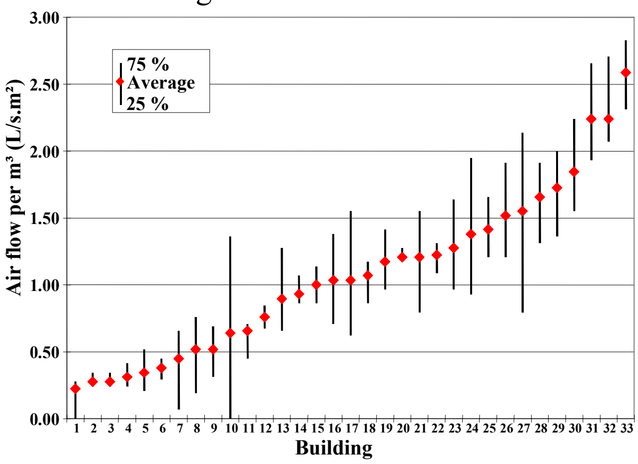

figure 7: Air flow results for 33 office buildings in Helsinki area - Source: Teijonsalo(1996)

7. STRATEGIES FOR AN APPROPRIATE IAQ AND ENERGY EFFICIENCY

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 (Bluyssen 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.

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. INDOOR AIR QUALITY AND ECONOMIC IMPLICATIONS

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.
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.

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.

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. 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, 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. AIR INFILTRATION AND VENTILATION CENTRE (AIVC)

The Air Infiltration and Ventilation Centre is operated under Annex V of the Energy Conservation in Buildings and Community Systems implementing agreement of the International Energy Agency.

The primary objective of the AIVC is to provide a high quality international technical and information forum covering the areas of ventilation and air infiltration in the built environment with respect to efficient energy use, good indoor air quality and thermal comfort. The main drivers for this work are the national and international concerns in the areas of sustainable development, responses to climate change impact and healthy buildings.

The AIVC provide different services which can be grouped as follows:

- Technical forum for all relevant international and national ventilation and related activities
- Synthesised leading edge research information to meet industry needs
- Synthesised information to the research community, policymakers, industry with emphasis on the end-use and practice.
- Advice on cost-effective measures for energy efficient buildings and good indoor climate conditions.

For more information: www.aivc.org. For a free subscription to the AIVC newsflash mail to aivc@bbri.be.

10. ACKNOWLEDGMENTS

The authors like to thank the other members of the ECA working group who prepared the report N° 23: Geo Clausen, Eduardo de Oliveira Fernandes, Willem De Gids, Sten Olaf Hanssen, Stylianos Kephalopoulos, Marie-Claude Lemaire, Thomas Lindvall, Fergus Nicol, Mat Santamouris, Olli Seppänen, Cor J M Van den Bogaard and Michael Wilson.

11. REFERENCES

1. ECA, Ventilation, Good Indoor Air Quality and Rational Use of Energy, ECA Report N° 23, Ispra, 2003
2. Official Journal of the European Commission, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Brussels, 2003
3. Leaman, A. J. and Bordass, W. T., Productivity in buildings - the killer variables, Workplace Comfort Forum, London, 1997
4. BBRI, The VLIET-SENVIVV study : final report, Belgian Building Research Institute, Brussels, 2000
5. Norlen U., Andersson K. (eds.), The indoor climate in the Swedish housing stock, Document D10:1993, Swedish Council for Building Research, Stockholm, 1993
6. Øie L., Stymne H., Boman C.A., Hellstrand V., The ventilation rate of 344 Oslo residences, Indoor Air, 1998
7. Teijonsalo J, Jaakkola J J K, Seppanen O, The Helsinki office environment study: air change in mechanically ventilated buildings, Indoor Air, No 6, pp 111-117, 1996
8. Bluyssen, P.; de Oliviera Fernandes, E.; Groes, L.; Clausen, G.; Fanger, P.O.; Valbjørn, O.; Bernhard, C.; Roulet, C. 1996. European indoor air quality audit

project in 56 office buildings. International Journal of Indoor Air Quality and Climate. Vol 6, No. 4.